Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas

Federal Ministry for Economic Cooperation and Development

THE LEAGUE OF ARAB STATES
THE ARAB CENTER FOR THE STUDIES OF ARID ZONES AND DRY LANDS
ACSAD 1968

gtz

International Workshop on

Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas

7-9 May 2007

Proceedings

***Editors*:**
Bobby A.Stewart
A. Fares Asfary
Abdelouahab Belloum
Kurt Steiner
Theodor Friedrich

Proof reading:
Thomas Teuscher
A. Fares Asfary

Organising Committee:
Abdelouahab Belloum
A. Fares Asfary
Berthold Hansmann
Kurt Steiner
Theodor Friedrich
Moncef Ben-hammouda
Mohamed A. O. Ibenouf
Lena Al Hasan (Secretary)

FIAT PANIS

UNEP/ROWA

A.A.A.I.D

Citation:
Bobby I.Stewart, A. Fares Asfary, Abdelouahab Belloum, Kurt Steiner, Theodor Friedrich
Conservation Agriculture for Sustainable Land Management
to Improve the Livelihood of People in Dry Areas.

About the Editors:
Bobby A.Stewart*: WTAMU Box 60278, West Texas A&M University, Canyon, Texas, USA, 79016*
A. Fares Asfary: *Conservation Agriculture Program, The Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD),P.O. Box; 2440, Damascus, Syria, Fax: 00963-11-5743063,*
E. mail: fasfary@acsad.org, fasfary@scs-net.org
Abdelouahab Belloum *: Conservation Agriculture Program, The Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD), P.O. Box 2440, Damascus, Syria, Belloum_a@yahoo.fr; Tel. : +963 11 5743063*
Kurt Steiner: *Goethestr.7, 69250 Schönau, Germany, e-mail: landconsult@kurtsteiner.de*
Theodor Friedrich: *Food and Agriculture Organization in the United Nations (FAO), Viale delle Terme di Caracalla, 00153 Rome, Italy*

Preface

In the last three decades an increasing pressure on the natural resources in the Arab region has been observed. One of the driving forces is the demographic development, the population increases at a progressive rate along with the food requirements. In addition, unsuitable agricultural practices spread all over the region exerting severe pressure on soils, vegetation and water to fulfill the increasing demand. The Arab region imports about 50 % of its food requirements. The food gap, however, will be more endangered by climate change with its impact on agricultural production. These alarming conditions stress the need for a quick action to introduce sustainable and more productive agricultural systems to bridge the food gap, improve the livelihood of people, sustain resources, combat desertification, and mitigate the adverse impact of climate change.

Conservation Agriculture, as a holistic approach, could provide a solution, as it permits an ecologically sustainable, and at the same time, economically viable agricultural production system. However, this production system is looked upon sceptically in the region, mainly because of the lack of information, the insufficient field experiments in the different agro-ecological zones, and the limited joint field trials with farmers.

The Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) initiated in conformity with its mandate to contribute to the implementation of the UNCCD in the countries of the Arab League, a coordinated research and development programme for Conservation Agriculture, with technical support of the German Agency for Technical Cooperation (GTZ), a pioneer of this agricultural production system.

The ACSAD/GTZ Conservation Agriculture Programme is promoting Conservation Agriculture in the Arab region in order to support the efforts of sustainable land management. In addition, Conservation Agriculture is also considered as an appropriate adaptation strategy to mitigate the forecasted dramatic negative impacts of climate change in the region.

ACSAD and GTZ organised the workshop “Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas” in order to collect and document the international experience in the field of Conservation Agriculture in semi-arid and arid regions and to make it available to all stakeholders. We expect that the workshop outcomes with the proceedings and the planned follow-up activities, especially those supporting farmers’ efforts to adopt CA, will enable the ACSAD/GTZ CA Programme to introduce and widely disseminate the System in the entire Arab region, for the benefit of the people, the farmers, and the environment.

Damascus, March 2008

Dr. Farouk Saleh Fares
Director General
ACSAD

Dr. Magdy El-Menshawy
Country Director, Syria and Lebanon
GTZ Office Damascus

Table of Contents

2 – Global Experiences

3- Dissemination and Networking

4- Annexes

Introduction

The first International Workshop ***"Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas"*** has been held at The Arab Centre for the Studies of Arid Zones and Dry Lands (ACSAD) with support of the German Agency for Technical Cooperation (GTZ) from 7th - 9th May, 2007.

Collaborative Partners in organizing the workshop were the United Nations Organisation for Food and Agriculture (FAO), the Arab Authority for Agricultural Investment and Development (AAAID) and the United Nations Environmental Programme - Regional Office for West Asia (UNEP-ROWA).

The 58 workshop participants came from nearly all Arab countries; special experts were invited from USA, UK, the Mediterranean and international development and research organizations notably FAO, UNEP-ROWA, GTZ, CIRAD, ICARDA, CIHEAM-IAMZ and ICRISAT. Representatives of manufacturers of agricultural machinery came from Germany and Brazil.

The general objective of the workshop was to develop the awareness of conservation agriculture and pave the way for implementing conservation agriculture in the Arab region by bringing together scientists, policy makers and practitioners to share different knowledge, experiences and competencies and discuss opportunities, tools and adaptations in Arab countries.

During the first part of the workshop keynotes, papers and posters were presented, structured into five sessions:

Session 1: Introduction to Conservation Agriculture (CA)

Session 2: CA impact on the environment

Session 3A/B: CA in dry lands: A global overview and in Arab countries

Session 4: CA potential in the Arab region

Session 5: Joining efforts: Scientists, farmers and investors

The second part of the workshop was dedicated to an extensive discussion covering two specific topics: The role of CA in the context of the UNCCD and how to enhance the exchange of information and experiences of CA in Arab countries.

The proceedings encompass almost all papers of the workshop. A few presentations were replaced by others to finalize editing for publication.

Chapter 1: "Conservation Agriculture: Concept and Implications" covers papers on present trends in dry areas of the Arab region. It provides the context of CA in terms of relevant cultivation methods, its ecological and technical feasibility (rainfall, soils), its beneficial results (water saving, maintenance of resource base) and its economic impact (input saving, increased outputs). As such, it gives detailed information of approaches, methodologies and interactions.

Chapter 2: "Global Experiences" reviews the present situation and future accomplishments in dry areas around the world. It includes presentations that assess global challenges and opportunities to be transferred into tools for preparing the next steps in disseminating CA in Arab countries.

Chapter 3: "Dissemination and Networking" covers papers that try to answer questions how to involve major stakeholders in CA and to provide evidence and impact indicators of CA on sustainable land management and livelihood of farmers.

At the end of the proceedings, an abstract is added summarizing the results of the discussion. The discussions confirmed that there is evidence enough that CA contributes substantially to the implementation of UN conventions, especially the UNCCD. The discussions also revealed that policy aspects were not sufficiently covered in the workshop; a key issue in the region for example is crop/livestock interactions. Therefore, a central issue in the discussion became the question how to activate suitable agricultural and environmental policies.

The workshop participants finally agreed to reinforce the dialogue by establishing a task force for organizing a "CA networking" to enhance the exchange of information on a regional and international basis. There was a general agreement amongst the participants that the exchange of qualitative and quantitative CA data will have great utility in disseminating new developments for specific environments and approaches and will help to develop CA in the Arab region further.

Conservation Agriculture (CA) in the Arab World between Concept and Application

Abdelouahab Belloum
Conservation Agriculture Program
The Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD)
P.O. Box 2440, Damascus, Syria
Belloum_a@yahoo.fr; Tel. : +963 11 5743063

Abstract

The high population growth rate, the degradation of agricultural lands and the scarcity of water have raised some doubt about the continuous suitability of the dominant agricultural systems in the dry lands of the Arab region. In face of these environmental and economic challenges and even though there are currently local solutions, there is a need to reconsider those classical agricultural systems and try new agricultural systems which may help preventing soil degradation and increasing its productivity.

Conservation agriculture (CA) is considered a promising solution for the region, but looked upon sceptically because of lack of information and because of the varying definitions and terms used (no-tillage, direct planting through a soil cover, conservation tillage, etc.). The system risks not to be accepted by farmers, if the (economical) benefits are not superior to those of the conventional systems, and if it is not supported by agricultural policies and scientific research. Great efforts by all partners and stakeholders are required to implement this system which remains a real hope for sustainable agriculture in the Arab countries, in rainfed as well as in irrigated agriculture.

Keys words: system CA, aridity index, adoption, rainfed agriculture, water resources

Introduction

As a result of the prevailing rainfall pattern and soil types, the semi-arid and arid areas constitute almost 90% of the entire area (14.3 million km^2) of the Arab region (ACSAD, 2004), and are among the most fragile and unstable ecosystems in the world. The rapid population growth (2.6% per annum) increases the pressure on the natural resources (AOAD, 2004), and consequently the degradation of land and water resources is alarming. This situation implies the need for a compromise between sustainable agricultural production that conserves the environment, and provides income to farmers at an acceptable productivity and a performance with a feasible cost for the state. Conservation agriculture, although it is perceived in the region with great caution due to the lack of information and to the ambiguity of the definitions given to it so far (no-tillage, direct drilling/seeding, drilling/seeding through a vegetative cover), could be the solution for agricultural production without degrading the natural resources. The system, however runs the risk of not being accepted by the farmers if the direct benefits it provides are not greater than, or similar to those offered by conventional agriculture. The dissemination has to be supported by appropriate agricultural policies and participative research programmes that deepen the knowledge of the biophysical mechanisms underlying the functioning of the system and the conditions for its adoption by farmers (CNEARC - CIRAD-CA, 2001).

An unfavourable geo-climatic context

An unfavourable climate, marked by spatio-temporal irregularities, coupled with growing tensions on land and water resources, stresses the importance of a progressive orientation towards an economically feasible and environmentally viable agriculture. Where soils were subjected to intensive agriculture, physical degradation followed automatically. Establishing a well managed system of conservation agriculture allows producers to increase and maintain soil organic matter and soil life. As such, the impact on soil stability, reduction of erosion, and increased water use-efficiency are remarkable (Blanchart et al., 2000).

The geo-climatic context of the region is mostly Mediterranean, characterised by a relatively temperate (rainy) season during which the cyclonic disturbances bring rain, sometimes substantial events, especially on hills. This is followed by a dry period and calm weather (Belloum, 1992). The rainfall pattern reflects the same trends and tendencies of the Mediterranean climate (alternating dry and wet periods). It is essential for the presentation of the rainfall distribution and its pattern to determine two indices that translate the nuances of the pattern and the inequality of the distribution. The index P/n is a direct function of the average annual rainfall (P) and is inversely proportional to the number of rainy days per year (n). In fact, it expresses the degree of the uneven rainfall distribution throughout the year. A high value of P/n indicates a concentration of rainfall or precipitation. A small value of this index indicates simply a rainfall distribution which is staggered over time; which is not the case of all the sites taken as example (Fig. 1).

The index S/P reflects perfectly the rainfall concentration in a period of maximum precipitation(S corresponding to three consecutive months during which the accumulated rainfall is highest). But its major importance lies in the fact that it explains a climatic characteristic, e.g., if the rainfall is concentrated

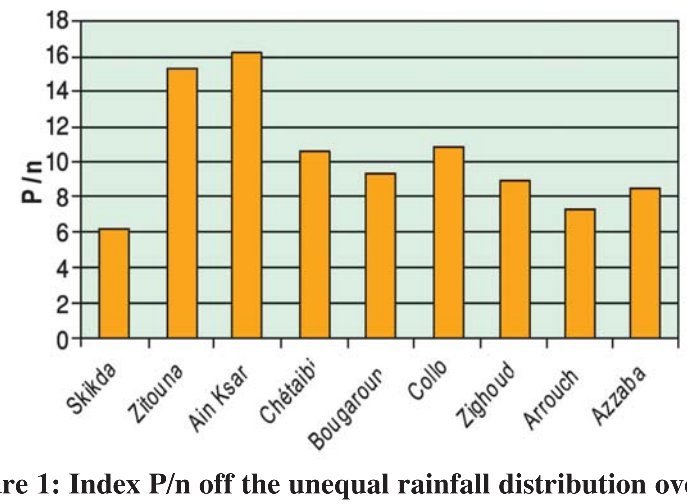


Figure 1: Index P/n off the unequal rainfall distribution over sites

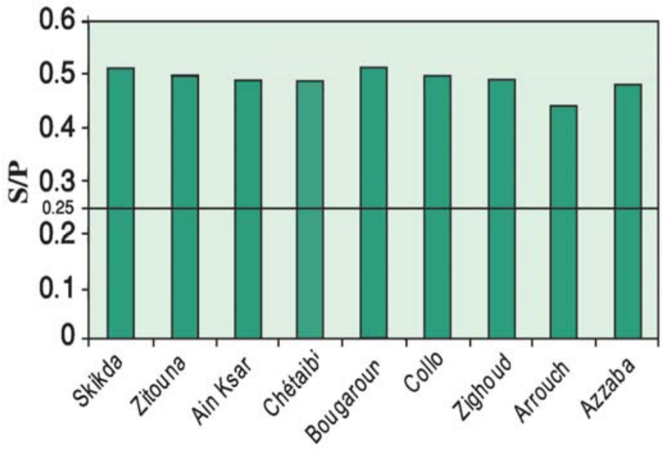


Figure 2: Index S/P for rainfall concentration over sites

in a single season, rains are in most cases heavy and torrential, having a high erosivity index (Fig. 2). The figure shows that all the selected sites had an S/P index close to 0.5, which means that 50% of the rainfall was concentrated in one period. Theoretically, the rainfall would be evenly distributed if the index value approaches 0.25 as opposed to a concentration where the index value approaches 1.

There are many indicators that can explain/express the climatic situation. Among these indices is the aridity index of De Martonne that characterises the climate of a region, but allows, above all, the delineation of the zones requiring irrigation (Belloum, 1991). This index is a function of the mean annual precipitation (Pa in mm) and mean annual temperature in °C, (I = Pa/ (T+10). The determination of monthly aridity indices (Am) based on a series of observations, within a sample area, allows a realistic definition of the irrigation period (Fig. 3).

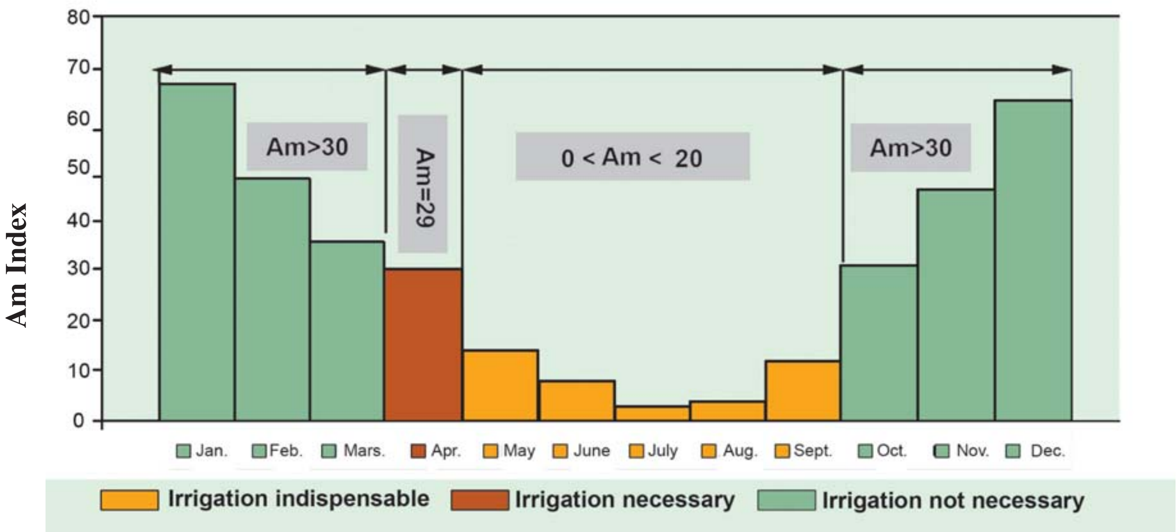


Figure 3: Monthly aridity indices of De Martonne and the irrigation seasons. (for coloured picture see annex #3, p.281).

In fact the Arab region lies within a transitional climatic region with a double affiliation with respect to seasons. In summer, it is a subtropical climate marked by increased drought, and in winter, the tendency is more towards the temperate or moderate areas, however with torrential rains. Under these conditions, the natural constraints limit the intensification of the land use in the region. This is expressed mainly by inundations during the rainy periods which prevent the use of lower lying areas, and by severe soil erosion on slopes, which not only results in a decline of soil fertility but also in the sedimentation of dams and lakes. Inappropriate agricultural practices, such as ploughing down-slope, intensify these processes.

The hydrological deterioration of these areas where rainfed agriculture prevails combined with anthropogenic actions is illustrated schematically in figure (4). Gréco (1979) said in his handbook for the protection and restoration of major soils in Algeria: "In this country of 28 million hectares, besides the Sahara, we estimate that about 13 million hectares or 45% of the total area are subject to erosion and should be placed under different regimes and forms of protection and rehabilitation. This mountainous country with steep slopes and an increasingly growing population, a livestock concentration well above the carrying capacity, looses its arable land at a striking rate".

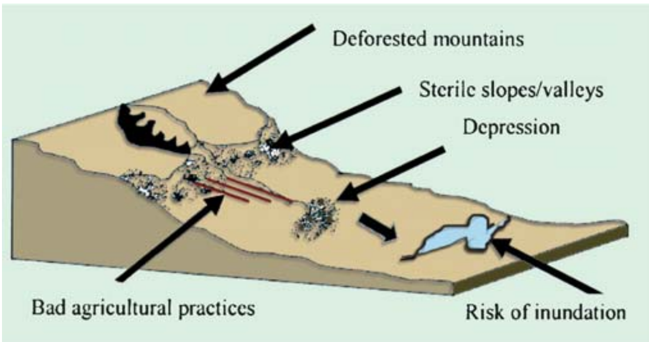


Figure 4: Hydrological and anthropogenic degradation in slopy areas.(for coloured picture see annex #3, p.281).

A critical state of water resources

The surface water resources average in the Arab region is estimated at 205 billion m^3/y. About 70% of this water comes from outside the region. The ground water resources are distributed over large basins and aquifers, some of which are trans-boundary. The estimated reserves of the ground water resources are ~ about 7730 billion m^3, with only 35 billion can be exploited nowadays (AOAD, 2005). The annual recharge of these resources is about 42 billion m^3. Non-conventional water resources including the sewage drainage and industrial waste water and the desalinated water of desalinisation installations, are estimated at around 7.5 billion m^3. Drainage water constitutes 5 billion m^3, and the desalinated water is about 2 billion m^3. However, there is a remarkable tendency in the Arab world to reuse sewage water.

The statistics on the use of water resources in the Arab region indicate a volume of about 191 billion m^3. Agriculture accounts for 89% of the use, domestic use for about 6% and industrial uses for about 5%. Despite this high use for agriculture, about 50% of the agricultural products are imported from outside the Arab region, as the food requirement in the region increases rapidly proportional to the population. The volume of water utilised for agriculture is estimated at 169 billion m^3, of which 147 billion m^3 are used for surface irrigation by gravity, with a water use-efficiency of only 38% (water use efficiency is the ratio of the crop water requirements to the total water supplied to the crop). The losses are estimated at 91 billion m^3. It is evident that the increase of the water use-efficiency in agriculture is of first priority.

New cropping systems and cultural practices have to be explored and adapted to the regional situation. Conservation agriculture represents one of the appropriate solutions for this specific context (Belloum, 2003). The indicators for land resources indicate that the area of agricultural lands for the year 2003 was 70.2 million hectares (4.9% of the total area of the Arab world), 24.3% of which are irrigated (AOAD, 2005). The Arab region could be subdivided into two agricultural zones based on the type of agriculture practised; countries where the climatic conditions allow a predominantly rainfed agriculture (Fig. 5a), and countries where irrigated agriculture is exclusive (Fig 6a). Figures 5b and 6b show undeniably the importance of water as the limiting factor in agriculture production.

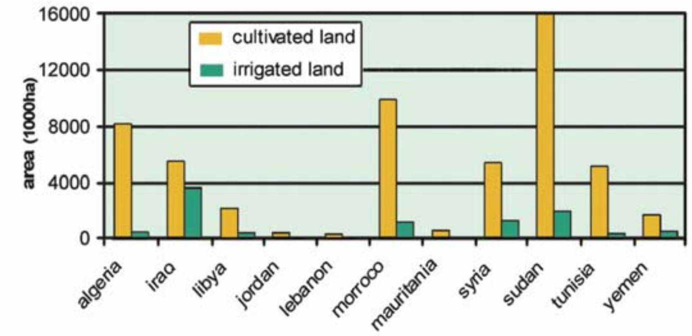


Figure 5a: Countries with mostly rainfed agriculture

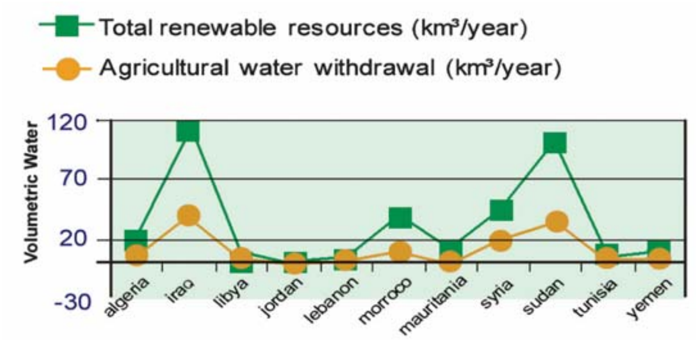


Figure 5b: Countries with volumetric water extraction for agriculture

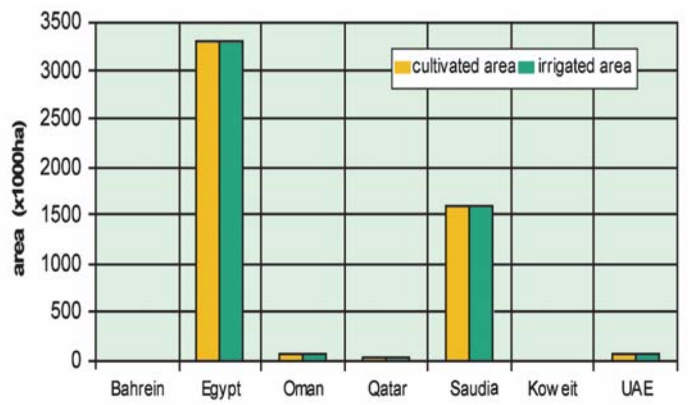


Figure 6a: Countries with exclusively irrigated agriculture

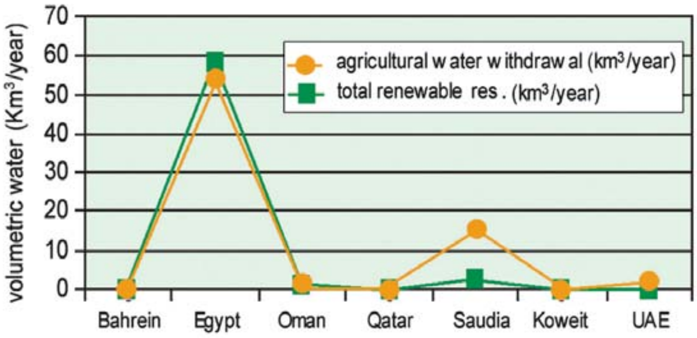


Figure 6b: Total renewable resources and of extraction for agriculture (km³/year)

Of the countries with predominantly rainfed agriculture, only five countries (Tunisia, Morocco, Lebanon, Algeria and Mauritania) use less than 50% of the available and renewable water for agriculture; while the other six use more than 50% and even more than 100% in Libya and Yemen. For the countries with exclusively irrigated agriculture, the situation is more critical. Apart from Egypt which uses 100% of its renewable water resources, all the others utilise proportions ranging from 125% in the Sultanate of Oman to more than 1000% in the United Arab Emirates.

The adoption of conservation agriculture differs in its approach and technical applications; but given the status of natural resource degradation in the Arab region, this system provides, given a well elaborated location-specific adaptation, a potential solution. The illustration presented by De Morales, et. Al., (2004), even though in a context different than that of the Arab region, presents the advantage of a clear vision of conservation agriculture, which is not really a new system, rather than a simulation of a natural vegetation ecosystem.

Impact of conservation agriculture on the Arab region

The degraded natural resources in the Arab Region, as stated before require conservation agriculture, a multi-functional system which sustains a ground cover, protects the soil from erosion, restores soil quality, controls weeds and sequesters carbon. It provides clear and obvious advantages for Arab agriculture. The ground cover not only protects the soil against erosion by intensive rains, and against high temperatures, it also reduces evaporation, and serves as a buffer against the weight pressure of machines and animals. Underneath the soil surface the root system acts like a web fixing the soil and the polysaccharides of the root exudates improve the aggregate stability. Carbon is continuously sequestered in the root system, which in turn strengthen soil biological activity (Séguy et al., 2001c). The nature of the vegetative cover, and whether or not the soil was worked, considerably influences the erosion phenomenon (Fig.7). The nutritional function of conservation agriculture stems from the interaction of the ground cover biomass with climate and soil (Fig8). The biomass through its lignin content and C/N ratio, merged with the climatic effects (rainfall, temperature) and the nature of the soil, along through mineralization processes, generates nutrients, organic acids and metabolites of the organic matter. This process has many advantages and allows solving many problems caused by conventional agriculture. It allows feeding the crops, the soil fauna, and to a certain degree, with appropriate management, allows feeding the livestock. The latter is important for the adoption of conservation agriculture under the ecological conditions of the Arab region.

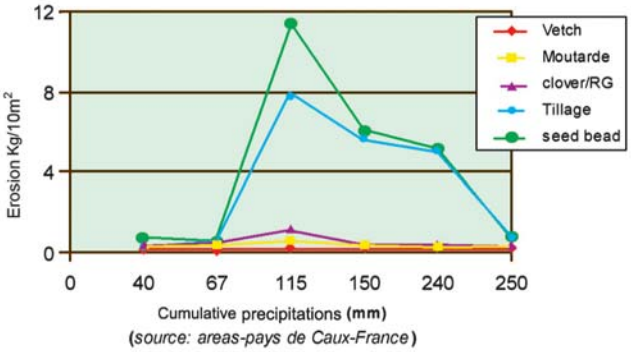


Figure 7: Erosion as a function of vegetative cover.

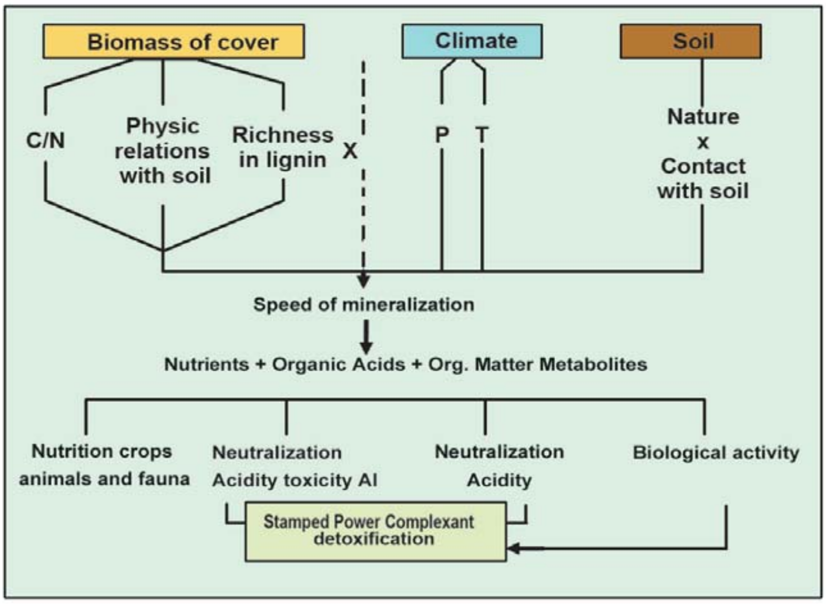


Figure 8: Nutritional function of conservation agriculture.

Based on the re-established biological activity of the soil, CA can solve well known phenomena in the region, such as water-logging and acidity frequently found in the soils of coastal strips and plains of the Arab region. Through its buffering capacity, it also aids to a certain degree overcoming salinity.

Impact on water dynamics

The permanent soil cover in conservation agriculture reduces run-off, leading to higher infiltration rates and more water available to crops. Also The Residual water left by the cover crop, which is usually dead when sowing the commercial crop, will be available for the succeeding crop, thus prolonging the humid period. Though the context is different in the Arab region, the results (Table 1) of CIRAD's research in the Cerrados of Brazil have shown the importance of water conservation enhancement and its efficient use in the CA systems (Scopel et al., 2005).

Table 1: Comparison of the water balance under CA and conventional systems

Water Balance for Maize							
Management	Pmm	R mm	Es mm	Ep mm	D mm	Tc Mm	ΔSt mm
Conv.	907	45	260	-	206	306	89
CA	907	9	159	56	202	350	131
Water Balance for Millets							
CA	63	1	63	16	0	126	-114
Water Balance for Rice							
Conv	856	95	229	-	396	127	-53
CA	856	47	208	30	403	141	-78
P = Rainfall; R=Run-off; Es= Evaporation from soil; Ep= Evaporation from mulch; D= Drainage; Tc= Transpiration of crops; ΔSt= (change in soil water)							

The data in table 1 are relevant for the application of CA systems in the Arab region, especially for highly permeable soils of sandy nature. It is evident that CA reduces water losses through run-off by 50%; the soil cover alone reduces evaporation losses by 10-20%. Hence, the commercial crop can benefit from this supplementary stored water in the soil and the humid period will be extended. This has been confirmed on an experimental field in the district of Zeghouane in Tunisia, where wheat under a conventional system had already reached maturity; while that on the plot under CA was still at the dough stage (Photo 1).

Photo 1: The effect on water dynamics under CA (B) and conventional systems (A) is reflected on crop growth period. The difference in colour is visible.
***Zone A is at maturity (bright, whilst zone B is still in the dough stage (dark).* (for coloured picture see annex #3, p.281).**
Site visit on June 28th, 2006, District of Zeghouane, Tunisia.

This supports the hypothesis resulting from numerous international experiments performed under different climatic conditions, on different soil types, and for all types of crops; that CA does not really have limits. The results presented in table 1 regarding the efficient use of water by the system (expressed as amounts of water used by the crops) confirm similar results obtained in Mexico (Scopel, 2001; Findeling, 2001). The research on water dynamics in CA systems executed in Morocco under humid and dry regimes showed clearly that not tilling the soil and mulching extended the humid period significantly (Mrabet, 1997).

Figure 9 show that it took 40 days to reach the wilting point in the no-tillage system, whereas it took only 15 days on the tilled soil. Higher infiltration rates and reduced evaporation losses under CA increased the water storage capacity of the soil compared to other managements of fallow in Morocco, the United States, and Australia (Fig. 10; Mrabet, 2001a). It is evident that CA with its higher efficiency in water use remains advantageous for rainfed agriculture as well as for countries with exclusively irrigated agriculture. In the Arab countries, water resources are the limiting factor

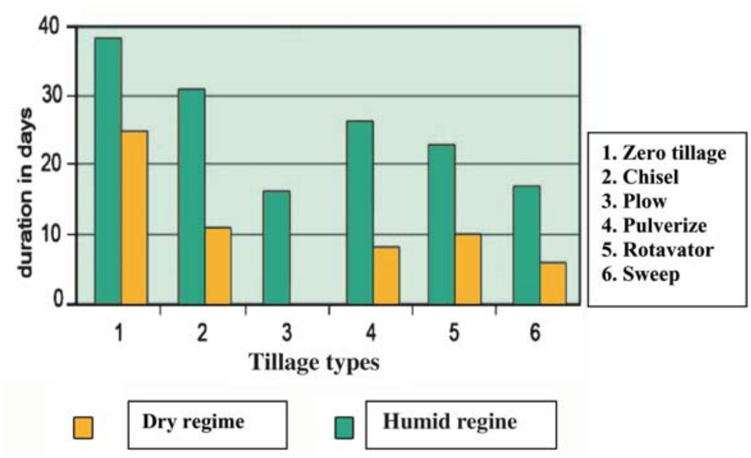


Figure 9: Number of days required to attain the wilting point in relation to soil tillage (CEA/TNG/CDSR/AGR, December 2001, Workings of Rachid Mrabet).

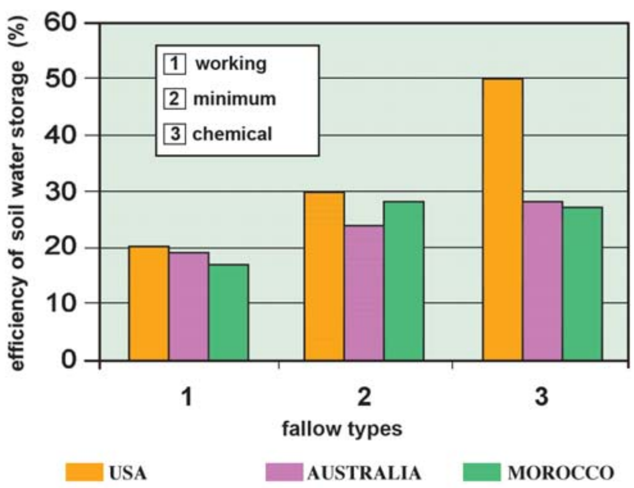


Figure 10: Efficiency of water storage in relation to fallow management (CEA/TNG/CDSR/AGR, December 2001, Workings of Rachid Mrabet).

for the agricultural, economic and social development. This situation is linked with an unfavourable physical environment namely low rainfall, less developed poor and low productivity soils, and a sparse vegetative cover subject to increasing pressures by livestock.

Constraints for the adoption of CA in the Arab region

The constraints facing the adoption of CA in the Arab region could be summarised as follows:

- Soil tillage is part of all production systems and consequently, the integration of new systems will be difficult and requires time for its adoption,

- There are difficulties to propose new systems such as CA which do not generate a short term cost recovery for farmers and farmer associations,

- The forage market in most of Arab countries is poorly developed, and when coupled with an important livestock population, leads to a high pressure on areas rich in biomass especially during the dry periods.

- The environmental impacts of CA are not well appreciated by farmers, because securing food in the short term has a higher priority than soil conservation or regeneration that can be only achieved on medium and long term.

Perspectives for conservation agriculture in the Arab region

Considering the economic, social and environmental constraints facing the Arab world in the search for hypothetical food security and the will to preserve natural resources, the search for new methods of land use is pertinent. The adoption of CA systems in a well planned and progressive manner could lay the foundations for a sustainable agriculture that would provide adequate solutions for the challenges cited above.

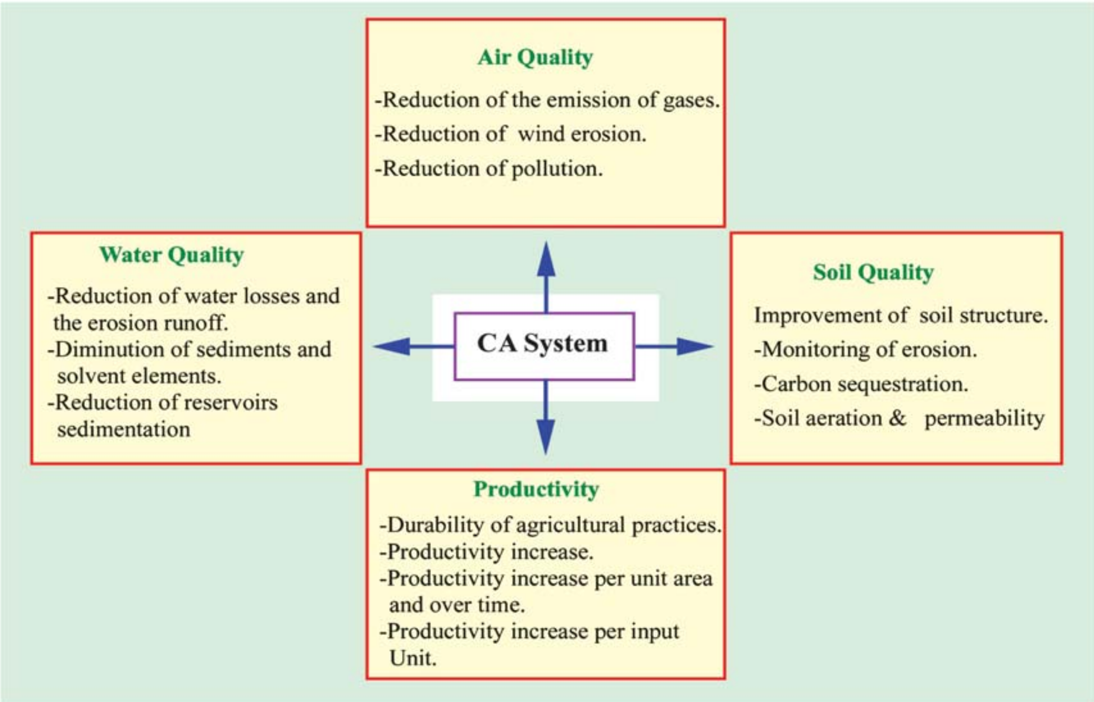


Diagram 1: Relation of direct drilling systems, environmental components and agricultural decisions (Mrabet, 2001a).

The multidimensional benefits and advantages of CA systems on the agricultural, economic and social levels are proven, without doubt (diagram 1). However, the application of the basic principles of CA in the geo-climatic and socio-economic context faces serious difficulties.

The agricultural experimentation in the region is conducted according to the local context and to the actual constraints. The experiments carried out by the International Center for Agricultural Research in Dry Areas (ICARDA), similar to those conducted in Morocco, took into consideration the competition for crop residues by livestock and therefore a main component of the conservation agriculture, the ground cover, is compromised. The definition of sustainable agriculture (Pieri and Steiner, 1997; Lamarca, 2000) is very much in line with the concept of CA. On the other hand, Mrabet indicated in the report of the Economic Commission for Africa (CEA/TGN/CDSR/AGR, 2001) that CA is a technical package that is based on four principles: the elimination of tillage, a permanent soil cover of crop residues or cover crops, direct seeding through this cover using appropriate tools, and weed control without disrupting the soil. The author concludes that omission or faulty application of any one of the four components of the system would jeopardize the desired success. The experiments of the Arab Authority for Agricultural Investment and Development based in Sudan (AAAID) are directed toward the dissemination of the system taking into account its prerogatives and objectives. But the major concern remains production and productivity, which neglects to a certain extent the ecological aspects when evaluating the system at the agricultural and socio-economic levels. In Tunisia, CA is applied already on a relatively large area. The approach focuses on relatively large farms, whose owners could be convinced of the, primarily economic, advantages of the system. Due to good results even within the first year, the system became quite popular and the area under CA is expected to reach 100,000 hectares by 2012. The relative success of CA in Tunisia can be explained by the good selection of pioneer farmers and the collaboration between research institutes, development programmes, and farmers associations. This experience would have been more fruitful and have spread to other parts of the Arab region, if a monitoring programme was set in place parallel to the dissemination approach.

ACSAD as a specialised Arab organisation within the framework of the League of Arab States, with the support of GTZ, has started a regional project to spread CA practices in the Arab countries. This project has already gained popularity among Syrian farmers, which can be attributed to good awareness of the developing programme and the selection of realistic objectives. The number of farmers that joined the project in Syria increased from 2 farmers in 2006 to 27 farmers in 5 Syrian provinces in 2007. The joint effort of ACSAD and the American University in Lebanon also succeeded in interesting large farmers in Lebanon to try CA practices.

In spite of the merits of CA its adoption within the region may be hampered by unfavourable environmental and socio-economic obstacles. The main constraint is probably the use of crop residues for feeding livestock which is not compatible with introduction of a permanent ground cover. The joint efforts of all the partners (public organisations, researchers and farmer groups) are a basic requirement for the adoption of CA systems. CA remains a real hope for the future of agriculture in the region.

References

1. ACSAD/CAMRE/UNEP. 2004. State of *Desertification in the Arab World (Updated Study), Dec. 2004, 634p (In Arabic).*

2. AOAD, 2005, Arab Food Security Report, Arab Organization for Agricultural Development, AOAD-Khartoum, Sudan, 89p.

3. BELLOUM, A. 1992 – Natural Constraints and Soil Exploitation in Algeria, the Skikda Region, MEDIT, 3rd Year, 4 the Issue, pp 26-33. Italia.

4. BELLOUM, A. Agricultural Hydrology in Algeria-a double problem, Hydrological Sciences Journal, IAHS PRESS, WALLINGFORD, Volume 38, pp 479-495 – United Kingdom.

5. BELLOUM, A. 2004, Overuse of Ground Water in Arab Agriculture, 3th International Conference on Water in Arab Region. Beyrouth – LEBANON.

6. BELLOUM, A. 2003. Les Structures institutionnelles de gestion des eaux dans le monde arabe, Options Méditerranéennes, Série A, n. 49, CIHEAM – France, pp 169-175.

7. BLANCHART, E., ACHOUAK, ALBRECHT, A., BARAKAT, M., BELLIER, G., CABIDOCHE, Y.M., HARTMANN, C., HEULIN, T., LARRE-LARROY, C., LAURENT, J.-Y., MATHIEU, M., THOMAS, F., VILLEMIN, G., WATTEAU, F., 2000, Déterminants biologiques dans les vertisols des petites antilles- conséquences sur l'érodibilité, Etude et gestion des sols, 7, 4, numéro spécial p. 309-328.

8. CNEARC-CIRAD-CA, 2001, Les systèmes de culture à base de couverture végétale et semis en zones tropicales, Etudes et Travaux n° 19. 164p.

9. GRECO J. 1979, La défense des sols contre l'érosion, Techniques d'avenir (agriculture), La maison rustique, I.S.B.N. 2-7066-0073-x – Paris 183p.

10. JOAO de MORAES SA & al. 2004, Le semis direct comme base de système de production visant la séquestration du carbone, Revista Plantio Direto, n°84, Nov-Dec. P. 45-61, Brasil.

11. LAMARCA, C.C., 2000, Les fondements d'une agriculture durable, PANAM, 317p.

12. MRABET, R., 1997. Crop residue management and tillage systems for water conservation in a semi arid region of Morocco, PhD, Diss. Colorado State University, Fort Collins, CO. USA, 209 p.

13. MRABET, R., 2001a. Le semis direct: une technologie avancée pour une agriculture durable au Maroc, bulletin de transfert de technologie en agriculture, MADREF-DERD, n° 76, 4p. http://agriculture.ovh.org.

14. PIERI, C. & STEINER K. G., 1997, L'importance de la fertilité du sol pour le cas de l'agriculture durable- Le cas de l'Afrique, Agriculture et Développement Rural n°1,23-26p.

15. SCOPEL E., FINDELING A. Conservation tillage impact on rain fed maize production in semi arid zones of western Mexico. Importance of runoff reduction. "Conservation agriculture, a worldwide challenge", lst World Congress on Conservation Agriculture, Madrid, 1-5 October 2001, 179-184.

16. SCOPEL E. & al. Impact des systèmes de culture en semis direct avec couverture végétale (SCV) sur la dynamique de l'eau, de l'azote minéral et du carbone du sol dans les Cerrados brésiliens, Cahiers Agricultures, vol. 14 n°1, janvier-février 2005.

17. SEGUY L., BOUZINAC S., MARONEZZI A. C., 2001c Document interne CIRAD, 203p.-34398-Montpellier Cedex-France.

*Conservation Agriculture: Impact on Farmers' Livelihoods, Labour, Mechanization and Equipment**

Theodor Friedrich and Josef Kienzle
Food and Agriculture Organization of the United Nations (FAO)
Viale delle Terme di Caracalla, 00153 Rome, Italy

Abstract

Conservation Agriculture (CA) is defined as a concept for resource-saving agricultural crop production that strives to achieve acceptable profits, high and sustained production levels while concurrently conserving the environment. It is regarded as sustainable land management tool for agricultural lands. CA is based on enhancing natural biological processes above and below the ground. Interventions such as mechanical soil tillage are reduced to an absolute minimum, and external inputs such as agrochemicals, nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with or disrupt the biological processes. In some cases external inputs are reduced to zero. CA is characterized by three principles which are linked to each other, namely:

1. minimum mechanical soil disturbance throughout the entire crop rotation
2. permanent organic soil cover,
3. diversified crop rotations in case of annual crops or plant associations in case of perennial crops

With the increased adoption of CA the experience with the system grew and other implications and benefits were noted. These benefits impact directly on the livelihoods of the farmer through the effect on profitability of farming and especially the largely reduced labour requirements. Especially for a small scale family farm a vulnerable households with limited labour resources the introduction of CA can lead to significant improvements in the livelihood through stabilizing the natural resource base and at the same contributing to more stable yields even in drought affected years.

By changing some key operations the approach has also an impact on the agricultural mechanization and the equipment choices and hence influences in the long term the agricultural machinery supply sector. Dealers and sales points in rural areas will likely to be encouraged to adjust their outlets if increased demand for CA relevant equipment gets more evident.

The paper will briefly explain the features of CA which lead to these changes and then report in more detail experiences which have been observed in the long term after the introduction of CA on the livelihood of farmers, labour requirements, mechanization and equipment use.

Keywords: conservation agriculture, livelihood, labour saving, mechanization

* The views expressed in this paper are the personal opinion of the authors and do not necessarily quote the official policy of FAO

Background – history of conservation agriculture

Conservation Agriculture has its origin in conservation tillage, which was developed to respond to the dramatic degradation of agricultural production resources. This was mainly soil erosion through wind and rain water impact. Closely connected to soil is the water resource, which is also addressed by conservation agriculture and is of particular importance for dry lands. In that respect the 'in-field' water management aspects are also addressed here.

Reducing the intensity of tillage for economic reasons (leading to minimum tillage) or for environmental reasons (leading to conservation tillage and finally to zero tillage practices) is not a new idea. One of the first references in modern agriculture to no-till farming is probably Edward Faulkner's "Ploughman's Folly" (1945). Over the last few decades the practice of minimum and no-tillage had its ups and downs. In some situations it worked well, in others less well. Minimum tillage, conservation tillage and zero tillage were all applied as practices within conventional concepts of agriculture and therefore were not universally applicable. However, there appears to exist evidence that no-tillage can be successfully incorporated into a new concept of truly sustainable agriculture. In this case, not tilling the soil mechanically becomes one underlying principle of a completely new understanding of agriculture. This concept shows in at least one world region over the last decade a consistent and exponential adoption curve. During the last few years it is, under the name of Conservation Agriculture (CA), gaining popularity all over the world (Derpsch, 2001).

Conservation Agriculture might well be based on old, well known principles. But it combines these principles in a new way achieving synergies which had not been considered in the past and which only recently are being understood and investigated. The main objective in CA changes towards providing a favourable microclimate for soil life by protecting the soil surface from sun, rain and wind as well as providing food for the soil micro and macro organisms. These organisms forming the soil life in CA are substituting biological tillage for mechanical tillage. While conventional agriculture is "cultivating the land", using science and technology to dominate nature, CA tries to "least interfere" with natural processes. Similar thoughts have been developed over the past 50 years also in the Far East by Masanobu Fukuoka (1975). While Fukuoka rejects even mechanization, this extreme is not justifiable in view of the requirements of modern agricultural production. But the approach naturally has implications for the required engineering interventions in agriculture and as such in the technical solutions offered.

During the last decade CA has been gaining popularity all over the world. It is now applied on about 95 million hectares (Derpsch, 2005). Together with other organizations and stakeholders FAO has been promoting and introducing CA in several countries in Latin America, Africa and Asia. Applying these three principles CA has been adapted to different climatic conditions from the equatorial tropics to the vicinity of the polar circle and to different crops and cropping systems, including vegetables, root crops and paddy rice. Today CA in its different applications is increasingly seen as a way to practice sustainable agriculture. It is becoming increasingly popular where conventional agriculture is facing serious problems due to land degradation and increasingly unreliable climatic conditions. In this way it is becoming also a popular concept in rehabilitation responses to emergencies caused by natural disasters.

The key element which CA is focussing on is soil organic matter which stabilizes soil and increases water holding capacity. This particular characteristic makes CA so important particularly for dry lands. Water is one of the most precious natural resources for agricultural production. Agriculture accounts for 70 % of the actual water use (FAO, 2002). The predictions are that by 2025 the water consumption will exceed the available "blue water" if the current trends continue (Ragab & Prudhomme, 2002). In the Indian state of Punjab, characterized by intensive irrigated agriculture, the ground water table is falling at a rate of 0.7 m per year (Aulakh, 2005). The decline of fresh water resources is not only due to increased consumption, but also due to a careless management of this precious resource. Agriculture is part of the problem by wasting water and by sealing and compacting the soils so that the excess water cannot anymore infiltrate and recharge the aquifer. Increasing numbers of flood catastrophes are one symptom of this (DBU, 2002). Especially in those world regions, where water is already now the limiting factor for agricultural production, this wasteful practice is threatening the sustainability of agriculture. Rising temperatures and evapotranspiration rates combined with more erratic rainfall aggravate the water problems in rain fed agriculture (Met Office, 2005).

Soil does not only impact on production, but has also an influence on the management of other natural resources, such as water. Soil structure is strongly correlated to the organic matter content and to the soil life. Organic matter stabilizes soil aggregates, provides feed to soil life and acts as a sponge for soil water. With intensive tillage based agriculture, the organic matter of soil is steadily decreasing, leading first to a decline in productivity, later to the visible signs of degradation and finally to desertification (Shaxson & Barber, 2003). The lack of yield response to high fertilizer dose in the Indo Gangetic Plains can be attributed to deteriorated soil health as a result of over-exploitation (Aulakh, 2005). In the Indian states of Uttaranchal or Haryana the organic carbon content in soils reaches minimum values below 0.1 % (PDCSR, 2005). Agricultural production has all over the world led to soil degradation, more pronounced in tropical regions, but also in moderate climatic zones. The world map of degraded soils indicates that nearly all agricultural lands show some levels of soil degradation (FAO, 2000).

What is conservation agriculture?

Conservation Agriculture is defined as a concept for resource-saving agricultural crop production that strives to achieve acceptable profits, high and sustained production levels while concurrently conserving the environment. CA is based on enhancing natural biological processes above and below the ground. Interventions such as mechanical soil tillage are reduced to an absolute minimum, and the use of external inputs such as agrochemicals, nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with or disrupt the biological processes. CA is characterized by three principles which are linked to each other, namely:

1. minimum mechanical soil disturbance throughout the entire crop rotation
2. permanent organic soil cover,
3. diversified crop rotations in case of annual crops or plant associations in case of perennial crops

Zero tillage

The principles of CA lead to the following effects on the soil. Since the soil is never tilled, soil structure changes. A system of continuous macro pores is established, facilitating water infiltration and aeration of the soil as well as root penetration into deeper zones. At the same time the soil bulk density might be higher than on conventionally tilled soils, since the soil matrix provides a firm structure. Tillage mixes air into the soil which leads to a mineralization (oxidation) of the soil organic matter. In the absence of soil tillage this mineralization is reduced. If organic matter in the form of roots and residues is added, soil organic matter contents increase with higher values near the surface, gradually declining at increased depth. Soil macro and micro fauna and flora are re-established resulting in better soil fertility.

Soil cover

The permanent soil cover through crops, mulch or green manure cover crops complements the zero tillage effects by supplying substrate for soil organic matter build up and for the soil life which is facilitated by not disturbing the soil. Through protection of the soil surface the mulch is reducing evaporation and avoiding crusting. It also suppresses weed growth. Problems experienced in direct seeding or zero tillage when applied in isolation are reduced in this way. On the other side the application of zero tillage and direct seeding technology facilitates the management of residues which in conventional systems are often considered a problem. In very dry regions where water is the most limiting factor to crop production it is often difficult to maintain a permanent full soil cover. Nevertheless, even with incomplete soil cover CA practices are still valid, as long as sufficient organic matter is supplied to the system to build up soil organic matter and to increase productivity. However, the weed control function of the soil cover cannot be achieved in this case. When livestock is competing for the residues it is important especially in the first years of transition to strike a balance between the different uses for the residues. Once the productivity is increased as a result of the increased soil organic matter, the system often delivers sufficient material to feed both the soil and animals.

Crop rotations

Also the crop rotations serve different purposes in the system and are linked to the other two principles. Besides the phytosanitary and weed management objectives, crop rotations serve to open different soil horizons with different rooting types. Applying a diversified crop rotation increases the overall productivity of the cropping system and as such also the long term profitability, compared to monocropping of economically attractive cash crops which in the long term always proves not sustainable. The crop rotation becomes at the same time part of the soil cover and residue management strategy with the objective to keep the soil constantly covered either under a live crop or dead residue mulch. The shorter turnover of no-tillage and direct seeding allows the application of crop rotations which under conventional agriculture would be impossible; for example, the addition of an additional cash, forage or cover crop.

Other resource conserving technologies

The three basic principles of CA can be complemented with other technologies providing additional synergetic benefits.

Bed planting provides benefits of water saving in systems where surface irrigation is applied. Under CA, the beds can be converted into permanent beds whereas any soil tillage would be limited to a periodic cleaning and reshaping of the furrows. The same permanent bed system would be applicable under CA also for crop rotations, which include crops grown on beds, for example for drainage purposes. All crops of the rotation can be grown on the same beds, regardless to whether they are row crops or small grain cereals. Water savings compared to flat surfaces of 26% for wheat and 42% for transplanted rice have been reported, with yield increases at the same time of 6.4% for wheat and 6.2% for rice (RWC-CIMMYT, 2003). However, the precondition for such a permanent bed system is the harmonization of the furrow distances and bed width for all crops in the rotation and for all mechanized traffic operations. In this way a permanent bed system leads also to controlled traffic taking additional advantage of that resource conserving technology.

Controlled traffic farming restricts any traffic in the field to always the same tracks. While these tracks are heavily compacted, the rooting zone never receives any compaction resulting in better soil structure and higher yields. Through border effects the area lost in the traffic zones is easily compensated by better growth of plants adjacent to the tracks so that the overall yields are usually higher than in conventional systems with random traffic (Kerr, 2001). Obviously controlled traffic farming is the ideal complement to zero tillage systems since soil compaction due to machine traffic in the cropping zone is completely avoided. Other benefits are fuel savings since the traction is more efficient when tires run on compacted tracks (RWC-CIMMYT, 2003).

Direct seeding is another complement to CA. Although transplanting of crops, including paddy rice, is possible under zero tillage, direct seeding is preferable for the reasons mentioned above. In addition direct seeding results in less soil movement than transplanting, which often involves some sort of strip tillage. At the same time CA facilitates direct seeding by reducing a number of problems, such as surface crusting or weed control, encountered when direct seeding is applied in isolation.

Laser levelling provides the same benefits to CA as to conventional agriculture under surface irrigation conditions. However, since it involves significant soil movement in the beginning, it would be considered an initial investment before converting to a permanent zero tillage cropping system as CA is. The benefit of such a strategy is that the investment in laser levelling would last much longer than in conventional systems, since under CA no further soil tillage would be applied which could upset the levelling of the field.

Effects of conservation agriculture

Land and water

Under CA the levels of soil erosion are inferior to the build up of new soil. On average the soil under CA "grows" at a rate of 1 mm per year in humid climates due to the accumulation of soil organic matter. This growth continues until a new point of saturation is reached in the soil which takes 30 to 50 years (Crovetto, 1999). This rate of increase is for humid areas where a lot of organic matter is produced; it will likely be much less in drylands. The organic matter levels rise by 0.1 - 0.2% per year due to the residues left on the soil surface, the remaining root biomass and the reduced mineralization. Within a crop rotation different root systems structure different soil horizons and improve the efficiency of the soil nutrient use. In general the soil structure becomes more stable (Bot & Benites, 2005). At the same time soils under CA improve the water efficiency. The increased amount of continuous vertical macropores facilitates the infiltration of rain water into the ground and hence a recharge of the aquifer. The increased soil organic matter levels improve the availability of water accessible to plants. 1% of organic matter in the soil profile can store water at a rate of 150 m^3/ha. The permanent soil cover and the avoidance of mechanical soil tillage reduce the unproductive evaporation of water. With this the water use efficiency is increased and the water requirements for a crop can be reduced by about 30 %, regardless whether under irrigation or rain fed conditions (Bot & Benites, 2005).

Long term experiences with CA show a decline in the use of agrochemicals due to enhanced natural control processes. Natural control of pests and diseases are improving over time and also the experience in weed management through crop rotations facilitates this long term decline in agrochemical use (Saturnino & Landers, 2002). The same is true for mineral fertilizer. Less fertilizer is lost through leaching and erosion, the different rooting systems recycle more soil nutrients from a larger soil volume and with this the overall efficiency of fertilizer use is improved in the long term. This is reflected in significant reduction of the fertilizer requirements to maintain the production and soil nutrient levels over the crop rotation (Saturnino & Landers, 2002).

In addition to these on-farm benefits, the reduced leaching of soil nutrients and farm chemicals together with reduced soil erosion leads to a significant improvement of the water quality in watersheds where CA is applied (Bassi, 2000;Saturnino & Landers, 2002).

Climate and climate change

There seems to be a general trend over the last decades that extreme climatic events have become more frequent and stronger. This includes extreme precipitations as well as extended drought periods or extreme temperatures (Met Office, 2005). Agricultural production systems are highly vulnerable to such changes.

Conservation Agriculture can assist in the adaptation to climate change by improving the resilience of agricultural cropping systems and hence making them less vulnerable to abnormal climatic situations. Better soil structure and higher water infiltration rates reduce the danger of flooding and erosion catastrophes after high intensity rainstorms (Saturnino & Landers, 2002). Increased soil organic matter levels improve the water holding capacity and enables crops to get through extended drought periods. Yield variations under CA in extreme years, regardless of whether they are dry or wet, are less pronounced than under conventional agriculture (Shaxon & Barber, 2003) (Bot & Benites, 2005).

Conservation Agriculture can also contribute to the mitigation against climate change, at least as far as the release of green house gases is concerned. With the increasing soil organic matter, the soils under CA can retain carbon from carbon dioxide and store it safely for long periods of time. This carbon sequestration can continue for 25 to 50 years before reaching a new plateau of saturation (Reicosky, 2001). The consumption of fossil fuel for agricultural production is significantly reduced under CA and burning of crop residues is completely eliminated, which also contributes to a reduction of green house gas release. Besides the carbon sequestration, soils under no-tillage, depending on the management, might also emit less nitrous oxide (Izaurralde et al., 2004). Particularly in paddy rice, the change to no-till systems and adequate water management can positively influence the release of other green house gases such as methane and nitrous oxides (Belder, 2005) (Gao, 2006).

Impact of conservation agriculture on farm power and labour

One of the most noticeable changes for the farmer after introducing CA is the reduced requirement for farm power and labour. CA can reduce the overall requirement for farm power and energy for field production by up to 60% compared to conventional farming (Doets et al., 2000). This is due to the fact that the most power intensive operations, such as tillage, are eliminated. Additionally, equipment investment, particularly the number and size of tractors, is significantly reduced (Bistayev, 2002). This effect applies equally to small scale farmer using only hand labour or animal traction.

Options exist for direct sowing by hand, draft animal power (DAP) or tractor. Leaving the soil protected with surface vegetation requires a change in mind set that will demand greater management ability, especially for weed and cover crop control (de Freitas, 2000). Equipment for controlling the surface vegetation is principally DAP and tractor powered and includes mechanical (e.g., knife rollers) as well as chemical (herbicide) control measures. In general, the time and power requirements for field operations related to crop establishment and crop husbandry are reduced. This flattens especially the traditional labour and power bottleneck during land preparation. Also the labour requirements for weeding are generally reduced, particularly if herbicides are used. However, during the learning period and especially during the first two years and in systems without the use of herbicides, new labour peaks for weed control can occur. New labour peaks can also occur during harvest time, especially when the introduction of CA results in significant yield increases which eventually can happen already during the first years.

A study on the impact of conservation tillage and cover crops on soil fertility and crop production in Karatu and Hanang districts in Northern Tanzania (Mariki, 2003) verified that the labour requirements for no-tillage maize plus cover crops decreased from 72 person-days/season in the first year to 34.7 person-days/season in year four. The control plot for conventional tillage maize remained stable at about 65 person-days/season. This indicates a saving of labour days through the adoption CA (CA) practices by 54% in the fourth year of implementing no-tillage maize with cover crops.

A study of the energy cost of tractor–powered crop production with conventional tillage and direct seeding (Doets et al., 2000) estimated that total inputs are 40-50% lower for CA. This is primarily caused by reduced absolute amounts of input: herbicide (in the cases studied), machinery and fuel. Machinery energy inputs are generally 20-40% lower with CA which is logically due to the elimination of the need to plough. The systems studied showed reductions of over 60% in fuel consumption and this would be an equivalent figure for both human-powered and DAP systems. This saving in energy will be of particular interest to small-holder farmers looking to invest less time in agricultural production and more in pursuit of off-farm jobs; or wishing to expand their cropped area.

Impact of conservation agriculture on farmers' livelihood

The effects of CA described above such as higher and more stable yields with lower input costs and a better adaptation to dangers of climate change clearly have a positive impact on farmers' livelihood. But there are also more direct impacts which have potential to turn around the daily and seasonal calendar and on the long term change the rhythm of farmers' family because of the reduced labour requirements for tillage, land preparation and weeding likely to occur. Especially women may be released from weeding tasks that traditionally were a 'woman's task. More time availability offers real opportunities for diversification options such as for example poultry farming or on-farm sales of produce, or other off-farm small enterprise developments that now (with time available) are a 'real' opportunity. An IFAD/FAO joint study that explored the potential of CA as a labour saving practice found out that the labour inputs in the CA system could be reduced by 75% (in the hand labour/hoe system) when a jab planter was used compared to hand hoe. In the draught animal powers category the CA system (with knife roller and direct seed drill) the labour reduction was 80% (IFAD/FAO, 2004). Farming without ploughing can in this context indeed also mitigate the labour shortages that affect small-scale farmers in the sub-Saharan region due to rural-urban migration and the rapid spread of HIV/AIDS.

A long term study of small scale farmers at manual or draft animal mechanization level adopting CA in Paraguay showed significant changes in the farmers' livelihoods. The study analysed farmers with 7 to 10 years experience in CA comparing them with conventional farmers and with their initial situation before adopting CA. All farms had increasing crop yields after the change to CA due to the rapidly improving soil fertility. In addition to this most farmers introduced new crops and diversified their crop rotations, which could have been done also under conventional farming but is more likely to happen under CA. These effects lead to increased farm income which combined with the reduced production costs resulted in significantly higher net income. Depending on the farmer's choice of the production system and the geographic region the increases in net income over the period of observation ranged from 50 to more than 600% (Lange, 2005). Further and as a result of the saved time and labour, most of the farms introduced other alternative sources of income such as forestry, bee-keeping, fish-farming, fruit and vegetable production, breeding of small animals and the related value adding activities.

The more visible impacts on the livelihoods of the farm families resulting from the increased farm income were that 50% of the farmers replaced their original wooden shacks with stone houses; one even bought a house in a nearby town. All purchased TVs, fridges, motorcycles horses and carts. The school age kids attended school at a regular base since their work input was not anymore required on the farm and the farmers could pay the school fees. Migration processes were stopped and even reverted since the farms provided sufficient income without the need for the farmer or the elder sons to look for off-farm work in the cities (Lange, 2005).

Similar experiences have been reported from Santa Catarina/Brazil, where the introduction of CA resulted in increased economic activities in rural areas dedicated to animal production and value adding (de Freitas, 2000).

Mechanization needs of conservation agriculture

Conservation agriculture obviously has equipment needs different from conventional farming. Specialized equipment is needed to carry out tasks under completely different conditions, such as direct seeding into unprepared soil under a mulch cover. In other cases the operations are carried out with a different objective, such as residue management not to accelerate decomposition but to slow it down to provide soil cover. On the other hand, tillage equipment is not anymore needed while operation and adjustments of general equipment like tractors or harvesting equipment might also change, as is the case in controlled traffic systems.

Direct seeding

There are many simple tools already in use which enable crop seeds to be sown through vegetation on the soil surface. These range from the planting stick with a sharpened point or a metal tip to the pioche or pick which is a small hole designed to make a hole big enough for seeding. Many more sophisticated jab planters have been developed over the years but have met with little success in terms of adoption. One exception is the matraca which has enjoyed widespread adoption in South America. The matraca has recently been introduced into SSA and has generated enthusiasm amongst farmers and artisans. It is yet to be proven if it achieves the same popularity as it receives in the American continent but there are signs that the demand is increasing in areas where CA is being adopted.

DAP pulled direct seeders have been developed by farmers and commercial manufacturers over the last 15 or so years in Brazil. Some examples have performed well also in SSA and direct seeders for tractors, both large and small, have been developed both by farmers and entrepreneurs. They generally incorporate both seed and fertilizer metering units and cut the surface vegetation with a disc, often fluted.

Seeders and planters have been developed to cope with high amounts of residues and to place the seed reliably at a uniform depth even in difficult soil conditions, while always minimizing the soil movement (Baker et al., 2006).

Residue management

Residue and cover crop management corresponds in CA to the land preparation for seeding. Ideally this operation takes place at harvest time and in many CA cropping systems the seeder is following the harvesting machine directly. The objective is to leave as many residues as possible in order to increase soil organic matter and to spread them as evenly as possible. Especially in environments where decomposition is fast and where the amount of residues is low it is not recommended to chop the residues. Instead it is better to leave them as long as possible which has the additional benefit of saving the energy required for chopping. Leaving crop residues anchored in the soil instead of cutting them, for example by harvesting grain crops with a stripper type header, facilitates the subsequent seeding operation. However, in order to achieve the weed control function it is not recommended to leave the residue standing, but to roll them down (Baker et al., 2006b). Exceptions might be irrigated systems with a relay crop undersown before harvest. In this case high standing stubble can reduce the risk of suppression of the seed by a thick layer of residue and it can also prevent the residue from floating and gathering in one part of the field.

A very useful tool specifically developed for the residue and cover crop management under CA is the knife roller, which flattens the residues and breaks the plants so that they eventually die. Applied at the right time and on the right cover crop this equipment could replace the use of herbicides for crop establishment (Baker et al., 2006b).

Supply and access to equipment

Change is risky and it is possible that yields are not maintained or increased during the adoption and learning period. There is also quite substantial investment costs associated with the acquisition of CA technology because a no-till seeder is considerably more expensive than a comparable conventional seeder. Farmers will need assistance to calculate the expected financial impacts of change. They may also need help to soften the financial impact of acquiring the necessary technology. This could be by means of machinery pools, grace periods on loan repayments; or other means of ameliorating the financial burden such as special term finance arrangement.

Although it is perfectly acceptable to promote the CA concept in a new region through the use of imported equipment, there will eventually be calls for local manufacture. However, in an initial phase the import of completely unassembled equipment with local assembly could be a suitable intermediate step between importation and local manufacturing. It would reduce the cost and facilitate the technology transfer for local production. As the farmer has to learn the farming operations under CA, the equipment manufacturer has to learn likewise how to construct good quality no-till seeders which have requirements completely different to conventional equipment. Simple equipment, such as rippers and jab planters could quite easily be made by local artisans. However the role of artisans is probably best kept to repair and the provision of replacement wearing parts such as chisel points and jab-planter beaks. Batch production should be the responsibility of better equipped, larger scale manufacturers who are able to control quality and ensure product uniformity. In SSA this has proved to be difficult as potential manufacturers almost unanimously ask for evidence of demand or require a pre-paid firm order before producing for an unknown, risky, market. The development of locally adapted equipment depends also on the active participation of all stakeholders in the process. The success of CA for small and medium scale farmers in Brazil has been due to the synergistic interactions of farmers, researchers and manufacturers. It is vital to have an active and healthy research and development capacity to facilitate adaptations to local conditions. The most likely venue for this kind of activity will be universities and agricultural research stations. However, these must be encouraged to apply themselves to research and development relevant to the realities of the local situation by working with farmer and manufacturer groups, rather than working in isolation as is too often the case at the moment.

Recently there ahs been a surge of interest in contract farming as a mechanism to govern linkages between farmers and agribusiness (da Silva, 2005). Supply chain management principles have found in the agri-food sector fertile ground for their application. Contracting is seen as a means to facilitate the integration of small farmers in supply chains and certainly has great potential with regard to the application of CA equipment.

National agricultural mechanization strategies aim to chart the development of this sector in a country-wide context. Strategies provide a range of possible options to farmers so that they can make sensible choices in the context of their own situation. Mechanization strategies need to look at the local manufacturing situation and to include measures which will stimulate it to provide such a range of choices. These could include the initial purchase of batches of equipment for subsequent distribution and cost recuperation. However, in view of the specific equipment needs of CA on one side and the implications of CA on the general mechanization on the other side, it is important for a government embarking on both sustainable land management and mechanization to include the CA concept into the mechanization strategies in order to give coherent signals to farmers and input supply sector (FAO, 2006, 1997).

A new German-funded FAO project aims to practically deal with all the challenges of CA relevant input supply and farmer innovation systems. Ultimately the project aim is to improve food security in Kenya and Tanzania through the promotion of CA. The three-year project will help promote the adoption of CA practices by smallholder farmers in the two East African countries through an expanded network of farmer field schools and by increasing the availability of CA equipment. Because of reasons outlined above, the project will bring in manufacturers and suppliers from Brazil, where wide-scale adoption of CA techniques has spurred a vibrant small-scale manufacturing sector for this specialized equipment which has gradually evolved, with increased demand, to include larger commercial manufacturers. Brazil – East Africa South-South technology and innovation exchange is envisaged for the benefit of both Brazil and East African entrepreneurs, business firms and farmers .Brazil manufacturers will benefit from access to the East African market, while potential producers in Kenya and Tanzania will receive training in manufacturing and marketing the equipment to bring elements of the Brazilian success story to bear on the East African situation (FAO, 2007).

Conclusions

Conservation agriculture is a holistic concept for sustainable management of agricultural lands. It achieves to a high degree environmental and economic sustainability of farming and also provides many benefits for the non-farming rural population.

However, by reducing labour requirements and drudgery of farming and by increasing the farm income, CA improves significantly the livelihoods of farmers and their families.

An important element for the adoption of CA, regardless to whether the farms are operating at manual level, with animal traction or at tractor level, is the accessibility of affordable and good quality equipment suited for the local needs of farmers, producers and entrepreneurs with intention to go towards CA practices. In many cases where CA is newly introduced the establishment of a commercial supply chain for this equipment does not happen spontaneously and requires special attention including technical assistance from FAO and other worldwide development partners.

References

Aulakh K S. 2005. Punjab Agricultural University, accomplishments and challenges, Ludhiana 2005, 23 p.

Baker C J, Ribeiro M F S, Saxton K. 2006b. Residue handling. In No-tillage seeding in conservation agriculture pp 134-158 Eds Baker CJ and Saxton KE. 2nd edition. CABI-FAO 326 pp.

Baker C J, Saxton K E, Ritchie W R, Chamen W C T, Reicosky D C, Ribeiro M F S, Justice S E, Hobbs P. 2006. No-tillage seeding in conservation agriculture; 2nd edition. CABI-FAO 326 pp.

Bassi L. 2000. Impactos sociais, econômicos e ambientais na Microbacia Hidrográfica do Lajeado São José, Chapecó, SC; EPAGRI, Documentos No 203, 50p.

Belder P. 2005. Water saving in lowland rice production: An experimental and modelling study. PhD thesis, Wageningen University, Wageningen, The Netherlands, 132 p. with English and Dutch summaries

Bistayev K S. 2002. Farmer experience with Conservation Agriculture technology in northern Kazakhstan, paper presented at the inception workshop of the FAO project on Conservation Agriculture for sustainable crop production in northern Kazakhstan, Ministry of Agriculture, Astana, Kazakhstan, September 11, 2002

Bot A, Benites J. 2005. The importance of soil organic matter, Key to drought-resistant soil and sustained food production; FAO Soils Bulletin 80, FAO, Rome

Crovetto C. 1999. Agricultura de Conservación, El grano para el hombre, la paja para el suelo, 3. ed, ISBN 84-930738-0-6

da Silva C A B. 2005. The growing role of contract farming in agri-food systems development: drivers, theory and practice. Rome, Italy. Food and Agriculture Organization of the United Nations (FAO). Agricultural Management, Marketing and Finance Services (AGSF); Agricultural Support Systems Division. 30 p.

DBU 2002. Innovativer Ansatz eines vorbeugenden Hochwasserschutzes durch dezentrale Maßnahmen im Bereich der Siedlungswassserwirtschaft sowie der Landwirtschaft im Einzugsgebiet der Lausitzer Neiße; Project report DBU-project AZ 15877, Deutsche Bundesstiftung Umwelt (German Federal Environment Foundation), Osnabrück

de Freitas V H. 2000. Soil management and conservation for small farms. Strategies and methods of introduction, technologies and equipment. Rome. Food and Agriculture Organization of the United Nations. FAO Soils Bulletin 77. 66 p.

Derpsch R. 2005. The extent of Conservation Agriculture adoption worldwide: Implications and impact, Proceedings of the 3rd world congress on Conservation Agriculture, Nairobi, Kenya, 3-7 October 2005; ACT, Harare

Doets C E M, Best G, Friedrich T. 2000. Energy and conservation agriculture. Rome. FAO, sustainable Development and Natural Resources Division Energy Program. Draft unpublished report. 28 p.

FAO 1997, A guide to preparing an agricultural mechanization strategy, FAO AGST Working Document, Rome, 33p

FAO 2000. Global Assessment of Soil Degradation GLASOD. FAO, Rome

FAO 2002. Agriculture: Towards 2015/2030; FAO, Rome, 420 p.

FAO, 2006. Farm power and mechanization for small farms in sub-Saharan Africa, FAO AGST Technical Report No. 3, Rome, 67p

FAO, 2007, News Article: http://www.fao.org/newsroom/en/news/2007/1000485/index.html

Faulkner E H. 1945. Ploughman's folly, Michael Joseph, 142 pp., London,

Fukuoka M. 1975. One Straw Revolution, Rodale Press, 138 p.; English translation of shizen noho wara ippeon no kakumei, Hakujusha Co., Tokyo

Gao Huanwen. 2006. The impact of conservation agriculture on soil emissions of nitrous oxide; draft report, Asian and Pacific Centre for Agricultural Engineering and Machinery, Beijing, China

Izaurralde R C, Lemke R L, Goddard T W, McConkey B, Zhang Z. 2004. Nitrous Oxide Emissions from Agricultural Toposequences in Alberta and Saskatchewan, Soil Sci. Soc. Am. J. 68:1285-1294 (2004).

Kerr P. 2001. Controlled traffic farming at the farm level; GRDC Research Update, Finley NSW, Australia

IFAD/FAO, 2004. Conservation Agriculture as a labour saving practice for vulnerable households, FAO Rome, 73p

Lange D. 2005. Economics and Evolution of Smallholdings Conservation Agriculture in Paraguay. mid-term experiences; FAO-GTZ, Asunción/Paraguay, 91 pp

Mariki W.L., 2003. The Impact of Conservation Tillage and Cover Crops on Soil Fertility and Crop Production in Karatu and Hanang Districts of Northern Tanzania (1999-2003) TFSC/GTZ Technical Report; Selian Agricultural Research Institute (SARI), P.O.Box 6024 Arusha, Tanzania

Met Office 2005. Climate Change, Rivers and Rainfall; recent research on climate change science from the Hadley Centre, Exeter/UK

PDCSR. 2005. Project Directorate for Cropping Systems Research, Annual Report 2004-05, Modipuram-Meerut, India, 143 p.

Ragab R, Prudhomme Ch. 2002. Climate Change and Water Resources Management in Arid and Semi Arid Regions: Prospective and Challenges for the 21st Century; Biosystems Engineering (2002) 81(1), 3-34

RWC-CIMMYT 2003. Addressing Resource Conservation Issues in Rice-Wheat Systems of South Asia: A Resource Book. Rice-Wheat Consortium for the Indo-Gangetic Plains – International Maize and Wheat Improvement Center. New Delhi, India. 305 p.

Saturnino H M, Landers J N. 2002. The Environment and Zero Tillage; APDC-FAO, Brasilia, Brazil UDC 504:631/635, CDD 631.521, 144 p.

Shaxon T.F, Barber R G. 2003. Optimizing soil moisture for plant production – the significance of soil porosity, FAO Soils Bulletin No. 79, FAO, Rome

Direct Drilling: an Agro-Environmental Approach to Prevent Land Degradation and Sustain Production

Moncef Ben-Hammouda[1], Khelifa M'hedhbi[2], Messaad Kammassi[1] and Houcine Goulli[1]

1 - ***Laboratory of Crop/Cereal Physiology, ESAK***
Le Kef 7100, Tunisia, benhammouda.moncef@iresa.agrinet.tn

2 - ***Centre Technique des Céréales***,
Bou-Salem 8170, P.O.-Box 120; Tunisia

Abstract

All over the world, water resources are very limited, and drought is continuously increasing. Desertification is spreading out in areas with low rain-fall, and the mediterranean region is endangered. Fewer natural resources are available for food and feed, making poverty and hunger two real threats to a steady growing population. In arid and semi-arid regions of the mediterranean, rain-fall is characterized by: i) irregularity, ii) suddenness, and iii) intensiveness. Under such climatic conditions, soils have to be permanently covered with mulch/residues and agronomy of opportunity concept [producing the maximum of biomass whenever the climate/rain-fall and the biology of the economic crop are favorable] has to be applied.

Conventional agriculture is essentially based on: i) plowing, ii) use of heavy machinery, and iii) spray of chemicals for insect/pest management. Yields could be relatively high but stationary with a small profit. Practicing such agriculture, soil fertility and soil microbial activity reached critical levels. Consequently, water retention capacity of soil went down, making beyond yield depression a serious damage to: i) dams by silting, ii) river/sea biology by both solid and chemical transports, and iii) roads by displacing slippery ground. However, conservation agriculture based on direct drilling is an alternative that gives chance to: i) save soil first, making out of it a water reservoir, and ii) produce with less energy (fuel) and chemicals (pesticides) without scarifying yield. Direct drilling simultaneously protects the soil and makes it more productive, enhancing both its organic matter rate and its 'microbial pump': the up-down movement of soil meso/micro-fauna is a 'biological plowing', improving physical properties of soil and its water infiltration capacity.

Conservation agriculture is an agri-environmental approach to crop production, since the mulch is the best physical and bio-chemical filter/barrier for pesticides that can easily reach and contaminate the surface water table. In addition, sowing without plowing reduces the oxidation of soil organic matter which is an important source of CO_2 emission known to heat the atmosphere of the mediterranean region. When applying DD, CO_2 is sequestrated in soil and residues, a way to reduce global warming.

Key words: Conventional agriculture, Conservation agriculture, Direct drilling, Mulch, Carbon sequestration.

Introduction

Mediterranean climate is characterized by a hot and dry summer and a cold-rainy winter season with: i) irregular, ii) sudden, and iii) intensive rain-fall. Some areas are known to have early fall rain (September, October) and others do have late spring rain (June, July). Under conventional drilling (CD), these types of rain are not efficiently used by the common cropping systems. The most erosive rain comes early in the fall, while farmers are plowing their soils for seed bed preparation, making them fragile and exposed to heavy solar radiations that inhibits microbial activity. Early cereal/plant establishment in the fall does not help much, due to the light plant canopy and its week root biomass, so the soil is not well fixed to stand against erosive rain. Soils free of any kind of cover (dry mulch as left residues, green mulch as a cover crop) undergo high risk of water erosion, associated to a run-off that gets intense as the slope is steeper, leaving behind soils with a productivity gradient which is usually difficult to cope with when planning a soil fertility program. With run-off, soil nutrients are lost and lots of solid constituents of soil go down to small dams shortening their duration by silting or to rivers and seas endangering their biology, and worst would be the case of lakes which water is hardly renewable.

In mediterranean region, climatic conditions (irregularity, suddenness, and intensiveness of rain; high temperature when water is scarce and low when water is available for a winter cereal) and edaphic conditions (soil on a steep slope; shallow soil; soil with a low capacity of water retention and infiltration; soil with low microbial activity) favor erosion dynamics originating physical, chemical and biological soil deterioration.

Photo 1: Slash and burn on a steep slope enhance soil erosion.(for coloured picture see annex #3, p.282).

Standard agriculture (SA) based on CD, left little room for economic profit which still possible only for large scale farm and qualified farmers when using high yielding varieties and well managing the reduction of production cost. This kind of agriculture is continuing, while polluting the environment (CO_2 emission, fuel combustion, excessive spray of pesticides, water table contamination with nitrate …), with no guaranty for a sustainable production.

A permanent mulching of the soil makes easy access to a field after a low rain of 10-15 mm. Mulching protects soil against the intense UV radiation that inhibits microbial activity and play the role of a biological filter to sprayed chemicals, keeping them from reaching surface water table. In addition, meso-faune (warms) up-down movement between day and night is enhanced, a kind of a 'biological pump' which helps to make enough galleries/capillaries shaping the soil with a 'biological plowing'. Therefore, organic matter build-up increases and water retention capacity of the soil too.

Photo 2. Rebuilt the soil by favoring reappearance of worms which are the soil labor.(for coloured picture see annex #3, p.282).

When compared to standard techniques of soil water conservation, DD could be considered one of them, but it goes beyond conservation to be a production technique too. For semi-arid zones of the mediterranean region, DD integrates a variety of agronomic practices related to: i) management of rain-fall (better water retention, reduction of evaporation by shopped residues or slightly grazed residues to bend cereal straws that could enhance soil water loss), ii) production (reduction of yield variability), iii) soil reclamation, such as the case of a clay soil that is left uncultivated after a heavy and early rain in the fall or the case of a stony soil, and iv) desertification control, especially in arid pockets which are frequent in the semi-arid zones of the mediterranean region.

Photo 3: Plowing down the slope is a common in conventional agriculture.(for coloured picture see annex #3, p.283).

Usually DD is associated with rain-fall conditions, dealing essentially with water management than water use to reduce yield fluctuation which is relatively high in the mediterranean region. However under irrigation conditions, DD is a tool for water economy whether the irrigation is full or complemented, since it reduces evaporation and consequently water application to a same surface area if cropped with a CD. With DD, irrigation could be done when a crop has no need for water in order to stock it (a certain soil nature is required) and let the crop use it later on in case of water shortage due to water resources limitation (case of dry season) or a technical problem between water source and the cropped field. This is a scenario where soil plays completely its essential role as water reservoir. When applying CD under irrigation, evaporation and salt migration to the top soil are relatively high in mediterranean region due to hot weather, low water quality (water with high concentration of salts), and frequent watering with low regime. However when applying DD, frequency of irrigation could considerably be reduced and at the same time water regime would increase, while lowering humectation of soil surface.

The actual shift to CA, based on DD, came as a reaction to the multi-faces damage of SA characterized by: i) excessive use of inputs/fertilizers-pesticides, ii) soil compaction by heavy machinery, iii) continuous clay pan formation, iv) decrease of water infiltration, v) erosion of soils with steep slopes, vi) decrease of organic matter and soil fertility, vii) rapid evapo-transpiration, and viii) monoculture. With a continuous monoculture, pathogens and weeds break out, leaving more chance to massive use of chemicals. This production model is in favor of agri-business, with little consideration to human or animal health and almost no care for the environment.

Photo 4: Heavy machinery originates soil compaction and makes clay pan, two barriers for water infiltration.(for coloured picture see annex #3, p.283).

History of direct drilling

Last century and prior to the 30's, agriculture research was oriented toward clean tillage, and only during the 30's that the positive role in water conservation of abandoned residues on the soil surface was recognized (Hallsted & Mathews, 1936), reducing run-off and evaporation (Russel, 1939, Hill & Blevins, 1973). Early in the 40's, residues management was worked out to reduce soil loss (Borst & Woodburn, 1942). In Tunisia, DD was introduced in 1999 (M'Hedhbi, Chouen & Ben-Hammouda, 2003) and it is diffusing slowly due different constraints which commonly come across any transfer of technology (Chouen & M'Hedhbi, 2003).

Promotion of DD started in USA as a type of residues management in no-till, and the progress of chemical industry was behind its development and expansion, especially when the two herbicides atrazine and paraquat were introduced in the 50's and the 60's, respectively (Hill ,Griffith, Steinhard & Parson, 1994). Outside USA, Brazil is the first country which shifted strongly to DD since the 70's (Seguy, Bouzinac, Maeda-E & Maeda-N, 1998). Lately, Argentina and Canada are trying hard to catch USA and Brazil (Crovetto, 1999).

When applying DD, seeds are placed in a non-disturbed soil using a special drill making a very small furrow which depth and width ensure an appropriate cover-up and contact of seeds with soil

(Seguy, Bouzinac, Trentini & Côrtes, 1996). In unfamiliar areas with CA, DD on standing residues/mulch may be confounded with no-till which has many types of DD: i) dressed stubble after removing straw bales out of the field, ii) dressed stubble with spread straw, and iii) burned residues (Christian et al., 1999). For summer crop such as grain sorghum, shopped residues is another type of no-till (Ben-Hammouda, 1994).

Traditionally, tillage is practiced to essentially prepare seed bed, eliminate weeds, and improve water infiltration within soil. But actually, weeds could be managed by specific or polyvalent herbicides (Schwab, Frevert, Edminster & Barnes, 1981). Tillage was long time criticized for high fuel/energy consumption, risk of erosion, and problems related to air and water pollution (Mock & Erbach, 1977). Mulching is defined by a creation of any technique to cover the soil, such as: i) dust mulch, ii) weed mulch or trash mulch, iii) stubble mulch to increase roughness and decrease blowing of the soil, and iv) straw mulch (Rosenberg, Blad & Verma, 1983). Continuing increase of fuel cost leaves little room for an economic return, and what (CD) is common today may be abandoned in the near future, especially for small size farms in developing countries (Hilel, 1982).

Abandoned residues on the soil surface reduce rain splash and erosion, while improving soil structure and water infiltration (Donahue, Miller & Shicluna, 1983). Residues are the precursor of organic matter which improves chemical and physical soil properties and supplies crops with significant amount of nutrients, after being decayed. In addition, residues affect water infiltration and water run-off (Reikosky & Wilts, 2005). Loss of biodiversity is an ultimate consequence of organic matter depletion, originating a slow nutrient recycling (Hendrix, Parmelee, Crossley & Coleman, 1986).

In arid zones, soils have low rate of organic matter and instable aggregates, which make them vulnerable to compaction, crust formation and erosion (Hilel, 1982). Organic matter is known to control aggregate stability of loam soil, enhancing its microbial activity (Annabi et al., 2007). Fungi (Degens, 1997), microbial products such as polysaccharides (Haynes & Francis, 1993) and humic substances (Piccolo & Mbagwu, 1999) are some organic fractions with binding forces which contribute partially in aggregate stability. Factors affecting erosion are: i) climate (rain, temperature, wind), ii) soil (physical, chemical and biological properties), iii) soil cover crop (under-ground biomass, above-ground biomass), and iv) land topography (slope steepness, slope length), such factors are influential in the nature of cropped topo-sequences (Schwab et al., 1981).

With 0.8 t/ha of straw-residues, soil loss was 34% of the loss obtained from a soil under fallow, where both soils were exposed to the same rain-fall regime and run-off conditions (Wischmeir & Smith, 1978), and with the same residues biomass, wind erosion was 50% reduced (Woodruff & Siddoway, 1965). However, any extra residues could be grazed with a special attention to leave the minimum requirement for a DD (Crovetto, 1999). To facilitate animal integration to DD, species producing important biomass should be recommended (Husson et al., 2003) and overgrazing is something to ovoid.

DD is an alternative for semi-arid zones as long as it leads to a more efficient use of water resources and a better control of soil erosion (Mrabet, 2003), which remains the obvious consequence of inadequate soil preparation (Gilbert, Mathurin & Francis, 1996), essentially related to abusive use of plowing which seriously endangers ag-production in the long run (Saber & Mrabet, 2002).

Agronomy of opportunity

When applying DD, there is no disturbance to soil, and it requires only an opening to place seeds at the right depth through an appropriate mulch biomass, covering permanently the soil. Moreover, management of cover crops, locals or introduced, is a key tool for DD. In addition, crop rotation has to be the rule and in line with the concept of specific site approach for crop production.

Ounce agro-climatic characterization (rain distribution, temperature as heat units) of the site is done, agronomy of opportunity concept could be applied, to produce the maximum biomass when the climate and the cropped species biology are favorable to do so.

Photo 5: Growing oat on a dormant lucerne is one agronomy of opportunity scenario, possible under irrigation conditions.(for coloured picture see annex #3, p.284).

For the mediterranean climate, three scenarios are possible: i) sowing a crop following a late rain while the economic crop is mature but not harvested, ii) sowing a crop that terminates its biological cycle while the prior crop was consumed and left dormant with a reduced above-ground biomass, and iii) sowing a crop just when receiving at least 30 mm rain after harvesting/cutting/grazing a main crop (Ben-Hammouda, M'Hedhbi, Nasr & Kammassi, 2005; Ben-Hammouda et al., 2007). Before any transfer of a successful agronomic package from one site to another, a based cluster analysis (Gower, 1967) of an agro-ecological characterization should be conducted to asses existing similarities between both sites; De Pauw et al., 1997).

Photo 6: Burning residues is going against conservation agriculture which requires a permanent mulching.(for coloured picture see annex #3, p.284).

Managing allelopathic residues

Allelopathic potential of some cereals, such as grain sorghum (Ben-Hammouda, 1994; Ben-Hammouda, Kremer & Minor, 1995-a) and barley (Ben-Hammouda, Ghorbal, Kremer & Oueslati, 2001) represents a main constraint that has to be managed when practicing DD in cereal production (Ben-Hammouda, Oueslati & Ben-Ali, 2003). Such management has to focus on the reduction of the depressive effect of a prior crop that may cause an important yield decrease for a following crop (Ben-Hammouda, 1994; Christian et al., 1999; Rasmussen, Pickman & Kleper, 1997). When expressed as phyto-toxcity, allelopathy is originated by allelochemicals in plant tissues that could be released either as root exudates (Ben-Hammouda, Kremer, Minor & Sarwar, 1995-b) or as results of tissues decay (Tollenaar , Mihaijlovic & Vyn, 1993). Allelochemicals of a prior crop persist in the soil and may depress heavily yield of a following crop (Guenzi, McCalla & Norstad, 1967, Ben-Hammouda et al., 2003. Allelochemicals decay is due to microbial activity (Roth, Sroyer & Paulsen, 2000), and any time allelopathic potential is not expressed, a major role is attributed to a microbial control of released substances out of residues (LaBarge & Kremer, 1989).

Direct drilling to control global worming

A fraction of 1/5 out of the emitted gas with a green-house effect (50-75% of methane and nitric oxide plus 5 % of CO_2) is originated by SA, where plowing is the major cause of CO_2 emission over cropped land (Mrabet, 2006). Carbon sequestration with cereal residues such as oat depends of mineral constituents of soil, a sequestration which is more favored with fine structure of clay (Gonzalez & Laird, 2003). A long term (22 years) experiment of a wheat/fallow sequence showed that organic carbon was concentrated in the top soil (depth < 8 cm) with no-till, while its loss in 0-30 cm depth is doubled from no-till to till (Doran, Elliot & Paustian, 1998).

Impact of DD on the balance of CO_2 emission is a quadruple: i) absence of plowing which contributes substantially in CO_2 release, ii) decrease of erosion at the soil surface which is the main generator of CO_2, iii) reduction by 30-60 % of fuel consumption by mechanization, depending on the cropping sequences and iv) residues build-up which leads to organic matter formation once are decayed, enhancing carbon sequestration with carbon: organic-matter ratio of 1:1.7 (Richard, 2004).

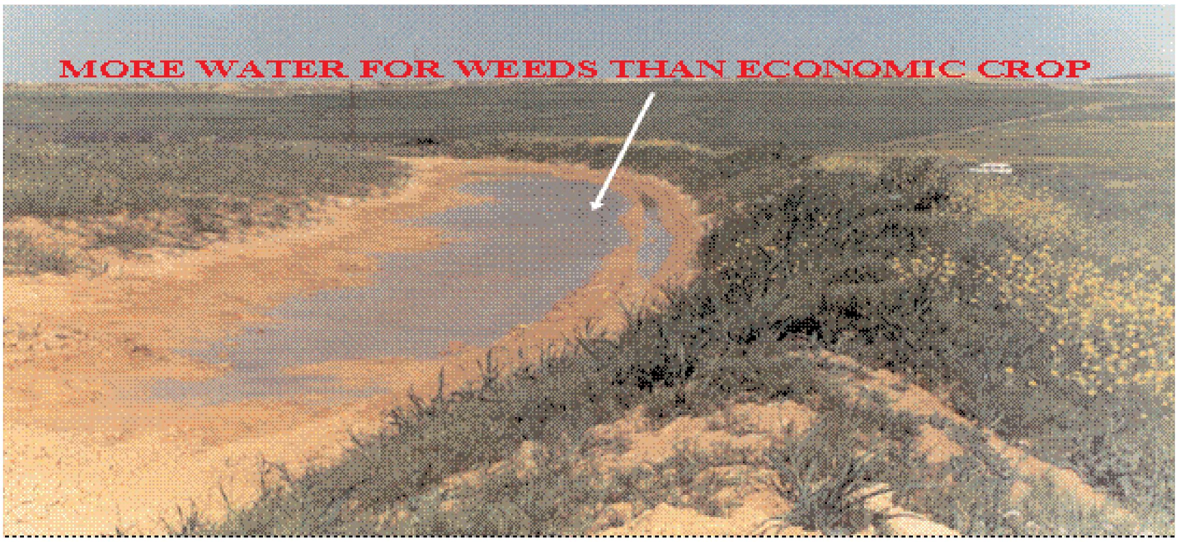


Photo 7: Terracing is a common technique for soil water conservation which often helps more weeds to grow than the economic crop.(for coloured picture see annex #3, p.285).

References

Annabi M, Houot S, Franco C, Poitrenaud M, Le Bissonnais Y. 2007. Soil aggregate stability improvement with urban composts of different maturities. Soil Science Society American Journal, pp. 71: 413-423.

Ben-Hammouda M. 1994. Differential allelopathic potential of sorghum hybrids on wheat. PhD Thesis. University of Columbia, Missouri. 179 pp.

Ben-Hammouda M, Ghorbal H, Kremer R J, Oueslati O. 2001. Allelopathic effects of barley extracts on germination and seedlings growth of bread and durum wheats. Agronomie, pp. 21: 65-71.

Ben-Hammouda M, Kremer R J, Minor H C. 1995-a. Phytotoxicity of extracts from sorghum plant components on wheat seedlings. Crop Science, pp. 35: 1652-1656.

Ben-Hammouda M, Kremer R J, Minor H C, Sarwar M. 1995-b. A chemical basis for differential allelopathic potential of sorghum hybrids on wheat. Journal of Chemical Ecology, pp. 21-6: 775-786.

Ben-Hammouda M, M'hedhbi K, Abidi L, Rajeh A, Chourabi H, El-Faleh J, Dichiara C. 2007. Conservation agriculture based on direct sowing. Proc. International scientific conference on the future of dry lands (under press). Tunis, Tunisie.

Ben-Hammouda M, M'hedhbi K, Nasr K, Kammassi M. 2005. Agriculture de conservation et semis direct: Zone du Kef. Les acquis de la recherche agricole: Actes des 12-èmes Journées Scientifiques. IRESA/Ministère de l'agriculture et des ressources hydriques. Hammamet. Tunisie, pp. 145-155.

Ben-Hammouda M, Oueslati O, Ben-Ali I. 2003. Persistence of the allelopathic potential of durum wheat residues. Proc. II World Congress on Conservation Agriculture. Iguassu Falls, Parana-Brasil, pp. 245-248.

Borst H L, Woodburn R. 1942. The effect of mulching and methods of cultivation on runoff and erosion from Muskiningum silt loam. Agriculture Engineering, pp. 23: 22-25.

Chouen S, M'hedhbi K. 2003. Conditions and constraints of testing direct sowing in semi-arid area (Tunisia). Proc. II World Congress on Conservation Agriculture. Iguassu Falls, Parana-Brazil, pp. 239-241.

Christian D G, Bacon E T G, Brockie D, Glen D, Gutteridge R J, Jenkyn J F. 1999. Interactions of straw disposal methods and direct drilling or cultivations on winter wheat (Triticum aestivum) grown on a clay soil. Journal of Agriculture Engineering Research, pp. 73: 297-309.

Crovetto L C. 1999. La conduite du non-labour. In Les Fondements d'une Agriculture Durable. Panam/Teknea, Toulouse-France, pp. 45-133.

Degens B P. 1997. Macro-aggregation of soils by biological bonding and binding mechanisms and the factors affecting these. A review: Australian Journal of Soil Research, pp. 35: 431-459.

De Pauw E, Ben-Hammouda M, Mokrane R, Zçelik H, Balaghi R. 1997. Provisional agroclimatic analysis of climatic stations in North Africa and Turkey using cluster analysis. ICARDA Report of training workshop on agroecological characterization of the highland areas of Algeria, Morocco, Tunisia and Turkey. Ankara, Turkey, 7 pp.

Donahue R L, Miller R W, Shicluna J C. 1983. Soils: An Introduction to Soils and Plant Growth. Prentice-Hall, Inc., Englewood Cliffs, New Jersy. 667 pp.

Doran J W, Elliot E T, Paustian K. 1998. Soil microbial activity, nitrogen cycling, and long-term changes in organic carbon pools as related to fallow tillage management. Soil & Tillage Research, pp. 49: 3-18.

Gilbert V, Mathurin M, Francis F. 1996. Semis direct dans l'aménagement de Sanguéré-Djaling. Cahiers Agricultures, pp. 5 (3): 161-169.

Gonzalez M, Laird D A. 2003. Carbon sequestration in clay mineral fractions from 14C-labeled plant residues. Soil Science Society American Journal, pp. 67: 1715-1720.

Gower J C. 1967. A comparison of some methods of cluster analysis. Biometrics, pp. 23(4): 623-637.

Guenzi W D, McCalla T M, Norstad F A. 1967. Presence and persistence of phytotoxic substances in wheat, oat, corn, and sorghum residues. Agronomy Journal, pp. 59: 163-165.

Hallsted A L, Mathews O R. 1936. Soil moisture and winter wheat with suggestions on abandonment. Kansas Agric. Stn. Bull. N° 273.

Haynes R J, Francis G S. 1993. Changes in microbial biomass C, soil carbohydrate composition and aggregate stability induced by growth of selected crop and forage species under field conditions. Journal of Soil Science, pp. 44: 665-675.

Hendrix P F, Parmelee R W, Crossley Jr D A, Coleman D C. 1986. Detritus food webs in conventional and no-tillage agroecosystems. Bioscience, pp. 36: 374-380.

Hill J D, Blevins R L. 1973. Quantitative soil moisture use in corn grown under conventional and no-tillage methods. Agronomy Journal, pp. 65: 945-949.

Hill P R, Griffith D R, Steinhard G C, Parsons S D. 1994. The evolution and history of no-till farming in the Midwest. National conservation tillage digest, Mid America Farm Publications, Perryville, Missouri. Xx pp.

Hillel D. 1982. Introduction to Soil Physics. Academic Press, Inc, New Work, pp. 200-207.

Husson O, Chabane A, Tuan H D, Lecomte P, Martin C, Castella J C, Tivet F, Séguy L. 2003. Integrating crops and livestock through direct seeding on vegetal cover in Vietnam. International Journal of Agricultural Sustainability, pp. 1-4.

LaBarge G A, Kremer R J. 1989. Effect of velvetleaf plant residues on seedling growth and soil microbial activity. Allelopathy Journal, pp. 43: 421-427.

M'Hedhbi K, Chouen S, Ben-Hammouda M. 2003. A recent Tunisian experience with direct drilling. Proc. II World Congress on Conservation Agriculture. Iguassu Falls, Parana-Brasil, pp. 132-135.

Mock J J, Erbach D C. 1977. Influence of conservation tillage environments on growth and productivity of corn. Agronomy Journal, pp. 69: 337-340.

Mrabet R. 2003. No-tillage as a technology to prevent desertification. Proc. II World Congress on Conservation Agriculture. Iguassu Falls. Parana-Brasil, pp. 182-193.

Mrabet R. 2006. Soil quality and carbon sequestration: Impacts of no-tillage systems. CIHEAM. Options méditerranéennes, pp. 43-55.

Piccolo A, Mbagwu J S C. 1999. Role of hydrophobic components of soil organic matter in soil aggregate stability. Soil Science Society American Journal, pp. 63: 1801-1810.

Rasmussen P E, Rickman R W, Klepper B L. 1997. Residue and fertility effects on yield of no-till wheat. Agronomy Journal, pp. 89: 563-567.

Reicosky D C, Wiltis A R. 2005. Crop-residues management. In (éd. Hillel, D), Encyclopedia of Soils in the Environment. 1-ère éd. Elsevier Academic Press, pp. 1: 334-338.

Richard J F. 2004. Agriculture de conservation et séquestration du carbone. Actes des deuxièmes rencontres méditerranéennes. Tabarka, Tunisie, pp. 144-147.

Rosenberg N J, Blad B L, Verma S B. 1983. Microclimate: The Biological Environment. 2nd Edition. John Wiley & Sons, Inc. USA, 495 pp.

Roth C M, Sroyer J P, Paulsen G M. 2000. Allelopathy of sorghum on wheat under several tillage systems. Agronomy Journal, pp. 92: 855-860.

Russel J C. 1939. The effect of surface cover on soil moisture losses by evaporation. Soil Science Society American Proceedings, pp. 4: 65-70.

Saber N, Mrabet R. 2002. Influence du travail du sol et des rotations de cultures sur la qualité d'un sol argileux gonflant en milieu semi-aride Marocain. Revue Etude et Gestion des Sols, pp. 9 (1): 43-53.

Séguy L, Bouzinac S, Trentini A, Côrtes N A. 1996. III-Le semis direct, un mode de gestion agrobiologique des sols. Agriculture et Développement, pp. 12: 38-60.

Séguy L, Bouzinac S, Maeda E, Maeda N. 1998. Brésil, semis direct du cotonnier en grande culture motorisée. Agriculture et Développement, pp. 17: 3-23.

Schwab G O, Frevert R K, Edminster T W, Barnes K K. 1981. Soil and Water Conservation

Engineering. 3-ème éd. John Wiley & Sons, Inc, USA, pp. 92-121.

Tollenaar M, Mihaijlovic M, Vyn T J. 1993. Corn growth following cover crops: Influence of cereal cultivar, cereal removal, and nitrogen rate. Agronomy Journal, pp. 85: 251-255.

Wischmeir W H, Smith D D. 1978. Predicting rainfall erosion losses-a guide to conservation planning. USDA Agric. Handbook N° 537.

Woodruff N P, Siddoway F H. 1965. A wind erosion equation. Soil Science American Proceedings, pp. 29: 602-608.

Weed Management in Conservation Agriculture for Sustainable Crop Production

W.L. Mariki and M. Z. Owenya
Selian Agricultural Research Institute
P.O. BOX 6024, ARUSHA, TANZANIA
wlmariki@yahoo.com, mariethaowenya@yahoo.co.uk

Abstract

Weed management includes land preparation by tractor or oxen ploughing and hand hoe to ensure a clean seed bed from weeds and trash. This practice leads to conventional tillage which degrades the soil by causing serious soil compaction and pulverization of the topsoil. Inversion of the topsoil during ploughing also brings up weed seeds to the ground surface, which then germinate and compete with crops for the limited moisture and nutrients. Weeding during the crop growth escalates labour demand for weeding while the source of labour is decreasing due to several factors including the spread of the HIV/AIDS and the increasing urbanization in the region.

A study was conducted on Conservation Agriculture (CA) using soil cover crops technology in 1999 to replace ploughing for weed management, labour and costs reduction while conserving the soil moisture and fertility and increase food production in the northern Tanzania.

Treatments used included lablab + maize, mucuna + maize, sole lablab and sole mucuna cover crop, where the plots without cover crops were used for control. Cover crops were first established in the first season 1999 and followed by direct seeding of maize in the mulch developed from the cover crops. Slashing and round up herbicide was used to kill the cover crops before seeding maize.

Results from the study showed that cover crops reduced weed counts from 18/m^2 under conventional tillage to 3/m^2 where maize was grown and managed under CA. Labour (number of man-days) required during land preparation and weeding was reduced from 72 in 1999 to 34.7man-days in 2002 under CA.

Weed management recommendations from the CA studies include agronomical/biological practices such as crop rotation, spacing, intercropping, and mulching (dead and live mulch), to suppress weeds and reduce some of the noxious weeds like digitaria and cyperus species. Mechanical practices for weed management during land preparation include knife rollers, slashing, shallow weeding and pulling/roughing by hand. Chemical weed management through application of herbicides using zam-wipes, knapsack sprayers, hand and animal pulled and tractor sprayers can also be recommended where necessary.

Mechanical methods in the crop stand include shallow weeding using scrapers, hand roughing and slashing is recommended to minimize soil disturbance. Safety and proper use of herbicides must be considered where chemicals for weed control are an option.

Key words: Conservation Agriculture, weed management, biological weed control /soil cover, mechanical weed control, chemical weed control.

Introduction

Crop production in Tanzania is affected by a number of factors that include weed competition, soil fertility and inadequate soil moisture. Conventional tillage using tractors and oxen ploughs for weed management is one of the major mechanical practices for cleaning fields before planting crops. This practice degrades the soil by causing serious soil compaction and pulverization of the topsoil. It also inverts the soil and bury weeds and trash into the soil and leaves the soil bare promoting soil erosion by wind and water. Inversion of the soil brings up weed seeds to the ground surface, stimulates seed germination thus enhancing weed growth and competition with crops for the limited soil moisture and plant nutrients.

The use of mechanical tillage for weed control and seedbed preparation has induced significant decline in soil quality through accelerated decomposition of soil organic matter. Decrease of carbon levels generally lead to decreased crop productivity (Benson and Mrabet, 2001). Decrease in organic material reduces the bulk volume of the soil and favours soil compaction and surface crusting, resulting in reduced water infiltration, aeration, and reduced rooting depth of crops. On the other side the costs of ploughing for weed management are increasing every year, due to the rising costs of fuel and machinery spare parts.

Labour demand for land preparation and weeding is increasing while the source of labour is declining due to several factors including the spread of the HIV/AIDS and the urbanization in the farming communities in Tanzania. Apart from the fact that HIV/AIDS affected persons are weakened by the disease, most members of the HIV/AIDS victim families are involved in taking care of the sick and have very limited time to weed their farms. (Lyimo, 2001)

A study on Conservation Agriculture (CA) using soil cover crops technology was conducted from 1999 to 2002. Replace ploughing for weed management by CA was expected to reduce labour and costs while conserving the soil moisture and fertility hence increase food production in northern Tanzania.

Materials and Methods

Cover crops treatments

1. Lablab (Dolichos lablab) + maize stovers
2. Mucuna (Mucuna pruriensis)+ maize stovers
3. Bare soil = Control (farmer practice)
4. Lablab , maize stover removed
5. Mucuna, maize stover removed

Establishment of the cover crop treatments:

1. In the Lablab + Maize stover treatment the maize stover was left in the field after harvest. Lablab continued growing to the following season and was then slashed and killed using Roundup (glyphosate isopropylane salt of N phosphono-methyl) and left to cover the soil surface for direct seeding of maize through the ground cover in the following season. (repeated every season).
2. The Mucuna + maize stover treatment was identical, only the cover crop species changed.

3. In the Control treatment the field was cleared by cutting and removing all the maize stover (after harvesting), that were either sold or fed to livestock, the plots were ploughed, seeds placed in the furrow and covered by the plough.. This is a common practice in farming communities in the project pilot areas
4. In the Sole Mucuna cover crop treatment all the maize stover was taken from the field, leaving only mucuna to grow and cover the soil during the dry season. At planting time Mucuna was slashed and left as mulch cover. Roundup was applied for pre-planting weed control in the first two seasons (2000 and 2001). Maize was directly planted through the mulch cover.
5. The Sole Lablab soil cover treatment was identical with treatment for except for the cover crop.

The mulch of the cover crops treatments also includes the crop residues from the short season bean crop seeded in October. The beans are normally harvested in early February before the seeding of Maize. Mucuna and Lablab were intercropped in the maize 6 weeks after planting maize. (3-4 weeks in marginal rainfall areas) in order to reduce competition.

Weed Management

Weeding in the conventional maize treatments started during land preparation by ploughing was followed by weeding three times at interval of three weeks using a hand hoe.

No tillage was done for weed management in the conservation tillage treatments weeds were controlled by slashing and pulling/roughing. The cover crops (lablab and mucuna) were killed by spraying Roundup two weeks before planting maize. The first weeding for the conservation tillage started 5 weeks after seeding maize and was done by hand roughing.

Seeding of the cover crops in between maize rows followed after the first weeding. There was only one additional weeding by roughing in the conservation tillage plots after intercropping of Lablab or Mucuna into maize.

Harvesting

Maize was harvested in early August that allowed the Lablab and Mucuna cover crops to spread their canopies in the field during September and October.

Some seeds from the Lablab plants were harvested in October by picking the dried pods while the plants remained green in the field to cover the soil up to the next season. Mucuna pods matured later. Most Mucuna plants died on the ground during the long dry season leaving a thick mulch cover.

Results

Effect of cover crops for weed management on labour requirements

Conservation agriculture treatments had a significant effect ($P < 0.05$) on labour requirements (Table 1). Conventional Tillage had highest labour requirement in all 3 years, except in the first year 1999. Labour requirements decreased over years in the cover crops treatments while in conventional tillage they remained almost constant over years (Table 1). The number of man-days required for land preparation and weeding was reduced from 72 in 1999 to 34.7man-days in 200, i.e. merely half of the man-days required in conventional tillage. This was a result of the reduced man-days for land preparation (ploughing) and for weeding.

In 2002, the no-tillage + Lablab treatment had a slightly lower labour requirement (34.7 man-days) compared to no-tillage + Mucuna treatment (38 man-days). Both treatments differed significantly from the conventional tillage which ranged from 64.7 to 66.0 man-days per hectare per season.

Reduction in labour days was a reality because ploughing was not necessary due to the good soil cover developed from the cover crops that suppressed weeds growth efficiently. Only two manual weedings, rouging, was required during the season in the conservation plots, primarily for preventing seed production.

Effect of cover crops for weed management to Digitaria, Cyperus and Argemone mexicana weed species

All cover crop treatments had significantly ($P < 0.05$) lower weed counts compared to the control (Table 2). Treatments with sole cover crops of Mucuna or Lablab had even lower weed counts/m2 and differed significantly from maize + cover crop treatments. This can be explained by a much denser ground cover developed by the cover crops, when planted in pure stands. Weed counts of Digitaria cyperus and Argemone mexicana in the treatments without cover crops were significant higher compared to the four cover crop treatments. All cover crop treatments had low weed counts ranging from 2 to 5 plants/m^2 and differed significantly from the control treatment which had highest weed counts of 16 to 18 counts /m^2 for all three species (Digitaria, Cyperus and Argemone mexicana) respectively.

The effect of cover crops and direct planting on maize yields.

Maize grain yields of all treatments with cover crops and direct planting (no-tillage) were significantly higher compared to the control = conventional tillage in all years (1999-2003), but at varying magnitude (Table 3). Maize grain yield from sole cover crops was always higher than from cover crops planted under maize. This can be explained by a higher biomass development and nitrogen fixation of the cover crops planted in a pure stand. Lablab and Mucuna had nearly the same effect on maize yields, with slight variations from year to year. The fact, that Lablab seeds were collected and exported from the field while Mucuna seeds remained in the field had apparently no expressed influence on the N and P supply of the subsequent crop.

Conclusion

Significant labour reduction observed under direct planting through cover crops resulted from the reduced weed competition from the Lablab, Mucuna and maize stover mulch sources. Reduced weed pressure under cover crops, reduced tillage or direct planting is also the result of reduced the stimulation of weed seed germination. Weeding is the greatest labour peak after soil preparation. The increasing labour shortage due to out migration of young men and the impact of HIV/AIDS results in late or insufficient weeding and subsequent yield reductions. Labour constraints during peak periods, land preparation and weeding, limit the acreage small-scale farmers can well manage and often negatively impact on crop yields (Mmbaga, 1994). Untimely planting and weeding, because of labour shortage can reduce potential yields up to 50%. Direct planting through cover crops can help to overcome labour constraints. This is of special interest for women specially AIDS widows who cannot cope with labour demands in conventional agriculture nor hire ploughs and labour.

Apart from saving labour direct planting through cover crops has also the positive effect of breaking labour peaks by spreading labour requirements. Labour savings through direct planting were observed also by other authors, e.g. Nyborg and Malhi (1989) working on barley based systems in Canada. . This reduction of production costs (e.g. hired labour, tractor hiring for ploughing) lead to increased net benefits, independent of yields and product prices. It is this reduction of production costs (including labour savings), which make direct planting through cover crops attractive to farmers, as every shilling saved is a net gain.

Recommendations for Weed Management in Conservation Agriculture for Sustainable Crop Production

Weed control in conservation agriculture is very important. Weeds should not be allowed to grow long enough to produce seeds. Slashing weeds after harvesting crops reduces the weed population in the following season. The critical weed competition persists for 60 days with the most severe competition at 30 – 60 days after emergence of the crop. (Mattowo, 1988).

Managing weeds under CA can be done in several ways using biological methods such as establishment of soil cover crops. The main crop is first planted, followed by intercropping of a cover crop at the right spacing. Planting of a cover crop or using of mulch followed by seeding main crop is recommended where land is not limited. Spacing, rotation of crops and intercropping of other crops for soil cover is also recommended.

Spacing

Crop spacing for weed management includes planting crops closer together in order to shade-out and suppress weeds. This is best applied where enough soil moisture and fertility have been conserved under conservation agriculture.

Soil cover crops

Use of cover crops that are adapted to the climate, soils, altitude and rainfall is recommended.

A cover crop that can grow quickly producing dense biomass and cover the soil before weeds take over is recommended. Good examples are the Lablab and Mucuna cover crops used in this study. These two cover crops can grow and cover the soil completely 2 months after seeding.

Relay planting of cover crops is possible where the rainy season is long enough to leave the cover crop continue growing and covering the entire field after harvest of the main crop. Weeding the cover crops early after seeding is recommended to ensure good canopy and biomass development.

Mechanical

Knife-rollers can be used to kill the cover crops and weeds by bending and crushing them to ground level. It is used for land preparation. Knife rollers can be pulled by oxen or by a tractor and can be made locally.

Hand pulling out weeds by hand or shallow weeding using slasher, sickle or machete is recommended for weed management in the crop where the biological methods are not sufficient, especially during the first seasons of CA adoption. Light weeding by hand hoe before cover crops develop enough soil cover, is another possibility.

Chemical

Roundup (Glyphosate) can be applied in CA especially for killing cover crops and weeds where the biological methods don't work properly. Glyphosate is a non-selective herbicide used for perennial weed control in minimum and no- tillage production systems (Mmbaga, 2006) Application of the herbicide for weed control in crops may be necessary in the first cropping seasons of CA if labour for weeding is limiting.

Herbicides for weed control need special equipment such as knapsack sprayers, weed wipers, hand and animal pulled sprayers and tractor sprayers depending on the scale of farming. Safety and proper use of herbicides must be considered where chemicals for weed control are an option. It is important to use the right amount of chemicals, mix them with clean water and follow instructions written by manufacturers on the labels. Training on how to use and handle herbicides is very important.

Acknowledgement

We thank the following persons and organizations for their contribution to some of the good results achieved in our Conservation Agriculture for Sustainable Agriculture to small-scale farmers 1999 to 2003 in Northern Tanzania.

Tanzania Farmers Services Centre (TFSC), Arusha, Tanzania, for funding the Conservation Agriculture project, through the FAO for introducing the direct planting implements from Brazil to Tanzania and follow up of the dissemination of CA Technologies.

Managing Director of TFSC for facilitation and funding of the Conservation tillage project.

Dr. Kurt Steiner (Senior Technical Advisor for Sustainable Agriculture) GTZ for his advice and facilitation for the CA project Director of TFSC, for his advice during fieldwork, tillage arrangements and crop management for CA.

The Northern Zone Director for Agriculture Research, Arusha, for providing Office, equipment and land for Conservation Agriculture and cover crops demonstrations.

The DALDOs of Hanang and Karatu districts in Northern Tanzania for providing assistance for Extension work on Conservation Agriculture in the Villages, where we were able to reach and know the farmers and work with them during the duration of the project.

Also the farmers who volunteered their land and time, from which other farmers were able to learn the no-till direct seeding of crops during field days and short courses.

Not to forget the TFSC and SARI secretaries and the drivers who at all times were generally involved to play their part in completing this project.

Appendices

Table 1: Effect of no-tillage and cover crops on labour requirements

Cover crops treatments	Labour requirements Man days/season			
	1999	2000	2001	2002
1. Lablab + maize stover	72.0 a	60.0 b	46.3 b	34.7 c
2. Mucuna + maize stover	71.7 a	62.0 b	40.7 b	38.0 b
3. Conventional tillage	64.7 b	65.3 a	66.0 a	65.7 a
Mean	69.4	62.4	51.0	46.1
C.V.	2.54	1.07	4.24	1.91
SD	1.02	0.38	1.25	0.51

Table 2: Effect of cover crops and direct planting on Digitaria, Cyperus and Argemone mexicana populations

Cover crops treatments	Weed Counts/m^2		
	Digitaria	Cyperus	Argemone mexicana
1. Lablab + maize stover	5.00 b	5.00 b	5.33 b
2. Mucuna + maize stover	3.67 b	5.33 b	3.67 bc
3. Without cover crop (control)	16.33 a	18.33 a	18.67 a
4. Sole Mucuna	2.00 b	1.33 c	2.67 bc
5. Sole Lablab	2.33 b	2.00 c	2.00 c
Mean	5.87	6.4	6.47
C.V.	0.81	0.61	0.77
SD	24.01	16.39	20.55

Table 3: The effect of cover crops on maize yield

Cover crops treatments	Maize Yield (t/ha)				
	1999	2000	2001	2002	2003
1. Lablab + maize stover	1.50 ab	0.33	1.60 a	2.07 c	2.87 a
2. Mucuna + maize stover	0.83 c	0.43 ab	1.77 a	2.30 ab	3.03 a
3. Without cover crop (control)	0.30d	0.22 c	0.63 b	0.67 d	0.57 b
4. Sole Mucuna	1.32 b	0.53 a	1.60 a	2.17	3.37 a
5. Sole Lablab	1.60 a	0.57 a	1.57 a	2.47 a	3.33 a
Mean	1.11	0.42	1.43	1.93	2.63
C.V.	9.3	18.6	8.92	5.09	12.79
SD	0.06	0.04	0.07	0.06	0.19

References

Benson, F. and Mrabet, R. (2001) "Time influence of no tillage on organic matter and quality of a vertic caclixeroll in a semi arid area of Morocco" National Agriculture Research Institute, Dry land Research Centre, Soil Physics Laboratory. P.O. Box 589 Settat 26000, Morocco.

Lyimo, S. D. (2001) Impact of HIV/AIDS on agriculture; Lively Study in the Northern Tanzania, SARI P. O. BOX, 6024, Arusha Tanzania.

Nyborg, M. and Malhi, S. S. (1989), "Effect of Zero and Conventional Tillage on Barley Yield and Nitrate Nitrogen Content, Moisture and Temperature of Soil in North-Central Alberta," Department of Soil Science, University of Edmonton, Alberta T6G 2E3, Canada.

Mmbaga, T. E. (1994) "Chemical weed control in maize – bean intercropping. Agricultural Research Institute, Lyamungu P. O. BOX 3004 Moshi, Tanzania.

Mmbaga, T. E. (2006) "Evaluation of Roundup dry 680 (Glyphosate 680 acid /kg) in maize production in Northern Tanzania, Selian Agricultural Research Institute, P. O. BOX 6024, Arusha, Tanzania.

Mattowo, P.R. (1988). "Optimum weeding in maize in the low and intermediate areas of Tanzania" SARI, P. O. BOX 6024, Arusha, Tanzania.

Water Conservation and Water Use Efficiency in Drylands

Bobby A. Stewart
Director Dryland Agriculture Institute, and Distinguished Professor of Agriculture
West Texas A & M University, Canyon, Texas, USA, 79016
bstewart@mail.wtamu.edu

Abstract

Controlling runoff is a primary objective of dryland cropping systems and the first step in a water conservation system. Runoff should be controlled by prevention or collection. However, runoff prevention by itself does not ensure infiltration and storage for use by crops because water can be evaporated before it can infiltrate. In other cases, water may move below the rootzone. Collected water can be beneficial in water harvesting systems. The second step is reducing evaporation. The goal of efficient water use in dryland regions should always be to maximize percentage of annual precipitation used for transpiration by decreasing losses from runoff, evaporation, and percolation. This is not always feasible because of the necessity to fallow lands for long periods in some climates to store water to supplement growing season precipitation that is insufficient for crop production. The use of surface mulches such as straw or stalks remaining after harvesting grain can reduce evaporation significantly. In many countries, the competing uses of plant residues for feed and fuel are considered higher priorities and residues are removed. This not only allows evaporation, but also increases runoff, and reduces the soil organic matter level that is the third important factor in controlling runoff. As water conservation decreases, water use efficiency is almost certain to decrease simultaneously. Water use efficiency is an important concept for understanding soil-crop systems and designing practices for water conservation. The most common definition is the amount of harvestable product per unit of evapotranspiration between the dates the crop is seeded and harvested, commonly expressed as kilograms per cubic meter. Evapotranspiration is the sum of the amounts of water transpired by the crop and lost by evaporation from the soil surface.

Key words: Evapotranspiration, crop residues, soil organic matter, controlling runoff, sustainability

Introduction

Drylands are defined by the Food and Agriculture Organization (FAO) as those regions climatically classified as arid, semi-arid, or dry subhumid based on length of growing period for annual crops (FAO, 2000). The growing period begins when monthly precipitation exceeds half of the monthly potential evapotranspiration (PET). The regions where the monthly rainfall never exceeds half of the PET have zero growing days and are not included in the drylands. They are classified as hyperarid areas with no agricultural potential.

Arid regions have 1 to 59 growing days, semi-arid have 60 to 119, and dry subhumid regions have between 120 and 179 growing days. Combined, these regions account for 45% of the world's land area 7% arid, 20% semi-arid, and 18% dry subhumid. The distribution of these areas among the different regions of the world is presented in Table 1. The hyperarid lands are not included in Table 1 but make up an additional 19% of the world's land area. The growing period classification system is based on agro-ecological factors and generally works well for assessing the potential of an area for growing crops. There are, however, some notable exceptions. For example, in much of the Great Plains of the USA, one of the largest dryland cropping regions of the world, there is not a single month of the year when average precipitation exceeds half of the PET. Based on the growing day classification, this area is classified as hyperarid with no agricultural potential. Dryland farming can be practiced in this region because management practices have been developed that allow the accumulation of 100 to 200 mm of plant available water during fallow periods to supplement precipitation received during the growing season. These cropping systems generally have a cropping intensity of less than one, meaning that a crop is not harvested every year. Examples are wheat (Triticulm aestivium L.)-fallow resulting in one crop every 2 years; wheat-sorghum (Sorghum bicolor (L.) Moench)-fallow resulting in two crops every 3 years, and wheat-sorghum-sorghum-fallow resulting in three crops every 4 years. The average annual precipitation for the U.S. Great Plains where dryland farming is practiced ranges from about 400 to 600 mm, but the amount for any given year for a specific location varies from about 50% of average annual to about 200%. The variation in yields is even greater, ranging from zero to about three times the average yield. Drought conditions occur every year but the extent and severity vary greatly.

Table 1: Percent of world land area (134.9 million km^2) in various regions, percent of land in regions for different dryland areas, percent of world population (6.2 billion) in various regions, percent of population in regions living in dryland areas, and percent of population in regions engaged in agriculture (Stewart & Koohafkan, 2004).

Regions	World land area (%)	Arid (%)	Semiarid (%)	Dry sub-humid (%)	Total world population (%)	Population in drylands (%)	Agricultural production (%)
Asia and Pacific	21.5	6	15	17	56	44	59.5
Europe	5.4	<0.5	13	16	12	18	13.5
North Africa and Near East	9.5	4	11	5	5	44	44.3
North America	14.8	12	28	23	5	19	3.0
North Asia and East of Urals	15.6	11	51	33	4	89	17.4
South and Central America	15.4	11	6	10	8	24	23.0
Sub-Saharan Africa	17.7	6	13	19	10	36	65.0
World (Total)	100	7	20	18	100	38	45.8

Dryland areas like the U.S. Great Plains are better classified by a climatic aridity index. One such index proposed by the United Nations Conference on Desertification (UNESCO, 1977) defines bio-climatic zones by dividing the annual precipitation (P) by the annual potential evapotranspiration (PET). Climatic zones were defined at hyper-arid (P/PET = <0.03), arid (0.03<P/PET<0.20), semi-arid (0.20<P/PET<0.50), and sub-humid (<0.50P/PET<0.75). Using the aridity index, most areas of the U.S. Great Plains where dryland cropping is practiced are classified as semi-arid.

This paper will focus on the semi-arid portion of the drylands. The semi-arid lands are where dry-land farming is primarily practiced. Dryland agriculture is that part of rainfed agriculture where water is the most limiting factor. Mathews & Cole (1938) stated that dryland farming in its broad-est aspects is concerned with all phases of land use under semi-arid conditions. Not only how to farm, but how much to farm, and whether to farm are questions that should be addressed for all semi-arid regions. Dryland farming systems must emphasize water conservation, sustainable crop yields, limited inputs, and wind and water erosion constraints. Dryland farming generally occurs in areas where the average crop water supply limits potential yield to <40% of full (water-unlimited) potential (Stewart & Koohafkan, 2004).

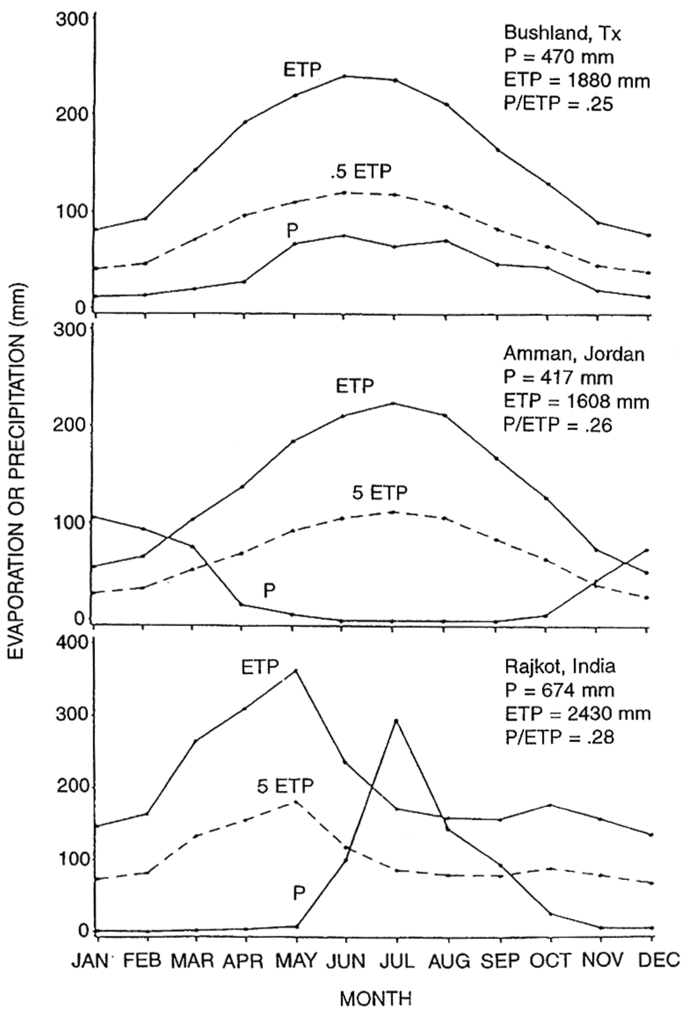


Figure 1: Agroclimatic characteristics of three representative dryland locations (Stewart, 1988).

Semi-arid regions are very different and each must be considered separately. The average monthly precipitation, potential evapotranspiration, and half potential evapotranspiration for three locations are presented in Figure 1. All three locations are classified as semi-arid by the aridity index (0.20 < P/ETP < 0.5). However, by the FAO growing period classification, only the Rajkot, India, location is classified as semi-arid. This location has a growing period of 96 days, which is within the 75- to 119-day range. The Amman, Jordan, location has a growing period in excess of 119 days, so this would be considered subhumid. Bushland, TX, is classified as dry, with a 0-day growing period, because the average monthly precipitation never exceeds 0.5 ETP. The cropping systems and water conservation practices used for these locations must be very different to be successful. There are, however, some characteristics common to all semi-arid regions. Bowden (1979) lists four keys that are unique to semi-arid lands.

Key 1. No growing season is or will be nearly the same in precipitation amount, kind, or range, or in temperature average, range, or extremes, as the previous growing season. Although this key is critical in any rainfed system, it requires absolute attention in dryland farming. Crop cultivation requires an adjustment every year, which leads to the second key.

Key 2. Crops cannot be planned or managed in the same manner from season to season. Most of the world's agricultural practices in either humid or arid areas have some annual predictability. In semi-arid climates, however, even highly mechanized, technically advanced, commercial farms such as those in the High Plains of North America or the out back of Western Australia do not have sufficiently stable production for the individual or government to rely on a given production figure for the following season.

Key 3. Soil and water resources are changed once agriculture is introduced into a semi-arid region. For example, the soils of most semi-arid lands developed under grass on relatively flat topography. The competition for water and nutrients to produce crops requires removal of the protective grass cover. Because the crops are annual and dependent on precipitation, little or no vegetative cover is produced during severe drought years leaving the soil highly vulnerable to wind erosion.

Key 4. There is abundant sunshine due to many cloud-free days. This has potential benefits and is shared with most arid climates. Abundant sunshine means higher temperatures that induce rapid growth, but it also creates a situation that demands careful management of soil water. Warm seasons, high sun and cloud-free conditions stimulate growth, but also increase evaporation and transpiration. It is possible for a grain crop to mature rapidly due to several weeks of rainless conditions and desiccate just days before ripening. It is equally possible for a few mm of precipitation to occur at almost the last moment and produce a good grain crop.

An understanding of all four characteristics is vital, but perhaps Key 3 deserves the most attention because it concerns the resource base that is affected by human activities and often changes rapidly for the worse. Sustainability of the soil resource base in dryland regions is a major concern and this is particularly true for lands that are cultivated. Land degradation is very common in most dryland areas and can lead to desertification. Desertification is defined as land degradation in arid, semi-arid, and dry sub-humid areas caused by climatic variability and human activities (FAO, 2000). Whenever an ecosystem like a grassland prairie in a semi-arid region is transformed into an agro-ecosystem for the purpose of food and fiber production, several soil degradation processes are set in motion, particularly if raindrops fall directly onto the soil surface without vegetation, crop residues, or mulches present. Some examples are soil organic matter decline, wind and water erosion, deterioration of soil structure, salinization, and acidification. In an ideal situation, soil conservation practices such as minimum or zero-tillage, crop rotations including legume crops, application of inorganic and organic fertilizers, crop residue management, terracing, and others that reduce degradation processes and maintain soil productivity are used to offset the degradation processes. In dryland areas, the degradation processes are often much more dominant than the soil conservation practices so the soil resource base can quickly degrade. In general, degradation processes proceed more rapidly as the climate becomes hotter and drier while the soil conservation practices become more difficult to implement under these conditions. As the soil degrades, the infiltration rate and water holding capacity decrease making the already limited water resource even less effective resulting in a downward spiral of soil quality and crop production.

Water conservation

Water conservation is the most important factor that must be addressed for developing successful agroecosystems in semi-arid regions. Lack of water for crop production occurs every year in semi-arid regions and every management practice used in semi-arid regions must be evaluated on the basis of how it affects the water balance. Stewart & Burnett (1987) listed three components necessary for successful agroecosystems in semi-arid regions. These are (i) retaining the precipitation on the land; (ii) reducing evaporation, and (iii) utilizing crops that have drought tolerance and that fit the precipitation patterns. Although these components have been known for centuries, new technologies and strategies are continuing to evolve that can increase yields in water-deficient areas. Stewart & Robinson (1997) summarized a number of technologies that have been developed in the U.S, China, and Australia in recent years.

The most successful sustainable agroecosystems are those that use some form of conservation agriculture. The goal of conservation agriculture is to conserve, improve and make more efficient use of natural resources through integrated management of available soil water and biological resources combined with external inputs (FAO, 2002). Conservation agriculture contributes to environmental conservation as well as to enhanced and sustained agricultural production. It can also be referred to as resource-efficient agriculture. Conservation agriculture is based on three principles:

* **Avoiding mechanical soil disturbance**

* **Maintaining a permanent soil cover, by crop residues and crops**

* **Crop rotation.**

Conservation agriculture is practiced on 45 million ha, mostly in South and North America (FAO, 2002). However, this accounts for only about 3 percent of the 15 billion ha of arable land worldwide. Conservation agriculture has been most successful in South America, particularly Brazil, where economic and environmental pressures are great. Conservation agriculture is practiced from the humid tropics to almost the Arctic Circle and on all kinds of soils. However, FAO (2002) stated "So far the only area where the concept has not been successfully adapted is the arid areas with extreme water shortage and low production of organic matter. In these areas both humans and animals compete with the soil for crop residues." Maintaining a permanent soil cover and utilizing crop rotations are the principles of conservation agriculture that are most difficult to practice under dryland conditions. The fact that it is difficult to carry out all the principles of conservation agriculture in dryland regions must not deter efforts to adapt the concepts as far as feasible in these regions. The dryland regions are where the benefits of conservation agriculture are critically needed and where soil degradation can be disastrous without the application of some of the concepts of conservation agriculture.

The greatest problem with applying conservation agriculture concepts in dryland regions is the lack of crop residues. Crop residues are lacking because the limited and highly variable precipitation limits biomass production. In many cases, the situation is made even worse because of the use of crop residues for animal feed and fuel. The removal of crop residues accelerates the already fast decline of soil organic matter common in dryland areas. This lowers the soil water holding capacity and fertility and results in even lower yields and a downward spiral of crop productivity and soil quality.

The long-term future of many dryland regions depends on stopping, or reversing, the downward spiral of crop productivity and soil quality. This is a particular challenge in many of the developing countries where yields are low and the demand for crop residues is great. FAO (1996) reported that the 1988-1990 average yields of wheat (Triticum aestivium L.), maize (Zea mays L.), and sorghum (Sorghum bicolor) in developing countries in semi-arid regions were 1100, 1130, and 650 kg/ha, respectively. These low grain yields result in relatively low amounts of crop residues.

There are numerous studies, however, that show even small amounts of crop residues can be beneficial for controlling wind erosion and increasing soil water storage. Fryrear (1985) established the relationship between soil loss by wind erosion and the percent of soil cover. Covering 20% of the surface reduced soil losses by 57%, and a 50% cover reduced soil losses by 95% compared to soils with no cover. Greb, Smika & Welsh (1979) were among the earliest researchers to clearly show the benefits of reduced tillage on water conservation in semi-arid regions. In a wheat-fallow system that included a 15 to 16 month fallow period, they found water storage in the soil profile during the fallow period increased every time the number of tillage operations decreased (Table 2). This is due to two factors. The first is that the soil is dried to the depth of tillage each time it is tilled. The second is that the less the soil is tilled, the greater the amount of mulch that remains on the surface to reduce the evaporation potential. More importantly, Greb et al. showed that only a few mm of additional soil water storage at time of seeding increased wheat grain yields dramatically. An increase of 55 mm of soil water storage at seeding doubled the grain yield of wheat from 1.07 to 2.16 Mg /ha (Table 2). The 55 mm increase was achieved by increasing the fallow efficiency from 19 to 33%. The reason that such a small increase of soil water increases grain yield so much is because the threshold amount of evapotranspiration required for grain production is already met and the additional water increases grain production directly.

Table 2: Progress in wheat-fallow systems at Akron, Colorado (Greb et al., 1979).

Years	Tillage	No. tillage operations	Fallow water (mm)	Fallow efficiency (%)	Wheat yield (Mg/ha)
1916-1930	Maximum tillage, plow and harrow	7 to 10	102	19	1.07
1931-1945	Shallow disk, rodweeder	5 to 7	118	24	1.16
1946-1960	Begin stubble mulch in 1957	4 to 6	137	27	1.73
1961-1975	Stubble mulch, herbicides in 1967	2 to 3	157	33	2.16
1976-1990	Minimum till, projected no-till	0 to 1	183	40	2.69

Conservation agriculture practices that leave crop residues on the soil surface also tend to increase the soil organic matter level that increases infiltration, improves soil structure, increases water holding capacity, and increases water conservation. These positive changes, however, do not occur quickly. The benefits of conservation agriculture accrue slowly and several years are often required before benefits are evident. Therefore, the adoption of conservation agriculture practices that focus on maintaining crop residues on the soil surface in semi-arid regions will likely remain a slow process. This will be particularly true in areas where crop residues are used for animal feed or household fuel. The short-term benefits of using crop residues for these purposes almost always take precedence over the long-term benefits of maintaining the soil resource base. This is a dilemma that will continue to challenge producers and policy makers in semi-arid regions because the long-range sustainability of soils in these areas cannot be maintained unless crop residues are returned to the soil or manures or other sources of organic matter are added.

Water use efficiency

Water use efficiency indicates the effectiveness at which water is used in agricultural production. The goal of most cropping systems, particularly in water deficient areas, is to increase water use efficiency. In general, the term efficiency quantifies the relative output obtained from a given amount of input. Water use efficiency can be defined in different ways so it is critical that one clearly understands how the term is used in each specific case. The most common water use efficiency expression relates crop production to the water consumed by evapotranspiration from planting to harvest (Jensen, 1987). Jensen defined this as WUE_{net}. Crop production generally means the amount of harvestable product. For example, for a grain crop, WUE_{net} = (yield of grain in kg)/(ET in cubic meters). This is a very meaningful measure and is widely used by researchers. However, it is often not a very meaningful term to producers because they generally do not have a means of measuring the evapotranspiration because they do not have measurements of other water losses such as runoff, drainage, and evaporation during the time periods when the crop is not growing. For rainfed crops, water use efficiency is sometimes used to relate crop production from harvest of one crop to the harvest of the next crop. This is particularly useful in areas where long fallow periods are used and only one crop is produced every 2 years or perhaps 2 crops every 3 years. These systems can result in a high WUE in terms of grain yield for ET between planting and harvest, but a rather low WUE in terms of water consumed or lost between the time of harvest of one crop and the time of the next harvest. Jensen (1987) defined this as WUE_{gross}. $WUE_{irrigation}$ is often used to evaluate the increase in irrigated crop production over rainfed production relative to the increase in evapotranspiration. In simple terms, there are five things that can happen to water that is added to cropland by precipitation or irrigation. It can runoff, percolate, evaporate, remain in the soil profile, or be transpired. Only the water that is ultimately transpired by the intended growing crop will result in increasing yield and an increase in water use efficiency.

The hypothetical example by Howell (1990) is presented in Figure 2 and is extremely useful in understanding water use efficiency under a variety of scenarios. In this example, the Q_o shows a case where the sum of water use from available soil water at time of seeding and rainfall during the growing season totaled 250 mm, and Q_m is the total field water supply of 1400 mm that includes the 250 already described plus 1150 mm of applied irrigation water. The yield of aboveground biomass produced and the yield of grain produced by a dryland crop is represented by P and Y, respectively. In this example, P was 6 Mg/ha and Y was 2 Mg/ha. Therefore, the harvest index (grain yield/total aboveground biomass) was 0.33. The maximum P_m and Y_m values are 24/Mg and 10/Mg, respectively and represent the yields obtained when water was not limiting. The WUE_{net} (yield of grain in kg)/(ET in cubic meters)for the dryland crop would be 2000 kg/2500 cubic meters, or 1 kg/m³. For the highest yield, Pm, the WUEnet would be approximately 10,000 kg/7500 cubic meters, or 1.33 kg/m³. Theoretically, there is a straight line relationship between water use and yield of either grain or aboveground biomass after the threshold amount has been supplied. Using the grain yield of this example, there was no grain produced until approximately 100 mm of water was utilized, but once the threshold value was reached, additional water utilized as ET water increased the yield about 1.5 kg/m³. Therefore, the WUE_{net} is always the highest as the highest yield because the threshold portion of the water used becomes a smaller portion of the total water used for ET. The $WUE_{irrigation}$ may decrease with increasing yields. In the example, 1150 mm of irrigation water was required to produce the maximum grain yield of about 10 Mg/ha, but the addition of only 450 mm would have produced about 9 Mg/ha. Therefore, the $WUE_{irrigation}$ would be much lower for the maximum grain yield. The deviation of the dashed curves from the lines represents the combined effects of the irrigation hydrology (runoff, deep percolation, soil water recharge, spray evaporation, drift, etc.) with the effects of the irrigation water salinity, irrigation application uniformity, and the spatial variability of the soil physical parameters. In theory, with high quality water and an efficient irrigation system, the deviation between the ET line and the dashed line representing field water supply can become very close to one another. Howell (1990) stated that for the example depicted in Figure 2 that (i) the maximum water use efficiency (Y/ET) occurs at the point (Y_m, ET_m), (ii) maximum irrigation use efficiency (Y/Q) occurs at a value of Q of about 600 mm, which is considerably less than the 1150 mm necessary to produce maximum grain yield (this value can be graphically determined by the tangent on the curve to a line constructed through the origin); and (iii) assuming a constant water cost, the maximum net profit will normally occur at a value of field water supply exceeding ET_m but $<Q_m$ (unless water is free) and will decrease as the water price increases for fixed land but increase with higher fixed production costs.

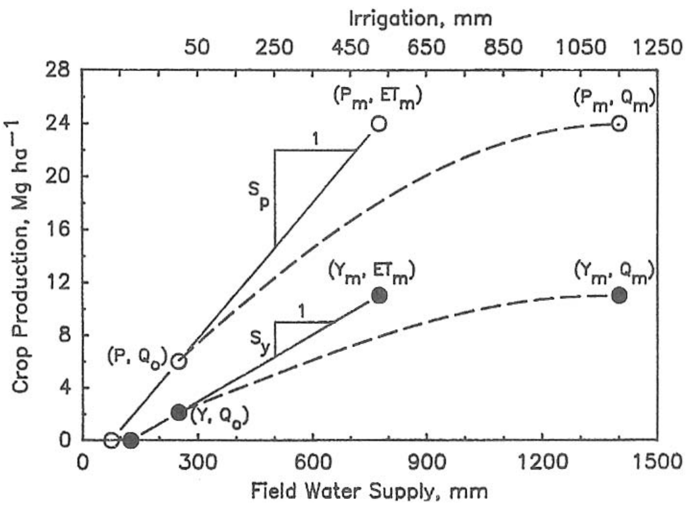


Figure 2: Hypothetical example illustrating a relationship between dry matter and grain production and field water supply (Howell, 1990).

Water use efficiency can basically be improved by two basic principles_conservation of water and enhancement of crop growth. Conservation of water in dryland systems involves reducing runoff and evaporation. For irrigated systems, these factors are also important but the conveyance of water from the source and the application efficiency of the irrigation water must be carefully managed. Enhancement of crop growth requires the optimal timing of planting and harvesting, maintaining adequate soil fertility, and using appropriate insect, parasite, and disease control.

Goal for applying conservation agriculture to dryland regions

Musick and Porter (1990), Rhoads and Bennett (1990), and Krieg and Lascano (1990) reviewed the literature regarding the water use efficiency of wheat, maize, and sorghum, respectively. While the efficiencies varied considerably depending on yield levels and climatic conditions, some reasonable guidelines can be developed from the many studies that have been conducted worldwide. A reasonable suggested guide is that 1.7 kg of maize grain, 1.5 kg of sorghum, and 1.3 kg of wheat can be produced in dryland regions for each additional m^3 of water used for evapotranspiration. The threshold values, however, are also different for each of the crops with wheat usually having the lowest and corn having the highest.

Based on the water use efficiency values above, the average yield of wheat could be increased by 325 kg/ha by increasing seasonal evapotranspiration by 25 mm. This could potentially increase the average wheat yield of developing countries by 30% because FAO (1996) reported that the 1988-1990 average yield of wheat was only 1100 kg/ha in these countries. The average yields of maize and sorghum were 1130, and 650 kg/ha, respectively. Likewise, increasing the seasonal evapotranspiration by 25 mm could potentially increase the average maize yield by 425 kg/ha and sorghum by 375 kg/ha that would be increases of 38% and 58%, respectively. Increasing evapotranspiration by 25 mm in semi-arid cropping regions over the next several years appears to be a reasonable goal, particularly in areas with average annual precipitation of 350 mm or greater.

Conclusion

Water conservation and water use efficiency in drylands can be improved by conservation agriculture but success will not be easy, and certainly not quick. Conservation agriculture is based on the principles of avoiding mechanical soil disturbance, maintaining a permanent soil cover by crop residues or growing crops, and crop rotation. While conservation agriculture has been highly successful in humid areas, its suitability for dryland regions has been questioned. However, there is ample evidence that shows some of the principles of conservation agriculture can be applied to dryland regions and crop productivity and soil quality can be enhanced as a result. Because water is so limiting in these areas, the amount of crop residues is insufficient to maximize water use efficiency and quickly change soil organic matter content. Reduction in tillage often requires the use of herbicides for weed control. This requires higher management skills and increased input costs, both of which are often lacking in dryland regions. Crop residues, particularly in developing countries, are also valued for use as animal feed or household fuel and this further complicates the situation. The long-term sustainability of dryland soils, however, may not be feasible unless some conservation agriculture practices are adopted. Researchers, change agents, and policy makers must promote these principles to the fullest extent feasible and develop strategies and policies that can be implemented successfully by the farmers.

References

Bowden L. 1979. Development of present dryland farming systems. In Agriculture in semi-arid environments. pp. 45-72. Eds. A.E. Hall, G.H. Cannell and H.W. Lawton. Springer-Verlag, Berlin.

Food and Agricultural Organization (FAO). 1996. Prospects to 2010: agricultural resources and yields in developing countries. In: Volume 1 Technical background documents 1-5. World Food Summit. pp. 26-36. Food and Agriculture Organization of the United Nations, Rome.

Food and Agriculture Organization (FAO). 2000. Land resource potential and constraints at regional and country levels. World Soil Resources Rep. 90. FAO of the United Nations, Rome.

Food and Agricultural Organization (FAO). 2002. Intensifying crop production with conservation agriculture. http://www.fao.org/ag/ags/AGSE/main.htm Food and Agriculture Organization of the United Nations, Rome.

Fryrear D W. 1985. Soil cover and wind erosion. Transactions American Society Agricultural Engineers 28:781-784.

Greb B W, Smika D E, Welsh J R. 1979. Technology and wheat yields in the Central Great Plains: Experiment station advances. Journal of Soil and Water Conservation 34: 264-268.

Howell T A. 1990. Relationships between crop production and transpiration, evapotranspiration, and irrigation. In Irrigation of agricultural crops. pp. 391-434. Eds B A Stewart and D R Nielsen. Agronomy 30. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, WI.

Jensen M E. 1987. New technology related to water policy-engineering. In Water and water policy in world food supplies. pp. 43-49. Ed. W.R. Jordan. Proceedings of the Conference, May 26-30, 1985. Texas A&M University, College Station, Texas.

Krieg D R, Lascano R J. 1990. Sorghum. In Irrigation of agricultural crops. pp. 719-739. Eds B A Stewart and D R Nielsen. Agronomy 30. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, WI.

Mathews O R, Cole J S. 1938. Special dry-farming problems. In Soils and men. yearbook of agriculture. pp. 679-692.U.S. Department of Agriculture, Washington, D.C.

Musick, J.T. and K.B. Porter. 1991. Wheat. In Irrigation of agricultural crops. pp. 597-638. Eds B A Stewart and D R Nielsen. Agronomy 30. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, WI.

Rhoads F M, Bennett J M. 1990. Corn. In Irrigation of agricultural crops. pp. 569-596. Eds B A Stewart and D R Nielsen. Agronomy 30. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, WI.

Stewart B A. 1988. Dryland farming: the north American experience. In Challenges in dryland agriculture_a global perspective. pp. 54-59. Eds. P.W. Unger, T.V. Sneed, W.R. Jordan, and R. Jensen. Proceedings of the International Conference on Dryland Farming, August 15-19, 1988, Amarillo-Bushland, TX. Texas Agricultural Experiment Station, College Station, TX.

Stewart B A, Burnett E. 1987. Water conservation technology in rainfed and dryland agriculture. In Water and water policy in world food supplies. pp. 355-359. Ed. W.R. Jordan. Proceedings of the Conference, May 26-30, 1985. Texas A&M University, College Station, Texas.

Stewart B A, Koohafkan P. 2004. Dryland Agriculture: Long neglected but of worldwide importance. In Challenges and Strategies ford dryland agriculture. pp. 11-23. Eds. S.C. Rao and J. Ryan. CSSA Special Publication 32, Crop Science Society of America, Madison, WI.

Stewart B A, Robinson C A. 1997. Are agroecosystems sustainable in semiarid regions? Advances in Agronomy 60:191-228.

Crop Roots and Water Use Efficiency in Conservation Agriculture and Conventional Tillage Systems in Drylands

Ammar Wahbi
Soil Science Dept. Faculty of Agriculture, University of Aleppo
Aleppo, Syria, e-mail: wahbi@scs-net.org

Abstract:

Dryland agriculture is facing many challenges and is considered a very fragile system. Among the challenges are soils with highly depleted soil organic matter contents that have little or no structure and highly prone to wind and water erosion. The result is soils with low soil fertility and poor water properties that encourage farmers to use low-input strategies. Thus, water and nutrients are the two main constraints for dryland agriculture. Cultivation makes the situation even worse by further destroying soil structure that tends to hold particles together and making them more vulnerable to erosion. Cultivation also provides more oxygen to the soil and exposes new surfaces of organic matter to decomposition. Evaporation of soil water is increased following tillage and the soil dries quickly to the depth of cultivation. The soil is also compacted below the zone of cultivation making it more difficult for roots to penetrate. Conservation agriculture (CA) with no-tillage or direct drilling reduces soil erosion, nitrate leaching, subsoil compaction, and soil organic matter decomposition. Some farmers in northern Syria where soil water amounts are usually small have used direct drilling very early in the season to obtain reasonable germination after a sufficient amount of precipitation occurred. CA was shown to have a positive effect on the root system resulting in better water and nutrient uptake, enhanced hydraulic conductivity, and increased biomass production. The end result was higher amounts of crop residues on the soil surface to improve the soil system.

Key words: dryland, root, water, tillage, low soil fertility, soil erosion

Introduction:

Dryland agriculture consists of two constraint components; weather and soil fertility. These constraints are also affected by management. Furthermore, they result in un-stable agricultural systems which encourage the farmers to use a low input strategy that results in these lands not being profitable. The end result is that farmers often pay less attention to these lands leading to further degradation.

Weather constraint:

The weather in the dry areas of Syria is described as having winters with precipitation and mild to cold temperatures and summers with hot temperatures and no precipitation.

Grain crops are usually planted in November or early months of winter to allow every drop of rain to be used by the crop. Early vigor is of great importance because growth during the cool winter months requires less transpiration than during the hotter season (Fischer, 1981).

As the season advances towards April and May, the rainfall decreases and the demand for water increases to meet the demand during the grain filling growth stage. Therefore, drought is common and is mainly related to a shortage of soil water and visual symptoms become clear when air temperatures increase.

The high variability of precipitation is often considered worse than the low amounts. As an example, the 40-year average precipitation amount at Breda located in northern Syria is 275 mm but it was only 117.6 mm during the 1988-1989 growing season compared to 432.2 mm for the 1987-1988 season (Figure 1). This almost four-fold difference in precipitation makes it extremely difficult to plan sound management strategies.

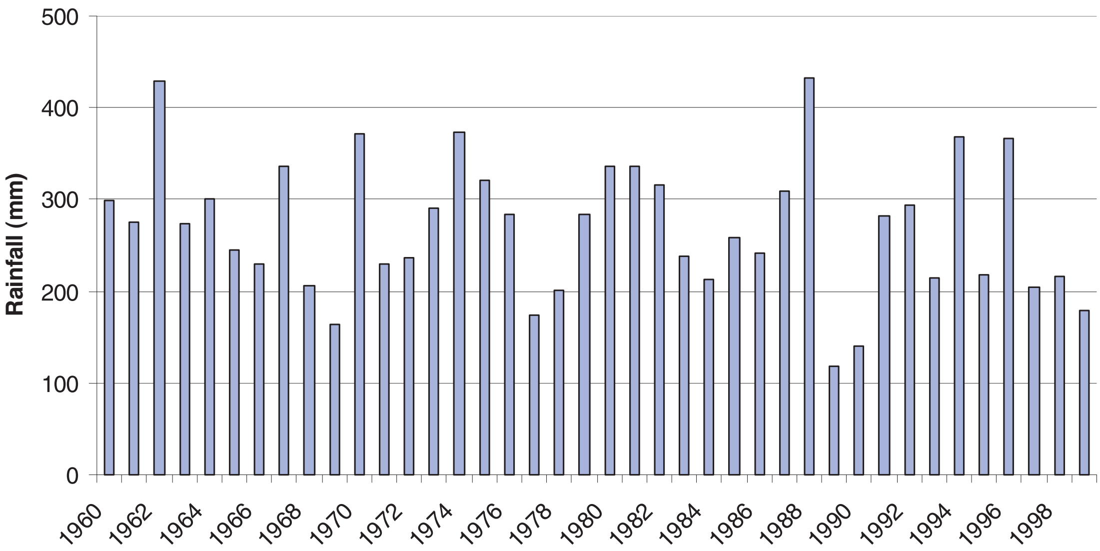


Figure 1: Total yearly rainfall at Breda (Northern Syria) from 1960-1999.

Soil fertility and management constraint:

Low and highly variable rainfall amounts result in low average production amounts in the dry areas. This encourages farmers to use low input strategies and pay little attention to the long-term view and sustainable use of the resources. A low input strategy usually consists of using little or no fertilizer of any kind and intensive tillage and mono-crop system. Such systems play a major role in soil deterioration and soil erosion becomes common in a relatively short period of time and the lands are withdrawn from the production pool.

Dryland agricultural system:

Drought is one of the main constraints in dryland agriculture. Scientists are facing an increased challenged to live with and/or avoid/resist drought in these areas. Farmers that live in these areas are poor and often do not have access to advanced technologies. As a result, some farmers do not stay in these dry areas during the entire year. They often only come for planting and harvesting. Therefore, farmers are not paying close attention. Tillage is often done when the soils are dry because it is less expensive than waiting until after some rainfall events have occurred. Also, crops are planted in dry soil with little if any fertilizer. Furthermore, these areas have dramatic fluctuations of temperature between day and night. High temperatures speed the decomposition of organic matter even though the amount is generally low. Consequently, low fertility and poor soil structure are common. So, low amounts of soil moisture, low soil fertility, and fragile soil structure result in soil erosion and low productivity and as time passes, these areas will be withdrawn from production due to non-profitability. López-Bellido (1992) and Bonari et al. (1994) stated that climatic restrictions and special social, structural, and economic features of dryland areas provide an unfavorable scenario for agriculture.

When these lands are abandoned by farmers, they will most likely be used by non-farmers that will plant the areas for grazing purposes, and in good seasons, they will earn extra incomes. These non-farmers are mainly interested in raising animals and generally move from one location to another. Therefore, they are not vitally interested in the long-term sustainability of the lands. As a result, the land is prone to over grazing that results in soil erosion by wind and water.

In summary, two major constraints limit dryland agriculture. First, the shortage of precipitation and the high temperatures during the grain filling period as well as large differences between day and night temperature; and second, low soil fertility and poor soil structure resulting soil loss by erosion and low crop productivity that is not profitable.

Conventional tillage system:

The goal of traditional tillage systems was to prepare a good seed bed. The tillage is presently done using heavy machinery. This heavy machinery produces subsoil compaction which reduces the penetration of water to the deep soil layers where it can be used in the later season when precipitation is generally lacking.

Farmers tend to cultivate the soil immediately after harvesting cereals in the summer and this causes the breakdown of the aggregates making the soil particles more susceptible to erosion by the summer winds. Soil erosion generally results in more fine particles than coarse particles and these results in a disproportionate loss of soil fertility and water holding capacity.

Soil organic matter is inherently low in dryland areas, and the use of tillage increases the oxidation and decomposition of the already low organic matter content to leave the soil extremely low in organic matter as a source of nutrition and as a binding agent to prevent the soil particles from eroding.

Logan et al. (1991) and Choudhary et al. (1997) stated that conventional tillage increases the risk of soil erosion, nitrate leaching, and subsoil compaction.

One of the goals of tillage is to reduce soil bulk density and consequently increase porosity. However, the effect of tillage on bulk density is temporary, and following tillage, the soil rapidly settles and returns to its former bulk density (Hernanz and Girón, 1988; Campbell and Henshall, 1991; Franzluebbers et al., 1995).

Intensive conventional tillage is known to degrade soil structure (Blevins and Frye, 1993) and make the soil even more degraded in the dryland areas.

Conservative Agriculture (CA):

CA, if it is to be successful, has to demonstrate that more water and nutrients become available compared to conventional agriculture systems, or in a farmer's perspective, show a higher net economic return. CA includes the use of a package of technologies aiming to have a higher and more sustainable level of production and, therefore, a better use of resources. And since the focus of this paper is dryland agriculture, water is the most important element in the system and saving it or using it in an efficient way is the challenge. Apart from the genotypic variation that can play a role in CA, management is the key factor affecting the production and the use of water. Wahbi (1986) illustrated in a field experiment in northern Syria (where annual long-term rainfall is about 275 mm/yr) that the landrace genotype of barley (Arabic White) had a transpiration efficiency (dry matter production per unit area and unit of 1 mm water used by plant transpiration) that varied within the season. For the period between stem elongation and anthesis, about 95.2 kg/ha of dry matter was produced for each mm of rainfall compared to 38.2 kg/ha dry matter production for each mm of rainfall between anthesis and physiological maturity (Table 1). However, the evaporation/evapotranspiration ratio was about 0.49 at stem elongation, increased to about 0.63 at heading stage, decreased to about 0.40 at grain filling, and then increased rapidly thereafter to about 0.70 (Wahbi, 1986). Good management and use of adequate genotypes could decrease this high evaporation portion.

Table 1: Total transpiration (mm) and transpiration efficiency (kg/ha/mm) for Arabic Abiad (local landrace) at different plant stages at Breda, Syria, (after Wahbi, 1986).

Plant stage	Sum of transpiration (T, mm)	Teff (kg/ha/mm)
Stem elongation to anthesis	34.72	95.2
Anthesis to maturity	29.09	39.2

An example of management is the use of mycorrhizae (Al-Agely and Wahbi, 2003) illustrating that the use of mycorrhizae in a pot experiment with maize, more water was present and used by transpiration compared to the non-mycorrhizae treatment (Fig. 2). Also, the normalized transpiration ratio (transpiration ratio was calculated as a ratio between daily transpiration of the drought pot treatment and the average daily transpiration of the wet pots treatment, normalization was done by calculating the average of transpiration ratio at the beginning of the drought treatments, then the transpiration ratio will be divided by this average to get the transpiration ratio normalized) decreased with the fraction transpired of soil water (FTSW) being 0.198 for the mycorrhizae treatment compared to 0.236 for the non-mycorrhizae treatment indicating the plant with mycorrhizae was sufficient to stand the shortage of soil water even though the FTSW was low (Al-Agely and Wahbi, 2003). The reason could be that more root surface was present in mycorrihizal treatment compared to the non-mycorrihizal treatment. And since more roots (surface or density) could be the reason for better utilization of water, Wahbi and Kamh (2000) indicated that the application of phosphorus in a pot experiment using nutrient solution as rooting media on maize and white lupine of different genotypes produced more roots compared to the non-phosphorus treatment. Also, a field experiment in Breda, Syria (dry area) where different barley genotypes were grown with and without phosphorus fertilizer indicated that the added phosphorus produced finer and denser roots as compared to the treatment without added phosphorus (Brown et al, 1987). Also, genotypic differences exist in root systems as was evident in several greenhouse and field studies in Syria (Wahbi, 1986). An example is shown in Fig. 3 (Wahbi and Gregory, 1989) for five genotypes of barley. Variation of crop varieties could play a role since some varieties have a denser root system, or different root distribution patterns than others. For example, Wahbi and Gregory (1989) showed that the Arabic white barley variety had a dense root system throughout the soil profile especially down to 45-60 cm, and this allowed this genotype to be superior to other varieties in terms of water use and yield of both straw and grain. The density and length of the roots are effective in terms of water utilization (Van Noordwijk, 1983).

The cropping pattern can also have a marked effect on root density and distribution. Wahbi and Kameh (2000) showed that more roots exudates were produced in white lupine (legume) compared with maize (cereal). This indicates the importance of crop rotation in the agricultural system. These roots exudates made the areas around the roots, the rhizosphere, have a lower pH which allowed the

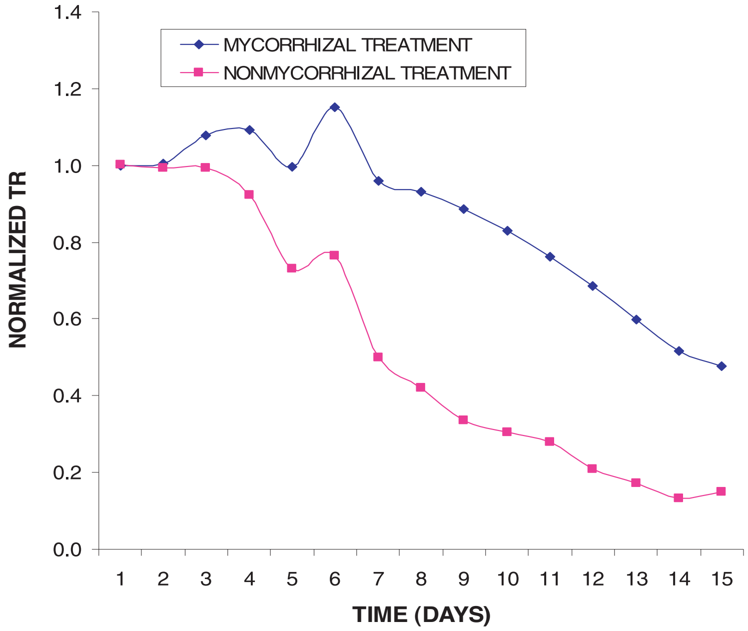


Figure 2: Normalized transpiration ratio for maize plant using mycrrihaze and non-mycrrihzae treatment throughout 15 days after emergence (after Al-Agely and Wahbi, 2003).

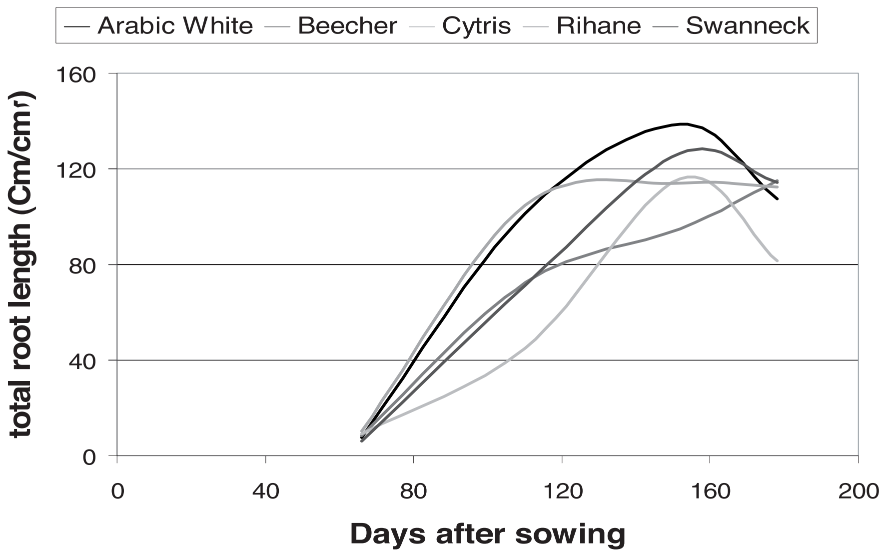


Figure 3: Total root length (cm/cm²) for five genotypes of barley throughout the season grown at Breda, Syria (after Wahbi and Gregory, 1989).

complex and non-available phosphorus to become available to the plants as well as improving the physical and chemical properties of the soil.

Referring back to CA which is comprised of several technologies, one of the important components is minimum tillage, zero-tillage, or direct drilling. The no or zero-tillage (NT) is not new technology. Some farmers in dry areas of northern Syria have planted directly using the drill machine without cultivation to save the cultivation cost. However, these drills have not been effective because they were designed to insert seed into soft soil following cultivation. Consequently, most of the seed grains stay on or near the soil surface resulting in very poor crop establishment. This often has no effect on the farmers because they are not expecting high production. However, the concept of not disturbing the soil clashes with the culture of some farmers who for years have disturbed the soil to obtain a soft medium for seed to obtain a better crop yield. For these farmers, undisturbed soil is perceived to be harder and more resistant to root penetration than tilled soil. In fact, high soil strength has been shown to reduce and even stop root growth (Atwell, 1993). More studies are needed to determine whether or not reduction or suppression of tillage can increase soil strength disturbing root and plant growth. The long term effect of NT under rainfed Mediterranean conditions has scarcely been studied. By contrast, NT practices in other areas such as USA, Australia and Canada are well-documented (Baker et al., 1996). NT has been found to increase soil water (and increase roots growth) and diminish soil erosion (wind or water).

Past experiments comparing NT with conventional tillage have shown different results. However, most of them showed that bulk density was higher in NT in the first 5-10 cm of soil (Ehlers et al., 1983; Pelegrin et al., 1988; Hill, 1990; Grant and Lafond, 1993; Hubbard et al., 1994, Wander and Bollero, 1999). A second group showed no differences in bulk density between the two tillage systems (McCalla and Army, 1961; Cassel, 1982; Logsdon and Cambardella, 2000). However, Crovetto (1998) showed that soil bulk density decreased with NT because of increased amounts of soil organic matter. In general, the differences between bulk densities become smaller with increasing time. In some soils, porosity under NT decreased compared to conventional tillage in the first few years until the soil recovered its natural structure (Kinsella, 1995).

A study of several years in Spain using barley and comparing NT to different tillage practices showed that NT resulted in a higher bulk density and the NT soil also had a higher penetration resistance (Lampurlanés and Cantero-Martínez, 2003).

Impact of tillage on roots and water use:

The root system acts as a bridge between the crop management and plant growth responses (Klepper, 1990). Root growth and development are affected by soil strength. The most common variables used to assess soil strength in tillage studies are bulk density (BD) and penetrometer resistance (PR). They are interrelated, but the use of only one may lead to misleading results (Campbell and Henshall, 1991). BD is inversely related to total porosity (Carter and Ball, 1993), and this provides a measure of the pore space remaining in the soil for air and water movement. The optimum BD for plant growth is different for each soil. In general, low BD (high porosity) leads to poor soil-root contact, and high BD (low porosity) reduces aeration and increases PR which limits root growth (Cassel, 1982). BD is related to natural soil characteristics such as texture, organic matter, structure (Chen et al., 1998), and gravel content (Franzen et al., 1994). BD varies continuously due to the action of several processes such as freezing and thawing (Unger, 1991), settling by desiccation and kinetic energy of rain (Cassel, 1982), and soil loosening action by root action and animal activity. Crop management practices such as tillage may also alter BD. One of the goals of tillage is to reduce BD by increasing soil porosity. This effect on BD, however, is temporary because following tillage the soil rapidly settles, recovering its former BD (Franzluebbers et al., 1995). In the first few years of NT, soil BD may be increased due to the repeated passes of the tractor and lack of loosening action of tillage. Therefore, NT results in better soil structure and an increase of macropores (Martino and Shaykewick, 1994) which benefits root growth (Lampurlanés et al., 2001). NT results in the stratification of soil nutrients, particularly immobile elements such as P (Crozier et al., 1999). Gregory (1994) showed that this induced a higher root length density (RLD). Rasmussen (1991) and Wulfsohn et al. (1996) showed that roots in a NT system accumulated largely in the 0 to 5 cm when compared to conventional tillage. Chan and Mead (1992) showed that the opposite occurred in the lower layers. The root diameters may be indicative of the effect of soil strength on root growth and affect the utilization of nutrients in the soil. Sidiras et al. (2001) reported thicker (in diameter) barley roots under conventional tillage compared with NT. Diameter of the roots is mostly control by soil BD, and often compact soil produce a thick roots. Slightly different results were obtained in a 5-year field trial of winter wheat at two locations in Switzerland, RLD and mean root diameter (MD) was studied for NT and CT (conventional tillage) conditions. Results showed that NT slightly lowers RLD and slightly increased MD compared with CT (Qin et al., 2004). However, compared with CT, the RLD was higher in the upper soil layer (0-5 cm), similar for the 5-10 cm depth and lower than the 10-30 cm depth for NT. The tillage effect disappeared below 30 cm (Qin et al., 2004). However, a study of several years in Spain using barley with NT and different tillage practices showed that NT produced higher root length density profiles that revealed a good soil condition for root growth (Lampurlanés and Cantero-Martínez, 2003).

Roots can exert a vertical pressure ranging from 0.7 to 2.5 MPa, depending on crop species (Gregory, 1994). BD values that limit root growth depend on soil water content (Pabin et al., 1998) and ranged between 1.46 and 1.90 Mg/m^3 (Campbell and Henshall, 1991). Mechanical impedance increases as BD increases and water content decreases (Ehlers et al., 1983). Penetration resistance measured with a penetrometer is usually 2 to 8 times higher than that actually experienced by the root tip (Atwell, 1993; Gregory, 1994) because of the different ways that a penetrometer and a root penetrates the soil. However, penetrometer values are well correlated with soil strength perceived by roots in soils with relatively homogeneous matrixes (Atwell, 1993).

Root growth increased as PR increased (Gregory, 1994), showing a linear (Ehlers et al., 1983), inverse (Atwell, 1993), or exponential (Hamblin, 1985) relationship. Penetrometer values greater than 2 MPa are generally reported to produce a significant root growth reduction (Atwell, 1993). However, in well-structured soils or those in which biochannels are preserved (as non-tilled soils), roots continue to extend at greater penetrometer readings because they can grow in the inter-aggregate spaces (Klepper, 1990; Campbell and Henshall, 1991). Therefore, more roots are expected in the NT, and this could be associated with a greater water uses (Wahbi, 1986) and resulted in a higher crop production.

References

Al-Agely, Abid, and Ammar, Wahbi (2003). Extractable soil water and transpiration rate of mycorrihizal corn. Presented (orally) at the 4th. International Conference on Mycorrhizae, between 10-15 August 2003 at Montreal, Canada.

Atwell, B.J. (1993). Response of roots to mechanical impedance. Environ. Exp. Bot. 33:27–40.

Baker C.J., K. E. Saxton, and W. R. Ritchie (1996). No-tillage seeding. Wallingford, Oxon, UK: Science and practice. CAB International

Bonari, E., M. Mazzoncini, and A. Caliandro (1994). Cropping and farming systems in Mediterranean areas. P. 636-644. In Proc. Eur. Soc. Agron. Congress 3rd, Abano-Padova, Italy. 18-

22 Sept. 1994. M. Borin and M. Sattin, Colmar Cedx, France.

Blevins, R.L., and W. W. Frye (1993). Conservation tillage: An ecological approach to soil management. Adv. Agron. 51:33–78.

Brown, S. C., P. J. Gregory, and A. Wahbi (1987). Root characteristics and water use in Mediterranean environments. In Drought Tolerance in Winter Cereals 275-283 (Eds J. P. Srivastava, E. Poreddu, E. Acevedo and S. Varma) Chichester: John Wiley & Sons.

Campbell, D.J., and J. K. Henshall (1991). Bulk density. p. 329–366. In K.A. Smith and C.E. Mullins (ed.) Soil analysis. Physical methods. Marcel Dekker, New York.

Carter, M.R., and B. C. Ball (1993). Soil porosity. p. 581–588. In M.R. Carter (ed.) Soil sampling methods of soil analysis. Lewis Publ., Boca Raton, FL.

Cassel, D. K. (1982). Tillage effects on soil bulk density and mechanical impedance. p. 45–67. In P.W. Unger and D.M. Van Doren (ed.) Predicting tillage effects on soil physical properties and processes. ASA Spec. Publ. 44. ASA and SSSA, Madison, WI.

Chan, K. Y., and J. A. Mead (1992). Tillage-induced differences in the growth and distribution of wheat-roots. Aust. J. Agric. Res. 43:19–28.

Chen, Y., S. Tessier, and J. Rouffignat (1998). Soil bulk density estimation for tillage systems and soil textures. Trans. ASAE. 41:1601–1610.

Choudhary, M. A., R. Lal, and W. A. Dick (1997). Long-term tillage effects on runoff and soil erosion under simulated rainfall for a central Ohio soil. Soil Tillage Res. 42:175–184.

Crovetto, C.C. (1998). No-till development in Chequén farm and its influence on some physical, chemical and biological parameters. J. Soil Water Conserv. 53:194–199.

Crozier, C. R., G. C. Naderman, M. R. Tucker, and R. E. Sugg (1999). Nutrient and pH stratification with conventional and no-till management. Commun. Soil Sci. Plant Anal. 30:65–74.

Ehlers, W., U. Köpke, F. Hesse, and W. Böhm (1983). Penetration resistance and root growth of oats in tilled and untilled loess soil. Soil Tillage Res. 3:261–275.

Fischer, R. A. (1981). Optimizing the use of water and nitrogen through breeding of crops. Plant and Soil, 58: 249-278.

Franzen, H., R. Lal, and W. Ehlers (1994). Tillage and mulching effects on physical properties of a tropical Alfisol. Soil Tillage Res. 28:329–346.

Franzluebbers, A. J., F. M. Hons, and D. A. Zuberer (1995). Tillage and crop effects on seasonal dynamics of soil CO2 evolution, water content, temperature, and bulk density. Appl. Soil Ecol. 2:95–109.

Grant, C. A., and G. P. Lafond (1993). The effects of tillage systems and crop sequences on soil bulk density and penetration resistance on a clay soil in southern Saskatchewan. Can. J. Soil Sci. 73:223–232.

Gregory, P. J. (1994). Root growth and activity. p. 65–93. In K.J. Boote, J.M. Bennett, T.R. Sinclair, and G.M. Paulsen (ed.) Physiology and determination of crop yield. ASA, CSSA, and SSSA, Madison, WI.

Hamblin, A. P. 1985. The influence or soil structure on water movement, crop root growth, and water uptake. Adv. Agron. 38:95–158.

Hernanz, J. L., and V. S. Girón (1988). Experiments on the growing of cereals with different tillage systems in central Spain. p. 691–696. In Proc. Int. Conf. of the Int. Soil Tillage Res. Organ., 11th, Edinburgh, Scotland. 11–15 July 1988. ISTRO, Edinburgh, Scotland.

Hill, R. L. (1990). Long-term conventional and no-tillage effects on selected soil physical properties. Soil Sci. Soc. Am. J. 54:161–166.

Hubbard, R. K., W. L. Hargrove, R. R. Lawrence, R. G. Williams, and B. G. Mullinix (1994). Physical properties of a clayey coastal plain soil as affected by tillage. J. Soil Water Conserv. 49:276–283.

Kinsella, J. (1995). The effects of various tillage systems on soil compaction. p. 15–17. In Farming for a better environment. Soil and Water Conserv. Soc., Ankeny, IA.

Klepper, B. (1990). Root growth and water uptake. p. 281–322. In B.A. Stewart and D.R. Nielsen (ed.) Irrigation of agricultural crops. Agron. Monogr. 30. ASA, CSSA, and SSSA, Madison, WI.

Lampurlanés, J and C. Cantero-Martínez (2003). Soil bulk density and penetration resistance under different tillage and crop management systems and their relationship with barley root growth. Agron. J. 95:526-536.

Lampurlanés, J., P. Angás, and C. Cantero-Martínez (2001). Root growth, soil water content, and yield of barley under different tillage systems on two soils in semiarid conditions. Field Crops Res. 69:27–40.

Logan, T. J., R. Lal, and W. A. Dick (1991). Tillage systems and soil properties in North America. Soil Tillage Res. 20:241–270.

Logsdon, S. D., and C. A. Cambardella (2000). Temporal changes in small depth-incremental soil bulk density. Soil Sci. Soc. Am. J. 64:710–714.

López-Bellido, L. (1992). Mediterranean cropping systems. P. 311-356. In C. J. Pearson (ed.) Field crop ecosystem. Ecosystem of the World 18. Elsevier, Amsterdam.

Martino, D. L., and C. F. Shaykewich (1994). Root penetration profiles of wheat and barley as affected by soil penetration resistance in field conditions. Can. J. Soil Sci. 74:193–200.

McCalla, T. M., and T. J. Army (1961). Stubble mulch farming. Adv. Agron. 13:125–196.

Pabin, J., J. Lipiec, S. Wlodek, A. Biskupski, and A. Kaus (1998). Critical soil bulk density and strength for pea seedling root growth as related to other soil factors. Soil Tillage Res. 46:203–208.

Pelegrin, F., F. Moreno, J. Martin-Aranda, and M. Camps (1988). The influence of tillage methods on soil-water conservation in SW Spain. p. 803–808. In Tillage and traffic in crop production. Proc. Int. Conf. Int. Soil Tillage Res. Organ., 11th, Edinburgh, Scotland. 11–15 July 1988. ISTRO, Edinburgh, Scotland.

Qin, Ruijun, Peter Stamp and Walter Richner (2004). Impact of tillage on root system of winter wheat. Agron. J. 96:1523-1530.

Rasmussen, J. K. (1991). Reduced soil tillage and Italian ryegrass as catch crop: II. Soil bulk density, root development and soil chemistry. (In Danish.) Tidsskr. Planteavl. 95:139–154.

Sidiras, N., D. Bilalis, and E. Vavoulidou (2001). Effects of tillage and fertilization on some selected physical properties of soil (0–30 cm depth) and on the root growth dynamic of winter barley (Hordeum vulgare cv. Niki). J. Agron. Crop Sci. 187:167–176.

Unger, P.W. (1991). Overwinter changes in physical properties of no-tillage soil. Soil Sci. Soc. Am. J. 55:778–782.

Van Noordwijk M. (1983). Functional interpretation of root densities in the field for nutrient and water uptake. In Root Ecology and Its Practical Application. pp. 207-226 Int. Symp. Gumpenstein, 1982, Bundesanstalt Gumpenstein, Iradning.

Wahbi, A. (1986). Varietal variation in root growth and its influence on water use. Ph.D. thesis, University of Reading, UK.

Wahbi, A., and P. J. Gregory (1989). Genotypic differences in root and shoot growth of barley (Hordeum vulgare) II. Field studies of growth and water use of crops grown in Northern Syria. Experimental Agriculture 25: 389-399.

Wahbi, A., and M. Kamh (2000). Possible role of root exudates in the mobilization of phosphorus by maize and white lupin cultivars. Presented in Mediterranean Conference of Rhizobiology "Symbiotic Nitrogen Fixation for Mediterranean Areas". Organized by Institut National de la Recherche Agronomique Centre (INRA) Montpellier, France, July 9-13, 2000.

Wander, M. M., and G. A. Bollero (1999). Soil quality assessment of tillage impacts in Illinois. Soil Sci. Soc. Am. J. 63:961–971.

Wulfsohn, D., Y. Gu, A. Wulfsohn, and E. G. Mojlaj (1996). Statistical analysis of wheat root growth patterns under conventional and no-till systems. Soil Tillage Res. 38:1–16.

Lasting Benefits from No-Tillage Systems: Erosion Control and Soil Carbon Sequestration

Rachid Mrabet

National Institute of Agricultural Research (INRA)

Regional Agricultural Research Center of Meknes

P.O. Box 578 Meknes 50000 Morocco

rachidmrabet@yahoo.co.uk; Phone: +21235300243; Fax: +21235300244

Abstract

Human nourishment and welfare are entangled with the judicious exploitation of natural resources (soil, water, biodiversity). In addition, agricultural production is certainly linked with the future of the environment. To avert land degradation (and desertification) and stop the conversion of unsustainable land, the soil productivity balance must be shifted from degrading to aggrading processes. This is possible only through new technological innovations that alleviate production constraints, bring about quantum amelioration in production, and prevent further decline in soil (land) productivity. In other terms, the world's agriculture is undergoing a paradigm shift from the conventional age to conservation era. All countries around the world are putting their resources and efforts into agricultural transformations to guarantee economical development and prosperity as well as to enrich the agricultural society. No-tillage (NT) systems are ultimate ways to succeed in this shift and movement. No-tillage, an agricultural system where soil is disturbed only at seeding, represents the most remarkable change in soil management and ecology in modern history of agriculture. It is also the oldest crop production system used by humans. While at the beginning it was thought that NT would only work under specific climates and soils and for certain crops, through the years NT has been shown to work in all kind of environments. The USA, Brazil, Argentina, Canada and Australia are the leading countries with the largest areas of no-tillage. Worldwide, NT systems are being adopted on more than 95 million ha. Adoption and acceptance of NT are rapid because of inherent environmental (soil and moisture conservation, carbon capture and sequestration and improved soil quality) and socio-economical (reduced labor, fuel, energy and equipment requirements and higher yields) benefits. In this paper, the well recognized positive effects of no-tillage associated residue management on erosion reduction and control are discussed in depth. NT systems are urgently needed where lands are subject to wind and water erosion. The other co-benefits are mainly carbon capture and sequestration in soils. In light of the available research agenda, NT agriculture can make an effective and sustainable contribution to the solution of agro-environmental problems. NT systems, in contrast to plow-based tillage systems, prevent and eventually reverse these ominous declines, due largely to alteration of soil functions and processes. A comprehensive study of the behavior of soils under NT led to the conclusion that these systems helped to improve soil cohesion and aggregation, to enrich soil nutrient pools, and to rehabilitate biological, physical and hydrodynamic characteristics of the soil. These later characteristics have co-effects on soil development. It is, however, important to conclude that conditions where the technology does not work are rare and can be overcome by using suitable equipment, skill, and knowledge.

Keywords: Soil conservation, carbon sequestration, erosion control, soil quality, no-tillage, crop residues.

1. Background & Definitions

Human nourishment and welfare are entangled with the judicious exploitation of natural resources (soil, water, biodiversity). Land degradation, caused by soil erosion, is a major threat to sustainable agricultural land use, causing serious and costly environmental deterioration (FAO, 2001b). In other terms, erosion is the most significant agricultural problem for soil conservation throughout the world. In fact, three types of erosion are defined and may co-exist on the land area. These are tillage, wind, and water erosion where erosion implies soil movement by external forces. In spite of the large amount of scientific research publications explaining and simulating erosion processes, there is still a strong belief that the soil has to be loosened by tillage to increase water infiltration and reduce runoff.

Almost any area where crops are grown has to deal with soil erosion and fertility depletion. However, carbon emission and erosion, forms of land production capacity loss, are not always readily visible on cropland because farming operations may mask their signs.

Visible tillage induced erosion is a severe problem and can cause an irreversible situation of soil degradation when inappropriately used in the field. In other terms, the utilization of inadequate technologies that are not adapted to site specific conditions (slope, rainfall intensities, and cropping system) results in runoff, soil erosion, and land degradation. In fact, mechanical tillage may cause complete desertification that includes soil denudation, a decrease of effective rooting volume, depletion of nutrient capital and a reduction of water holding capacity (Unger et al., 2006).In addition to making agricultural land unproductive, erosion and runoff result in the deposition of soil particles and solutes in unwanted remote areas (sedimentation of roads, creeks, rivers, lakes, and dams) with all its depressing consequences for traffic, the production of electricity, and the delivery of drinking water. This results in important costs for the government (FAO, 2001a) as well as for society in general (Uri et al., 1998; Uri, 1999). Uri et al. (1998) estimated that the benefits of reducing losses from sheet, rill and wind erosion for the United States from the existing areas under conservation tillage ranged from US$90.3 million to US$288.8 million in 1996. Pimentel et al. (1995) estimated the worldwide cost of soil erosion to be US$400 billion per year. According to Laflen and Roose (1998), soil erosion is a threat to the long-term sustainability of mankind in all regions of the globe. Hence, erosion protection and the associated conservation of nutrients, organic matter, soil water holding capacity and biota should be of significant concerns worldwide. Effective and efficient soil erosion control measures should involve four interacting aspects: social, economic, ecological and agronomic. Among pertinent measures that fulfil these requirements are conservation tillage systems, particularly no-tillage technology (Papendick, 1997; FAO, 2001b).

Conservation tillage, by most definitions, embraces crop production systems involving the management of surface residues (Table 1). It excludes conventional tillage operations that invert the soil and bury crop residues (Phillips et al., 1980).

Parr et al. (1990) defined conservation tillage as any tillage or planting system in which at least 30% of the soil surface is covered by plant residue after planting to reduce erosion by water. Where soil erosion by wind is the primary concern, the term refers to any system that maintains at least 1120 kg/ha flat, small grain residue equivalent on the surface throughout the critical wind erosion period. Figure 1 shows that erosion is reduced by at least 50 percent (compared to bare, fallow soil) when 30% of the surface is covered with residue.

The no-till system is a specialized type of conservation tillage consisting of a one-pass planting and fertilizer operation in which the soil and the surface residues are minimally disturbed (Parr et al., 1990). The surface residues of such a system are of critical importance for soil and water conservation. Weed control is generally achieved with herbicides or in some cases with crop rotation.

Table 1: Crop residue management and tillage system definitions

Unmanaged crop residues	Crop residue management			
Intensive or conventional tillage	Reduced or ini-mum tillage	Conservation tillage systems		
		Mulch tillage	Ridge tillage	No-tillage or direct seeding
Moldboard plow or other intensive	No use of mold-board plow and intensity of tillage reduced	Full-width tillage, but further decrease in tillage intensity	Only the tops of ridges are tilled	No tillage performed since harvest of previous crop
<15% residue cover remaining	15-30% residue cover remaining	30% or greater residue cover remaining on soil surface after planting		

2. No-tillage systems: general situation worldwide

No-tillage is presumed to be the oldest system of soil management. However, tillage as symbolized by the moldboard plow became almost synonymous with modern agriculture (Lal et al., 2007). Although there were many ancient attempts to cultivate crops without tillage, modern no-tillage research started in the 1940s and adoption by farmers in the early 1960s. No-tillage, a system which originated from US farm development, is the ultimate technology of modern history. The system has spread in various regions worldwide with contrasting soil, climate, crop and cropping systems (Dumanski et al., 2006). More than 95 million ha of land are under no-tillage systems. According to 2005 statistics, the countries in the world with the largest areas under no-tillage are the USA with 25.3 million hectares followed by Brazil with 23.6 million ha, Argentina with 18.3 million ha, Canada with 12.5 million ha, Australia with 9 million ha and Paraguay with 1.7 million ha of the technology being practiced by farmers (Derpsch, 2005). About 1 million ha are under no-tillage systems in countries of European Union and almost twice that area in Asia.

According to data gathered by the German agronomist Rolf Derpsch, who has promoted no-tillage systems in South America since the 1970s, approximately 47% of the zero tillage technology is practiced in South America, 39% in the United States and Canada, 9% in Australia and about 3.9% in the rest of the world. According to Derpsch (2005), while at the beginning it was thought that no-tillage would only work under certain climates and soils, it has become clear that the technology can be practiced successfully in a wide range of climatic, soils and geographic conditions. No-tillage cropping systems have worked from the Equator, e.g., Kenya and Uganda, to a latitude of 40º S, e.g., Argentina and Chile, to 60º N, e.g., Finland; from sea level to 3000 m, e.g. Bolivia and Colombia; in soils with 90% sand, e.g., Australia and Paraguay, to 85% clay e.g., Brazil and Paraguay, from 200 mm of rain, e.g., Western Australia, to 2000 mm of precipitation, e.g., Brazil, or 3000 mm, e.g., Chile. Through the years, no-tillage has been shown to work in all kind of environments. Conditions where the technology does not work are rare and often limiting conditions can be overcome by using appropriate technologies.

1- Although No-tillage was initially tested in the United Kingdom, it was the United States of America who adopted and further developed it in the early 1960s.

2- Between 1991 and 2004, Brazil increased its grain production from 57.8 million tons to 125 million tons from a cultivated area of 42 million hectares, 22 million of which was under no-tillage systems.

3. No-tillage systems: Is there any permissible level of erosion and contamination?

Soil degradation is the single most important threat to global food production and security. Occurrence of erosion can be considered the most important factor causing soil degradation. Under the concept of sustainability, the first negative factor in relation to productivity and profitability, and the major aggressor of the environment is soil erosion. Consequently, economic sustainability can only be achieved if soil erosion is minimized. (Stopped completely is probably not feasible.) Schematically, soil erosion has four effects on croplands: enhanced carbon and nutrient loss, decreased water storage capacity, increased crop damage, and reduced farm ability.

Wind and water erosion are the main forms of degradation, and conservation tillage systems (including no-tillage) represent effective methods for controlling this problem (den Biggelaar et al., 2004a, b). The benefits of crop residues (surface and standing) for protecting the soil against erosion are well documented (Holland, 2004; Unger, 1994). In fact interest in no-tillage systems has increased in response to the need to limit erosion and promote water conservation. Control of soil erosion is still one of the main driving forces for no-tillage adoption. As pointed out by Baker et al. (1996), no technique yet devised by mankind has been anywhere near as effective at halting soil erosion and making food production truly sustainable as no-tillage.

No-tillage systems effectively halt soil erosion by providing a protecting layer to the soil surface, increasing resistance against overland flow, and enhancing soil surface aggregate stability and permeability through its combined physical and biological effects. The resulting reduction in soil erosion is impressive and has been repeatedly observed both in temperate and tropical environments. According to Fryrear & Bilbro (1994) crop residues are the main line of defense against wind erosion damage of agricultural lands.

According to Alberts & Neibling (1994), crop residues cause significant reductions in inter-rill and rill erosion. Erosion declines asymptotically to zero as cover increases (Figure 1). A near complete soil cover can conceivably almost eliminate soil erosion by both water and wind (Lal, 1997). In fact, in controlling erosion, no-tillage residue cover acts to increase rainfall interception, decrease soil sealing, increase time to runoff initiation, decrease peak and equilibrium runoff rates, and decrease sediment concentrations through a reduction in raindrop and concentrated flow energy (Figure 1). The benefits of crop residues (surface and standing) for protecting the soil against erosion are well documented in USA, Brazil, Canada, Australia, Italy, Spain and many other countries but not in south Mediterranean and Middle East countries (Ryan et al., 2006).

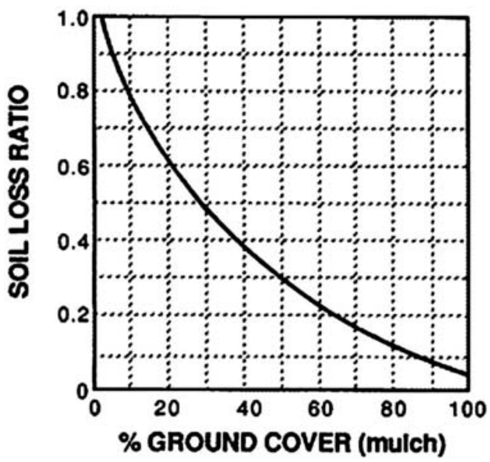


Figure 1: The effect of percent ground cover by residue (mulch) on the soil loss ratio (compared to a bare, fallow soil) (McCarthy et al., 1993).

It can be anticipated that with time, beneficial effects of NT on soil conservation and runoff control in North African and Middle East countries will result from the improvement of aggregate stability and organic matter accumulation. Maintenance of residue at the soil surface will certainly decrease the impact of erosion rainfall (Ryan et al., 2006). Research has shown that soil cover is the most important factor that influences water infiltration into the soil, thus reducing runoff and erosion. The concept of no-till system symbolizes ecological principles and services of negligible or no soil manipulation, continuous preservation of vegetal and/or mulch cover on the soil surface, reinforcement of natural processes that improve soil structure and recycle nutrient elements through the activity and species diversity of soil microflora and fauna, and maintaining and/or enhancing soil organic matter content. NT systems alter the entire soil ecology including a profound water conservation effect, a reduction of temperature oscillations and evaporation, an amelioration of organic matter stocks, and a creation of favorable soil habitat, biota activity, and availability of nutrients pools. These improvements in soil ecology provide barriers to runoff and erosion and facilitate water entry and movement into soils.

Water capture, the first step in soil water storage, is often limited by the water infiltration rate. Under conventional agriculture where soils are manipulated with tillage implements, many high-intensity storms exceed the soil's water infiltration capacity and water ponding and/or runoff occurs. Both result in water loss. Judicious management of crop residues can help ameliorate these water-loss problems. According to Shaver et al. (2002), no-tillage cropping systems that produce more biomass and return more residue to the soil surface have: (1) decreased bulk density; (2) increased porosity; (3) increased sorptivity; (4) increased overall soil aggregate size distribution; and (5) improved overall system water capture and storage.

A no-tillage system not only reduces erosion to a minimum, but also substantially increases the proportion of rainfall that infiltrates into the soil (Figure 2). Furthermore, the runoff from NT areas is clear and contains less solutes than that from cultivated soils. Lower surface runoff implies less flood damage, greater aquifer recharge, and a cleaner environment.

According to field studies conducted on small watersheds under natural rainfall on highly erodible land, erosion rates of land tilled with a moldboard plow were reduced by 70 percent or more with no-tillage (USDA, 1997). These same studies reported that surface residues help intercept nutrients and chemicals and hold them in place until they are used by the crop or degraded into harmless components, which provide cleaner surface runoff (Wagenet, 1987). Other studies under field conditions indicate that while the quantity of water runoff from no-till fields was variable depending on the frequency and intensity of rainfall, clean-tilled soil surfaces produce substantially more runoff (Edwards, 1995). Average herbicide runoff losses from treated fields under no-till and mulch-till systems for all products and all years were about 30 percent of the runoff levels from moldboard-plowed fields (Fawcett et al., 1994). Fawcett (1995) reported results that water runoff was reduced by 30 percent for a no-till treatment compared to a conventionally tilled treatment and that water quality was enhanced.

Crop residues on the soil surface, by creating tiny dams, enhance infiltration, reduce surface crust formation, and slow water runoff, which increases water infiltration and soil moisture (Edwards, 1995). The channels or bio-macropores created by earthworms and old plant roots, when left intact with no-tillage, improve infiltration to help reduce or eliminate field runoff and provide water quality benefits.

Combined with reduced water evaporation from the top few cm of soil and with improved soil characteristics, the higher level of soil moisture can contribute to higher crop yields in many cropping and climatic situations (Mrabet, 1997). Continuous no-tillage improves soil structure by increasing soil particle aggregation (small soil clumps), aiding water movement through the soil so plants expend less energy to establish roots (Mrabet, 2006). No-tillage practices increased rain infiltration and minimized runoff and these are important to increase water use efficiency (Ruan et al., 2001).

According to Lang and Mallet (1984), the increase of infiltration was curvilinearly related to the ground-cover percentage, and the infiltration was 54% greater with 45% residue cover than without residue cover. Baumhardt and Lascano (1996) found that cumulative infiltration was lowest (28.7 mm) on bare soil, and increased curvilinearly with increasing residue amounts, leveling off at 49 mm. The leveling off (asymptotic limit) occurred at a residue amount of 2.4 t/ha.

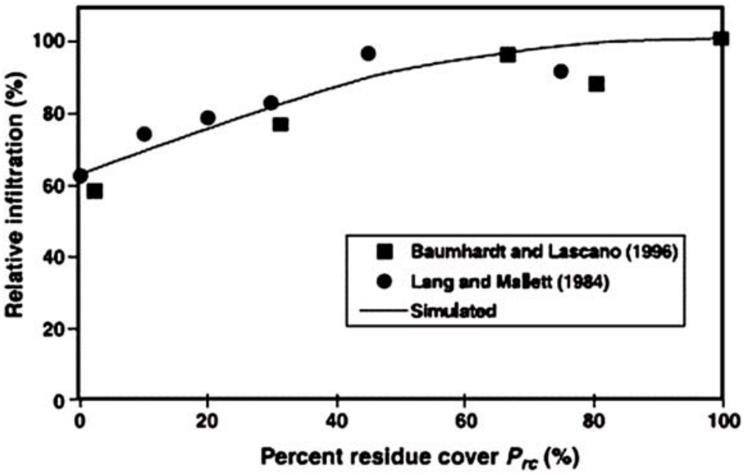


Figure 2: Water capture as a function of biomass retention under no-tillage systems (Ruan et al., 2001).

The presence of increased crop residue usually reduces the volume of contaminants entering surface waters by constraining runoff (including dissolved chemicals and sediments) and enhancing infiltration (Baker, 1987).

Enhanced water infiltration associated with greater surface residue provides additional soil moisture to benefit crops during low rainfall periods, but raises concerns about potential leaching of nitrates and pesticides to shallow ground water (Wauchope, 1987). However, increased volume of infiltration normally dilutes the concentration level of contaminants in the percolate to groundwater. Scientific evidence suggests that, under normal climatic and hydrologic conditions, conservation tillage systems are no more likely to degrade ground water quality than other tillage systems (Onstad and Voorhees, 1987).

4. Carbon sequestration & dynamics in no-till soils

Carbon dynamic in the soil is attracting considerable research effort given its implication in terms of global climate change. Soil organic matter (SOM) is the most reported soil attribute from tillage experiment, since it is the keystone soil quality indicator, being inextricably linked to other soil properties. Carbon sequestration can be defined as the capture and secure storage of carbon that would otherwise be emitted to or remain in the atmosphere (FAO, 2000). The idea is to (i) prevent carbon emissions produced by human activities from reaching the atmosphere by capturing and diverting them to secure storage, or (ii) remove carbon from the atmosphere by various means and stores it. Agricultural carbon dioxide emissions have led to an increase in their concentration in the atmosphere. Carbon sequestration in soils is one of the three technological approaches to reduce these emissions (IPCC, 1996). Carbon sequestration in soils is based on the assumption that fluxes or movements of carbon from the air to the soil can be increased while the release of soil carbon back to the atmosphere is decreased. Instead of being a carbon source, soils could be transformed into carbon sinks, absorbing carbon instead of emitting it. This approach relies on the main natural processes that control the carbon cycle: photosynthesis, through which carbon from the air is converted into organic material, and respiration, through which carbon is returned to the atmosphere. Soil organic matter contributes to the productivity and physical properties of soils, which are benefits of carbon sequestration. Sequestering carbon in soils is often seen as a 'win–win' proposition; it not only removes excess CO_2 from the air, but improves soils by augmenting organic matter, an energy and nutrient source for biota (Janzen, 2006). The soil organic carbon (SOC) pool in the top 1-m depth of world soils ranges between 1462 and 1576 Pg. It is nearly three times that in the aboveground biomass and approximately double that in the atmosphere (Lal et al., 1995). Generally, tillage of soils decreases soil organic matter content and enhances the flux of carbon dioxide from soils (Reicosky et al., 1997). Recent estimates of the near-term potential for sequestration in agricultural soils globally are 400-900 MT carbon yr-1 (Lal, 1997). Consequently, a sizeable carbon sequestration potential exists over the long-term when lands are converted to less invasive soil management systems (i.e., no- and mulch tillage systems) (Bell et al., 2003).

The need for agricultural involvement in greenhouse gas mitigation has been widely recognized since the 1990s. As a result, the movement for sustainable agriculture is growing in momentum throughout the world (Brundtland, 1988). Moreover, policymakers have included the usage of C sinks for mitigation purposes in international negotiations, as set forth in the Kyoto Protocol (Article 3.3 and 3.4, UNFCCC (1997) & Smith (1999)) and Marrakech Accords.

At the Marrakech meeting of the COP-7, sequestering atmospheric C in agricultural soils was advocated as a possibility to partially offset fossil-fuel emissions (Smith, 2004). Such an endeavor requires a paradigm shift in our thinking of soil and its management. Rapidly rising concentrations of atmospheric CO_2 have prompted a flurry of studies on soils as potential carbon sinks. The conservation of sufficient SOM levels is crucial for biological, chemical and physical soil functioning in both temperate and tropical ecosystems. Appropriate levels of SOM ensure soil fertility and minimize agricultural impact on the environment through sequestration of carbon, reducing erosion and preserving soil biodiversity (Six et al., 2002). Soil carbon sequestration can be accomplished by management systems that add high amounts of biomass to the soil, cause minimal soil disturbance, conserve soil and water, improve soil structure, and enhance soil fauna activity. Continuous no-till crop production is a prime example (Table 2). Interest in carbon sequestration is increasing because of potential climate changes resulting from accumulations of atmospheric carbon dioxide and other greenhouse gases. Potential regulation of greenhouse gas emissions in addition to consumer interest to purchase environmentally friendly products will provide incentives for developing efficient sequestration techniques. Agricultural practices can render a soil either a sink or a source of atmospheric CO_2, with a direct influence on the greenhouse effect. Among pertinent advantages of no-tillage is reduction of carbon dioxide emission and enhancement of carbon sink of soils. Recently, the importance of soils in contributing to greenhouse effect gained momentum. Increasing soil organic matter is important because soils can be a large global carbon sink and contribute to a reduction of atmospheric CO_2 (Reicosky, 2001, Lal, 1997). Soil organic matter represents a major pool of carbon within the biosphere and it is the storehouse of all nutrients (Baldock and Nelson, 2000). In addition, SOM offers to the soil a resistance to slaking, crusting and hence to structural degradation. SOM, and mainly its light fraction, is directly related to aggregation of soils (Dalal and Bridge, 1996; Bessam and Mrabet, 2001, 2003). First conceived as an efficient soil conservation method, no-tillage has evolved to an economic and sustainable production system that not only improves soil physical, chemical and biological characteristics, but also improves the environment by reducing the emission of greenhouse gases. The impact of no-tillage practices on carbon sequestration has been of great interest in recent years. The literature is replete with studies that show an increase in soil organic carbon (SOC) stock with conversion to NT, at least in the surface soil (Dick et al., 1997a,b; Mrabet et al., 2001). NT impacts SOC stock in two ways: (i) by reducing disturbance which favors the formation of soil aggregates and protects SOC encapsulated inside these stable aggregates from rapid oxidation (Six et al., 2000) and (ii) by modifying the local edaphic environment: bulk density, pore size distribution, temperature, water and air regime that might also restrict SOC biodegradation (Kay and VandenBygaart, 2002). Paustian et al. (1998) and Lal et al. (1998) summarized the rate of accumulation of SOC stock under NT at 300–800 kg SOC /ha/year.

Based on US average crop inputs, no-till emitted less CO2 from agricultural operations than conventional tillage, with 137 and 168 kg C/ha/yr, respectively (Paustian et al., 1997). It has been argued that widespread adoption of conservation tillage within the United States could sequester 24 - 40 Mt C/yr (Lal et al., 2003).

Results from semiarid Alberta (Canada) by Larney et al. (1997) suggested that although relative increases in soil organic matter were small, increases due to adoption of NT were greater and occurred much faster in continuously cropped than in fallow-based rotations. Hence, intensification of cropping practices, by elimination of fallow and moving toward continuous cropping, is the first step toward increased C sequestration. Reducing tillage intensity, by the adoption of NT, enhances the cropping intensity effect. The stratification of soil properties is an important effect of no-tillage systems (Mrabet, 2002) that could potentially be used as an indicator of soil quality (Franzluebbers, 2002). Stratification of SOC is common with no-tillage. Zibilske et al. (2002), in a semi-arid region of Texas, demonstrated that the organic carbon concentration was 50% greater in the top 4 cm of soil of a no-tillage experiment compared with plowing, but the difference dropped to just 15% in the 4 - 8-cm depth zone. This is typical of organic carbon gains observed with conservation tillage in hot climates. Bayer et al. (2001), working on a sandy clay loam Acrisol, also found that the increase in SOC was restricted to the soil surface layers under no-tillage but that the actual quantity depended on the cropping system. Similar to the merits of no-tillage reported in North America, Brazil and Argentina (Lal, 2000; Sa et al., 2001), several studies have reported the high potential of carbon sequestration in European soils (Holland, 1994; Smith et al., 2000a,b). Smith et al. (1998) estimated that adoption of no-tillage has the potential to sequester about 23 Tg C /yr in the European Union or about 43 Tg C/yr in the wider Europe including the former Soviet Union. In addition to enhancing SOC pool, up to 3.2 Tg C/yr may also be saved by reducing agricultural fossil fuel emissions. Smith et al. (1998) concluded that 100% conversion to no-tillage agriculture could mitigate all fossil fuel C emission from agriculture in Europe. This is also possible in West Asia and North Africa region (Lal, 2002). Changing from conventional tillage to no-till is estimated to both enhance C sequestration and decrease CO_2 emissions (West and Marland, 2002; West and Post, 2002). The benefits of NT systems on carbon sequestration may be soil/site specific, and the improvement in soil organic matter may be inconsistent in fine textured and poorly drained soils (Wander et al., 1998). This is not the case of clay soils of Morocco (Mrabet et al., 2001).

Table 2: Carbon sequestration under conservation agriculture in selected regions

Measure No-tillage	Region	Potential soil carbon sequestration rate (t C /ha/yr)	Reference
	Canada	0.07-0.14	Smith et al. (2000a,b)
		0.16	Janzen et al. (1998)
	Europe	0.3-0.4	Freibauer et al. (2004)
Conservation tillage	Australia, Canada, USA	0.2-0.4	Watson et al. (2000)
	Drylands	0.1-0.2	Lal (1999)
	Europe	< 0.4	Freibauer et al. (2004)
	Tropical areas	0.2-0.5	Lal (1999)
Conservation agriculture	Drylands	0.15-0.3	
	Tropical areas	0.3-0.8	
Elimination of Fallow	Canada	0.17-0.76	Watson et al. (2000)
	Drylands	0.05-0.1	Lal (1999)
Mulch farming and cover crop	Tropical areas	0.1-0.3	
	Europe	0.2-0.7	Freibauer et al. (2004)

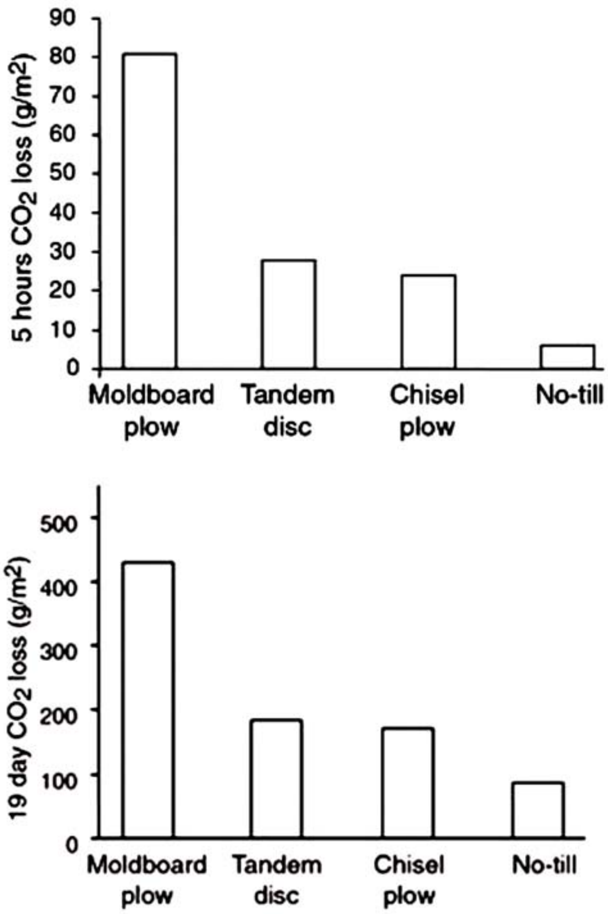


Figure 3: CO_2 emissions over 5 and 19 days following different tillage methods (Reicosky and Lindstrom, 1993).

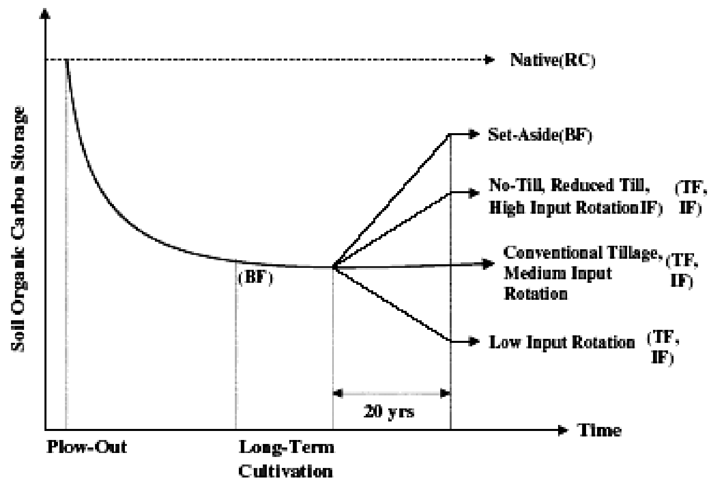


Figure 4: Conceptual framework for the IPCC method. Long-term cultivation causes substantial losses of SOC from the amounts found under native vegetation. Changing tillage, cropping system or set-aside land from crop production are management activities that can alter the long-term loss of soil organic carbon in agricultural lands (Ogle et al., 2005). RC = reference factor, BF = base factor, TF = tillage factor, IF = Input factor.

Based on an analysis of IPCC using the method of Ogle et al. (2005), agricultural lands can potentially sequester carbon and mitigate greenhouse gas emissions through adoption of reduced and no-till management, use of high C input rotations that include hay, legumes, pasture, cover crops, irrigation or organic amendments, setting aside lands from cropland production, and through cropping intensification (Figure 4).

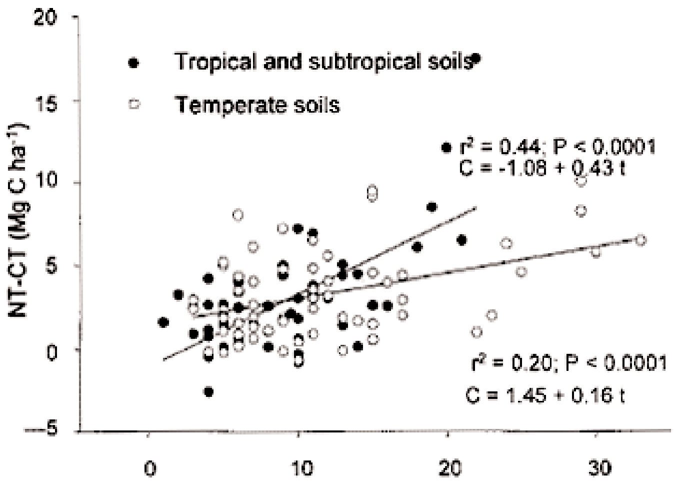


Figure 5: Carbon sequestration under no-tillage (NT) compared to conventional tillage (CT) with time in (sub) tropical and temperate soils (Six et al., 2002).

Six et al. (2002) found that with an increase in years under NT, both tropical and temperate soils had an increasing SOC stock compared with CT (Figure 5). Based on results presented in this figure, implementation of no-tillage led to the largest increases in soil organic carbon storage under tropical moist conditions and the smallest increases under temperate dry conditions.

5. Conclusions

This paper was prepared to review the relationships between continuous application of no-tillage systems and environmental benefits and services provided by these systems (principally erosion control and carbon sequestration). Changes in available crop residue, soil management, and technological inputs enable agriculture to reduce soil losses and to begin restoring and sequestering soil organic matter.

The literature overwhelmingly supports success of no-tillage practices in achieving reduction of soil erosion and runoff. This brief review helped re-confirm that no-tillage management reduces the potential for soil erosion by mitigating the effects of wind and water on soil movement. In fact, the efficiency of no-tillage for reducing soil erosion and improving water storage is universally recognised. One of the main options for greenhouse gas mitigation identified by the IPCC is the sequestration of carbon in soils. Consequently, this review identified that no-tillage system is one of the most efficient practices for sequestering C in cropland. It is also important to conclude the synergic benefits of reducing soil erosion, halting degradation and restoring soil ecology through build-up of organic matter content. These benefits have been well documented (Ogle et al., 2005), and are in themselves sufficient to justify the promotion of no-tillage strategies.

No-tillage systems leave substantial amounts of crop residue evenly distributed over the soil surface. This reduces soil erosion by wind and reduces the kinetic impact of rainfall, surface sediment transport, and water runoff. As a result, water infiltration and moisture retention are increased. Increased organic matter in the surface layer of soil results in cleaner runoff, and thus benefits water quality by reducing the flow of contaminants such as sediment and adsorbed/dissolved chemicals into reservoirs, lakes and streams. Increased surface residues also filter and trap sediment and sediment-adsorbed chemicals (fertilizers and pesticides) and result in cleaner runoff.

Elimination of tillage prevents and eventually reverses soil organic matter decline, due largely to the accumulation of plant residues on the soil surface. This is responsible for increased carbon storage and reduced exchange of gas and energy between the soil surface and the atmosphere. Therefore, NT provides more favorable conditions than mechanical tillage for sequestering carbon and tapping the soil's potential to serve as a sink for atmospheric C. This study, by analyzing selected works around the world about trends in evolution of erosion and carbon dynamics, support the need to shift to NT.

As a summary, no-tillage based sustainable agro-ecosystems aim to conserve soil and sequester soil organic matter which supports crop growth by providing the fuel (i.e., the carbon-containing compounds) and nutrients that drive soil nutrient cycles and other microbial processes that maintain soil productivity.

References

Alberts, E.E. & Neibling, W.H. (1994). Influence of crop residues on water erosion. In: Unger, P.W. (Ed). Managing agricultural residues. Lewis Publishers. pp: 20-39.

Baker, C.J., Saxton, K.E. & Ritchie, W.R. (1996). No-tillage Seeding, Science and Practice. CAB International, Wallingford, Oxon, UK, 158 pp.

Baker, J. L. (1987). Hydrologic Effects of Conservation Tillage and Their Importance to Water Quality. In Logan, T.J. et al. (eds.) Effects of Conservation Tillage on groundwater Quality: Nitrates and Pesticides. Lewis Pub., Chelsea, MI, pp. 113-124.

Baldock, J.A., & Nelson, P.N. (2000). Soil organic matter. In Handbook of soil science. Sumner, ME (ed). CRC Press, Boca Raton, USA. B-25-71.

Bayer, C., Martin-Neto, L., Mielniczuk, J., Pillon, C.N., & Sangoi, L. (2001). Changes in soil organic matter fractions under subtropical no-till cropping systems. Soil Sci. Soc. Am. J. 65:1473–1478.

Bell, J.M., Smith, J.L., Bailey, V.L. & Bolton, H. (2003). Priming effect and C storage in semi-arid no-till spring crop rotations. Biol. Fertil. Soils. 37:237-244.Bessam, F. & Mrabet, R. (2001). Time influence of no tillage on organic matter and its quality of a vertic Calcixeroll in a semiarid area of Morocco. In proceedings of I World Congress on Conservation Agriculture. Garcia-Torres et al. (eds). Madrid, Spain. October 1-5, 2001. pp: 281-286.

Bessam, F. & Mrabet, R. (2003). Long-term changes in soil organic matter under conventional and no-tillage systems in semiarid Morocco. Soil Use & Management. 19:139-143.

Brundtland, G. H. (1988). Our Common Future. World Commission on Environment and Development, Geneva, Switzerland.

Baumhardt, R.L. & Lascano, R.J. (1996). Rain infiltration as affected by wheat residue amount and distribution in ridged tillage. Soil Sci. Soc. Am. J. 60:1908–1913.

Dalal, R.C., & Bridge, B.J. (1996). Aggregation and organic matter storage in sub-humid and semi-arid soils. In: Structure and organic matter storage in agricultural soils. Carter M.R. &

Stewart, B.A (eds). CRC Press, Boca Raton, FL. Pp: 263-307

den Biggelaar, C., Lal, R., Wiebe, K., & Breneman, V. (2004a). The global impact of soil erosion on productivity I: Absolute and relative erosion-induced yield losses. Adv. Agron. 81: 1–48.

den Biggelaar, C., Lal, R., Wiebe, K., Breneman, V. & Reich, P. (2004b). The global impact of soil erosion on productivity II: Effects on crop yields and production over time. Adv. Agron. 81:49–95.

Derpsch, R. (2005). The extent of Conservation Agriculture adoption worldwide: Implications and impact. III World Congress on Conservation Agriculture: "Linking Production, Livelihoods and Conservation", 3rd to 7th October 2005, Nairobi, Kenya. 15p.

Dick W.A. & Durkalski J.T. (1997a). No-tillage production agriculture and carbon sequestration in a typic fragiudalf soil of northeastern Ohio. In: Lal R. et al. (eds), Advances in Soil Science: Management of Carbon Sequestration in Soil. CRC Press, Boca Raton, FL, pp. 59–71.

Dick W.A., Edwards W.M. & McCoy E.L. (1997b). Continuous application of no-tillage to Ohio soils: Changes in crop yields and organic matter-related soil properties. In: Paul E.A. et al. (eds), Soil Organic Matter in Temperate Agroecosystems: Long-term Experiments in North America. CRC Press, Boca Raton, FL, pp. 171–182.

Dumanski, J., Peiretti, R., Benites, J., McGarry, D. & C. Pieri. (2006). The paradigm of conservation tillage. Proc. World Assoc. Soil and Water Conserv., P1: 58-64.

Edwards, W. M. (1995). Effects of Tillage and Residue Management on Water for Crops. In Crop Residue Management to Reduce Erosion and Improve Soil Quality: Appalachia and Northeast Region. Blevins, R.L. & Moldenhauer, W.C. (eds.), U.S. Dept. Agr., Agr. Res. Serv., Conservation Research Report No. 41.

Fawcett, R.S., Tierney, D.P., & Christensen, B.R. (1994). Impact of Conservation Tillage on Reducing Runoff of Pesticides into Surface Waters, Journal of Soil and Water Conservation. 49(2): 126-135.

Fawcett, R. S. (1995). Agricultural tillage systems: Impact of Conservation tillage on pesticide runoff and leaching. In Farming for a Better Environment. Soil and Water Conservation Society, Ankeny, IA.

FAO (2000). Carbon Sequestration Options Under the Clean Development Mechanism to Address Land Degradation. World Soil Resources Reports 92. FAO and IFAD, Rome

FAO (2001a). The Economics of Conservation Agriculture. 73p.

FAO (2001b). Conservation agriculture. Case studies in Latin America and Africa. FAO Soils Bulletin 78.

Franzluebbers, A.J. (2002). Water infiltration and soil structure related to organic matter and its stratification with depth. Soil Till. Res. 66:197–205.

Freibauer, A., M. D.A. Rounsevell, P. Smith & J. Verhagen. (2004). Carbon sequestration in the agricultural soils of Europe. Geoderma 122:1 –23

Fryrear, D. W. & Bilbro, J.D. (1994). Wind erosion control with residues and related practices. In Unger, P.W. (ed). Managing agricultural residues. Lewis Publishers. pp: 8-17.

Holland, J.M. (2004). The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. Agriculture Ecosys. Environ. 103:1–25.

IPCC (1996). Climate Change 1995. The science of climate change. The contribution of working

Group I to the second assessment report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.

Janzen, H.H., Campbell, C.A., Gregorich E.G. & Ellert, B.H. (1998). Soil carbon dynamics in Canadian agroecosystems. In. Lal, R. et al. (eds). Soil processes and the carbon cycle. CRC Press. Boca Raton. FL. pp: 57-80.

Janzen, H.H. (2006). The soil carbon dilemma: Shall we hoard it or use it? Soil Biology & Biochemistry. 38: 419-424.

Kay, B.D. & VandenBygaart, A.J. (2002). Conservation tillage and depth stratification of porosity and soil organic matter. Soil Till. Res. 66:107–118.

Laflen J.M. & Roose E.J. (1998) Methodologies for assessment of soil degradation due to water erosion. In: Lal, R. et al. (Eds.). Methods for assessment of soil degradation, Advances in Soil Science, CRC Press, Boca Raton. pp: 31-55.

Lal, R., Kimble, J., Levine, E. & Whitman, C. (1995). World soils and greenhouse effect: An overview. In: Lal, R. et al. (eds.). Soils and global change. CRC Press, Inc. Boca Raton, Florida, MI., USA. pp. 1-7.

Lal, R. (1997). Residue management, conservation tillage and soil restoration for mitigating greenhouse effect by CO2 enrichment. Soil Till. Res. 43:81-107.

Lal, R., Kimble, J.M., Follett, R.F. & Cole, C.V. (1998). The Potential of U.S. Croplands to Sequester Carbon and Mitigate the Greenhouse Effect. Ann Arbor Press, Ann Arbor, MI, 128 pp.

Lal, R. (1999). Global carbon pools and fluxes and the impact of agricultural intensification and judicious land use. Prevention of Land Degradation, Enhancement of Carbon Sequestration and Conservation of Biodiversity through Land Use Change and Sustainable Land Management with a Focus on Latin America and the Caribbean. World Soil Resources Report 86. FAO, pp. 45– 52.

Lal, R. (2000). World cropland soils as a source or sink for atmospheric carbon. Advances in Agronomy 71:145–191.

Lal, R. (2002). Carbon sequestration in dryland ecosystems of West Asia and North Africa. Land Degradation & Development 13:45-59.

Lal, R., Follett, R.F. & Kimble, J.M. (2003). Achieving soil carbon sequestration in the United States: a challenge to policy makers. Soil Sci. 168:827–845.

Lal, R., Reicosky, D.C. & Hanson, J.D. (2007). Evolution of the plow over 10,000 years and the racional of no-till farming. Soil & Till. Res. 93:1-12.

Lang, P.M. & Mallett, J.B. (1984). Effect of the amount of surface maize residue on infiltration and soil loss from a clay loam soil. S. Afr. J. Plant Soil 1:97–98.

Larney, F. J., Bremer, E., Janzen, H.H., Johnston, A.M. & Lindwall, C. W. (1997). Changes in total, mineralizable and light fraction soil organic matter with cropping and tillage intensities in semiarid southern Alberta, Canada. Soil Till. Res. 42(4):229-240.

McCarthy, J.R., Pfost, D.L & Currence, H.D. (1993). Conservation Tillage and Residue Management to Reduce Soil Erosion. Univ. Missouri Extension Publ. G 1650.

Mrabet, R. (1997). Crop residue management and tillage systems for water conservation in a semiarid area of Morocco. Ph.D Dissertation. Colorado State University. Fort Collins, CO. USA.

220p.

Mrabet, R., N. Saber, A. El-Brahli, S. Lahlou & F. Bessam. (2001). Total, Particulate Organic Matter and Structural Stability of a Calcixeroll soil under different wheat rotations and tillage systems in a semiarid area of Morocco. Soil & Tillage Research 57:225-235.

Mrabet R. (2002). Stratification of soil aggregation and organic matter under conservation tillage systems in Africa. Soil Tillage & Research 66:119-128.

Mrabet, R. (2006). Soil quality and carbon sequestration: Impacts of no-tillage systems. Options Méditerranéennes 69:43-55.

Ogle, S.M, Breidt, F.J. & Paustian, K. (2005). Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions. Biochemistry. 72: 87–121

Onstad, C. A. & Voorhees, W. B. (1987). Hydrologic Soil Parameters Affected by Tillage. In Logan, T. J. et al. (eds.). Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides. Lewis Pub., Chelsea, MI.

Papendick, R.I. (1997). No till farming: The way of the future for a sustainability of agricultural production. Advances in GeoEcology. 31:1179-1186.

Parr, J.F., Papendick, R.I., Hornick, S.B. & Meyer, R.E. (1990). The use of cover crops, mulches and tillage for soil water conservation and weed control. In: Organic-matter Management and Tillage in Humid and Sub-humid Africa. IBSRAM Proceedings No.10. Bangkok: IBSRAM. pp. 246-261.

Paustian, K., Levine, E., Post, W.M. & Ryzhova, I.M. (1997). The use of models to integrate information and understanding of soil C at the regional scale. Geoderma 79:227-260.

Paustian, K., Cole, C.V., Sauerbeck, D. & Sampson, N. (1998). CO2 mitigation by agriculture: An overview. Climatic Change 40(1):135-162.

Phillips, R.E., Blevins, R.L., Thomas, G.W., Frye, W.W. & Phillips, S.H. (1980). No-tillage agriculture. Science 208: 1108–1113.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R. & Blair R. (1995). Environmental and economic costs of soil erosion and conservation benefits. Science 267:1117-1123.

Reicosky, D.C. & Lindstrom, M.J. (1993). Fall tillage method: Effect on short-term carbon dioxide flux from soil. Agron. J. 85:1237–1243.

Reicosky, D.C., J.L Hatfield, & .RL. Sass. (1997). Agricultural contributions to greenhouse gas emissions. In Climate change and Global crop productivity. Reddy, KR and HF Hodges (eds). CABI Publishing, pp: 37-54.

Reicosky, D.C. (2001). Conservation agriculture: global environmental benefits of soil carbon management. In Benites et al. (eds). First World Congress on Conservation Agriculture. Madrid, Spain. Pp: 3-12.

Ruan, H., Ahuja, L.R., Green, T.R. & Benjamin, J.G. (2001). Residue Cover and Surface-Sealing Effects on Infiltration. Numerical Simulations for Field Applications. Soil Sci. Soc. of Am. J. 65:853-861.

Ryan, J., de Pauw, E., Gomez, H. & Mrabet, R. (2006). Chapter 15 - Drylands of the Mediterranean Zone: Biophysical Resources and Cropping Systems. In Dryland Agriculture (2nd edition).

G.A. Peterson et al. (edts). American Society Agronomy Monograph N° 23. Pp: 577-624.

Sa, J.C.M., Cerri, C.C., Dick, W.A., Lal, R., Filho, S.P.V., Piccolo, M.C. & Feigl, B.E. (2001). Organic matter dynamics and carbon sequestration rates for a tillage chronosequence in a Brazilian Oxisol. Soil Sci. Soc. Am. J. 65: 1486–1499.

Shaver, T.M., Peterson, G.A., Ahuja, L.R., Westfall, D.G., Sherrod, L.A. & Dunn, G. (2002). Surface soil physical properties after twelve years of dryland no-till management. Soil Sci. Soc. Am. J. 66:1296-1303.

Six, J., Eliott, E.T. & Paustian, K. (2000). Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. Soil Bio. Biochem. 32: 2099–2103.

Six J., Feller, C., Denef, K., Ogle, S.M., Sa, J.C.M., & Albrecht, A. (2002). Soil organic matter, biota and aggregation in temperate and tropical soils - Effects of no-tillage. Agronomie 22:755-775.

Smith, P., Powlson, D.S., Glendining, M.J. & Smith, J.U. (1998). Preliminary estimates of the potential for carbon mitigation in European soils through no-till farming. Global Change Biology. 4(6): 679-685.

Smith, K.A. (1999). After Kyoto protocol: can scientists make a useful contribution? Soil Use and Management 15: 71- 75.

Smith, W.N., Desjardins, R.L. & Patty, E. (2000a). The net flux of carbon from agricultural soils in Canada 1970 – 2010. Global Change Biology. 6:557– 568.

Smith, P., Powlson, D.S., Smith, J.U., Falloon, P. & Coleman, K. (2000b). Meeting Europe's climate change commitments: quantitative estimates of the potential for carbon mitigation by agriculture. Global Change Biology. 6:525– 539.

Smith, P. (2004). Monitoring and verification of soil carbon changes under Article 3.4 of the Kyoto Protocol. Soil Use and Management. 20:264-270.

USDA (1997). Chapter 4.2: Crop Residue Management. Agricultural Resources and Environmental Indicators, 1996-97, AH-712. July. United States Department of Agriculture, Economic Research Service.

Unger, P.W. (1994). Managing agricultural residues. Lewis Publishers. 448p.

Unger, P.W., Fryrear, D.W. & Lindstrom, M.J. (2006). Soil conservation. In. G.A. Peterson et al. (eds). Dryland Agriculture 2nd ed. Agronomy Monograph N° 23. pp: 87-112.

UNFCCC (1997). Kyoto protocol to the United Nations Framework Convention on Climate Change. Document found at http://unfccc.int/resource/docs/convkp/kpeng.html.

Uri, N.D., Atwood, J.D., & Sanabria, J., (1998). The environmental benefits and costs of conservation tillage. Sci. Total Environ. 216:13–32.

Uri, N.D. (1999). Conservation tillage in US agriculture: environmental, economic and policy issues. New York, Haworth Press.

Wagenet, R. J. (1987). Processes Influencing Pesticide Loss with Water under Conservation Tillage. In Logan, T. J. et al. (eds.). Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides. Lewis Pub., Chelsea, MI, pp. 190-204.

Wander, M.M., Bidart, M.G. & Aref, S. (1998). Tillage impacts on depth distribution of total and particulate organic matter in three Illinois soils. Soil Sci. Soc. Am. J. 62:1704–1711.

Wauchope, R. D. (1987). Effects of Conservation Tillage on Pesticide Loss with Water. In T. J. Logan et al. (eds.). Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides. Lewis Pub., Chelsea, MI, pp. 201-215.

Watson, R.T., Noble, I.R., Bolin, B., Ravindranath, N.H., Verardo, D.J. & Dokken, D.J. (Eds.) (2000). Land Use, Land Use Change, and Forestry. Cambridge Univ. Press, Cambridge, UK.

West, T.O. & Marland, G. (2002). A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: comparing tillage practices in the United States. Agric., Ecosystems and Environment. 91(1-3):217-232.

West, T.O. & Post, W.M. (2002). Soil organic carbon sequestration rates by tillage and crop rotation: A global data analysis. Soil Sci. Soc. Am. J. 66:1930-1946.

Zibilske, L.M., Bradford, J.M. & Smart, J.R. (2002). Conservation tillage induced changes in organic carbon, total nitrogen and available phosphorus in a semi-arid alkaline subtropical soil. Soil Till. Res., 66: 153 - 163.

Soil Management and Soil Erosion

Sid P. Theocharopoulos
National Agricultural Research Foundation (NAGREF)
Soil Science Institute of Athens
14123 Lykovrissi, Athens Greece
E-mail: Sid_Theo@nagref.gr

Abstract

The effect of soil management on soil degradation and soil erosion in the context of conservation agriculture has been studied in an integrated approach based on portable rainfall simulator studies, on data from field erosion plots, and on the Cs-137 technique. Using portable rainfall simulation, in ploughed and unploughed (no tillage) soils cropped with wheat, ponding time, runoff and sediment yield were monitored for thirty minutes after ponding and sediment yield and runoff water were analysed for N, P, and K. In nine field erosion plots, the erosion and runoff rates for wheat, fallow land, and bare (herbicide treated) soil were studied for about two years. The Cs-137 isotopic technique was also used to estimate long term soil erosion under conventionally cultivated wheat, with ploughing across slope, in the grid points of a first order catchment to estimate the 3-D distribution of erosion rates.

With rainfall intensity of 80 mm/h, it was found that the ponding time in the eight ploughed fields studied varied from 1.8 to 12 minutes. The percentage of the rain water runoff, with duration of 30 min after runoff initiation, varied from 30 to 71% of the rainfall. The soil erosion rates varied from 1.06 to 3.78 t/ha. The soil organic matter lost varied from 26.42 to 117.73 kg/ha, the N lost varied from 1.59 to 9.75 kg/ha, the K lost varied from 0.58 to 1.38 kg/ha and the P lost varied from 0.02 to 0.10 kg/ha. The nitrates in the runoff water varied from 1.74 to 19.53 kg/ha. The total K amounts in the runoff water varied from 0.63 to 1.98 kg/ha while the P concentrations from traces to 140 g/ha. Runoff and sediment yields from the field erosion plots during the two year experiment showed almost ten times higher erosion rates from bare soil than from conventionally cultivated winter wheat and fallow land, highlighting the role of soil cover with plant and residues reducing soil erosion. Based on Cs-137 residuals, erosion rates, tillage erosion included, under wheat were estimated in grid points and varied from 3.54 to 95.78 t/ha/yr.

Key words: soil erosion, erosion rates, soil management, conventional agriculture

Introduction

Agricultural practices today seem to be shifting globally from conventional tillage to organic farming and conservation agriculture (Dumanski et al., 2006). In all types of agriculture today, emphasis is being placed on reducing land and water pollution, soil erosion, long-term dependency on external inputs, enhancing environmental management, improving water quality and water use efficiency, and reducing emissions of greenhouse gases through restricted use of fossil fuels.

Soil degradation and soil erosion seem to be the most important threats for soils and ecosystems in the arid and semiarid conditions. This has been enhanced by the tendency to increase yields and ignore the environmental impacts. A better insight on these processes will reveal the detrimental effects of different management practices on soil erosion. In the north Mediterranean type semiarid climate, the irregular terrain with steep slopes, which occur in Greece, in combination with human activities, accelerate (Bintliff, 1992; Thornes, 1999) soil erosion, which is one of the main, if not the main, natural and man enhanced degradation process. In order to address this, policies, legal instruments, education, advisory services and research are undertaken.

Soil erosion is a very complicated natural and anthropogenic process depending on several interacting factors, operating under significantly diverging temporal and spatial variability (Morgan, 1979; Lal, 1994). The need to understand, describe, predict and quantify soil erosion under specific management for Mediterranean conditions is the first step in starting to address it. Knowledge of the effect of erosion factors is important for the adoption of suitable management and anti-erosion measures, and for estimating the economic and environmental on and off-site effect.

Presented in this paper is the study of the effects of conventional management, i.e., ploughing, on soil erosion for different Mediterranean soil types, using portable rainfall simulation, and the effect of conventional tillage, fallow land and bare soil on soil erosion and runoff using both field erosion plots and rainfall simulation. In addition, the long-term conventional management effect on erosion determined by the Cs-137 technique is also presented. The results present the effect of management on soil erosion and highlight the need for measures and actions needed to reduce erosion in conventional agriculture or even the need to shift to conservation agriculture.

Methodology

The effect of soil management on soil erosion was studied in an integrated approach. Using the portable rainfall simulator, (Theocharopoulos et al., 2004) the behavior of eight representative ploughed soils of central Greece (Viotia) was studied (Fig.1). The rainfall simulator was similar to that described by Bowyer-Bower and Burt (1989). The size of the rainfall application area was 50 cm 100 cm, while the adjustable simulated rainfall intensity varied from 10 mm/h to 120 mm/h. Using this rainfall simulator, soil losses and runoff amounts were determined by applying varying rainfall intensities for thirty minutes after ponding (time of initial runoff). Ponding time, soil erosion, and runoff volume were monitored in the field by collecting samples every five minutes, for thirty minutes after ponding. The eroded soil was analyzed for organic matter content, total N, available P, and exchangeable K, using the techniques described by Page (1982). The runoff water was analyzed for NO_3-, P, and K, in order to estimate nutrient losses and their on and off site effects. The eight representative mapping units (Fig.1) subject to erosion were selected according to Theocharopoulos (1992) and Davidson & Theocharopoulos (1992) in the Viotia area, in order to cover the main geological substrate and soil types of the area. One representative experimental field in each mapping unit (Table 1) was selected in which soil erosion was studied.

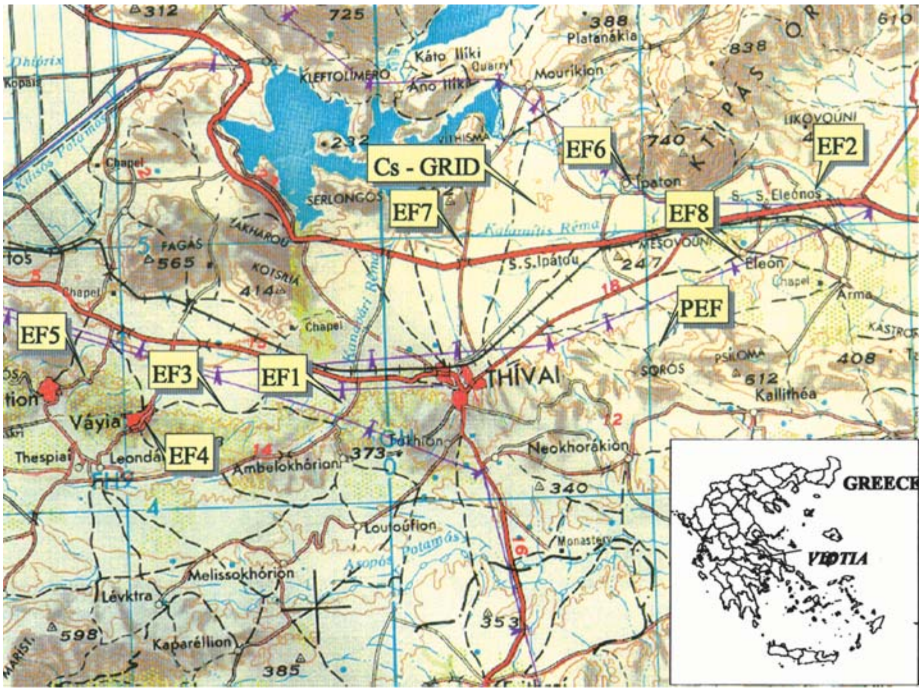


Figure 1: Greece, study area, experimental fields (EF1-EF8), field erosion plots (PEF) and Cs-137 study area (Cs-GRID).(for coloured picture see annex #3, p.285).

In order to study the effect of rainfall on soil erosion and runoff in ploughed soils of the eight experimental fields (EF1-EF8), three replicate experiments using the rainfall simulator were conducted, with a rainfall intensity of 80 mm/h, for thirty minutes after ponding. In order to study the effect of the topsoil surface management on soil erosion, replicate experiments were also conducted in the three experimental fields (EF1, EF2, EF8) with a slope of 5^{o}.One field had a ploughed topsoil surface, one was not ploughed (bare uncultivated land), and one was covered by wheat with about 60% plant coverage (empirical estimation). Simulated rainfall intensities were 40 mm/h and 20 mm/h.

Property	EF1	EF2	EF3	EF4	EF5	EF6	EF7	EF8
Slope (degrees)	5(5-9)	5(3-9)	9(5-9)	5(5-9)	8(5-9)	9(5-9)	6(5-9)	5(5-9)
Clay %	44	60	40	50	40	54	42	42
Silt %	22	20	24	22	24	16	28	28
pH	7.1	7.5	7.9	7.8	7.7	7.9	7.8	7.9
CaCO3 %	55	16	67	22	13	1	36	20
Org.matter %	1.8	1.8	1.5	0.8	2.2	3.9	2	1.1
CEC (meq/100g)	40	38	22	36	22	52	32	30
Total N(meq/100g)	130	125	100	90	115	115	150	70
Olsen P(mg/Kg)	13	8	13	15	10	22	75	2
K(meq/100g)	0.6	1.1	0.5	0.6	0.3	0.8	1.5	1.2
Porosity %	39	59	31	52	44	72	43	27
Bulk Density (g/cm ^{3})	1.3	1.1	1.4	1.2	1.1	1	1.2	1.5
Field Capacity %	26	40	28	40	37	58	34	37

Table 1: Description of the physical and chemical properties of experimental fields (EF)

In nine field erosion plots, with 7^o slope, of 22 2m, both soil erosion and runoff water losses were studied, in three replicates, under winter wheat, fallow land and bare soil treated with herbicide (paraquat) (Theocharopoulos, 1998). For about two years, runoff water and eroded material were collected in specially designed collectors. In a first order representative catchment, the Cs-137 technique (Theocharopoulos et al., 2003) was used to study the long term erosion and deposition rates under conventional tillage across the higher slope, cropped with winter wheat, using the mass balance model (MBM3) incorporating tillage erosion.

Results and discussion

Each ploughed soil type presented its own structure stability, resistance to erosion and behavior relative to the applied simulated rain and its own pattern of nutrient losses with time. The runoff initiation time (Table 2) varied from 1.8 minutes to 12 minutes. The total runoff varied from 170.42 to 300.46 m^3/ha in 30minutes. The total soil loss varied from 1.06 to 3.78 t/ha for 30minutes. In this lost soil material, the organic matter loss was from 26.42 to 117.73 kg/ha, the P loss from 0.02 to 0.10 kg/ha, the K loss from 0.58 to 1.38 kg/ha, and the total N loss from 1.59 to 9.75 kg/ha for 30 minutes rainfall after runoff initiation. In the runoff water the NO_3- loss varied from 1.74 to 12.72 kg/ha, P from traces to 0.14 kg/ha and K from 0.63 to 1.98 kg/ha.

The great variability observed between fields was probably due to different soil properties and previous managements.

Soil loss (Fig.2a) with time varied from soil to soil, and showed either irregularity or mostly an increase with the rainfall duration. There were also fields where soil loss was relatively stable throughout the experiment. These data highlight the different behavior of different soil under similar rainfall and soil treatment conditions. The increase with time was probably due to soil structure destruction, reduction of porosity and probably to soil capping formation. Soil losses varied from 99 kg/ha to 864 kg/ha for 5 minutes rainfall intensity of 80 mm/h.

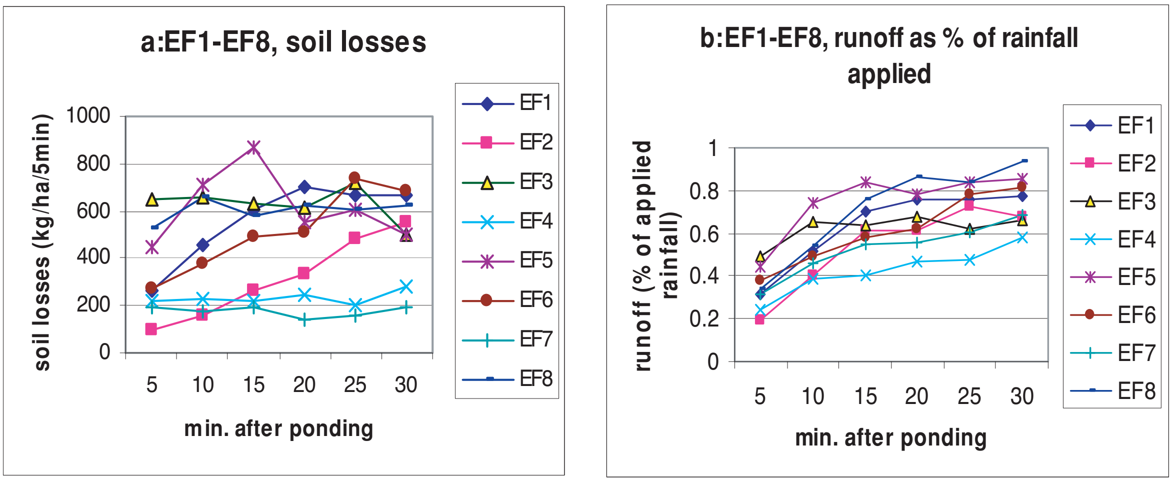


Figure 2: Average soil loss and runoff in EF1-EF8, under 80mm/h rainfall intensity and for 30 minutes after runoff initiation (ponding)

The runoff water (Fig.2b) also varied from field to field while it presented a tendency to increase with the rainfall duration. Runoff varied from 19 to 93% of the rainfall applied inside the 5 minutes rainfall duration. This could be explained by the fact that the more rainfall that applied the greater the structure deterioration that occurred. All the above data could be used to highlight the effect of ploughing to erosion, to predict rainfall intensity and duration for runoff initiation, to predict or estimate erosion and runoff rates and to plan anti-erosion management and measures in different soils.

Measured parameter	EF1	EF2	EF3	EF4	EF5	EF6	EF7	EF8
Runoff initiation time (min)(+)	5.80 (1.26)	6.50 (1.80)	2.80 (1.60)	12.00 (5.00)	1.80 (0.60)	9.00 (3.60)	3.00 (0.50)	2.70 (2.90)
Total runoff (m^3 ha^{-1} in 30min of runoff) (*)	254.80 (0.03)	214.42 (0.43)	248.56 (0.24)	170.42 (0.27)	300.46 (0.08)	244.88 (0.34)	211.82 (0.38)	284.92 (0.30)
Soil loss (t ha^{-1}) for 30 min. runoff (*)	3.36 (0.39)	1.88 (0.67)	3.78 (0.21)	1.40 (0.51)	3.68 (0.26)	3.08 (0.90)	1.06 (0.46)	3.62 (0.50)
Organic matter loss (kg ha^{-1}) (*)	74.11 (0.00)	48.92 (0.13)	79.34 (0.17)	26.42 (0.11)	117.73 (0.44)	61.55 (0.10)	77.70 (0.18)	61.57 (0.19)
P-loss (kg ha^{-1})(*)	0.04 (0.07)	0.02 (0.30)	0.07 (0.14)	0.02 (0.11)	0.04 (0.15)	0.10 (0.06)	0.08 (0.27)	0.05 (0.21)
K loss (kg ha^{-1})(*)	0.84 (0.00)	1.27 (0.03)	0.75 (0.14)	0.58 (0.10)	1.28 (0.07)	1.38 (0.07)	0.82 (0.07)	1.20 (0.11)
N-loss (kg ha^{-1})(*)	4.65 (0.03)	3.35 (0.06)	4.95 (0.15)	1.59 (0.12)	9.75 (0.07)	4.06 (0.14)	4.99 (0.06)	4.49 (0.16)
NO_3-in runoff water kg ha^{-1} (*)	6.24 (0.76)	3.22 (0.79)	7.80 (0.70)	1.74 (0.56)	19.53 (0.73)	12.72 (0.42)	2.64 (0.75)	5.33 (0.73)
P-in runoff water (kg ha^{-1})(*)	0.00 (0.00)	0.01 (0.00)	0.14 (0.67)	0.01 (0.26)	0.01 (0.16)	0.07 (0.60)	0.04 (0.17)	0.02 (0.65)
K-in runoff water (kg ha^{-1}) (*)	1.17 (0.24)	1.05 (0.49)	1.28 (0.38)	0.63 (0.12)	1.47 (0.08)	1.00 (0.11)	1.98 (0.28)	1.60 (0.15)

Table 2: Average runoff initiation time, total runoff, soil loss, nutrient loss in the eroded soil and runoff water, with 30 min. rainfall after ponding and 80 mm/h rainfall intensity in experimental fields (EF) 1 to 8

In Fig.3 are presented the organic matter, total N, P and K losses in the eroded material. The organic matter content and total N of the soil lost varied among soils. The former ranged from 1.1% to 8.7% and the general trend for the latter during the experimentation was slight reduction with some fluctuation, varying from 105 mg/100g to 545 mg/100g soil. The P varied from 8.5 mg/kg to 134 mg/kg while the K content in the eroded soil varied from 0.44 meq/100g to 2.4 meq/100g soil. These concentrations in the soil lost are much higher than in the (total) soil (Table 1), a fact that highlights the preferential movement of fine soil fraction containing more N, P and K. The fluctuation during experimentation could be explained by the plot micro relief and the differentiated added rainfall effect in each of the studied soils.

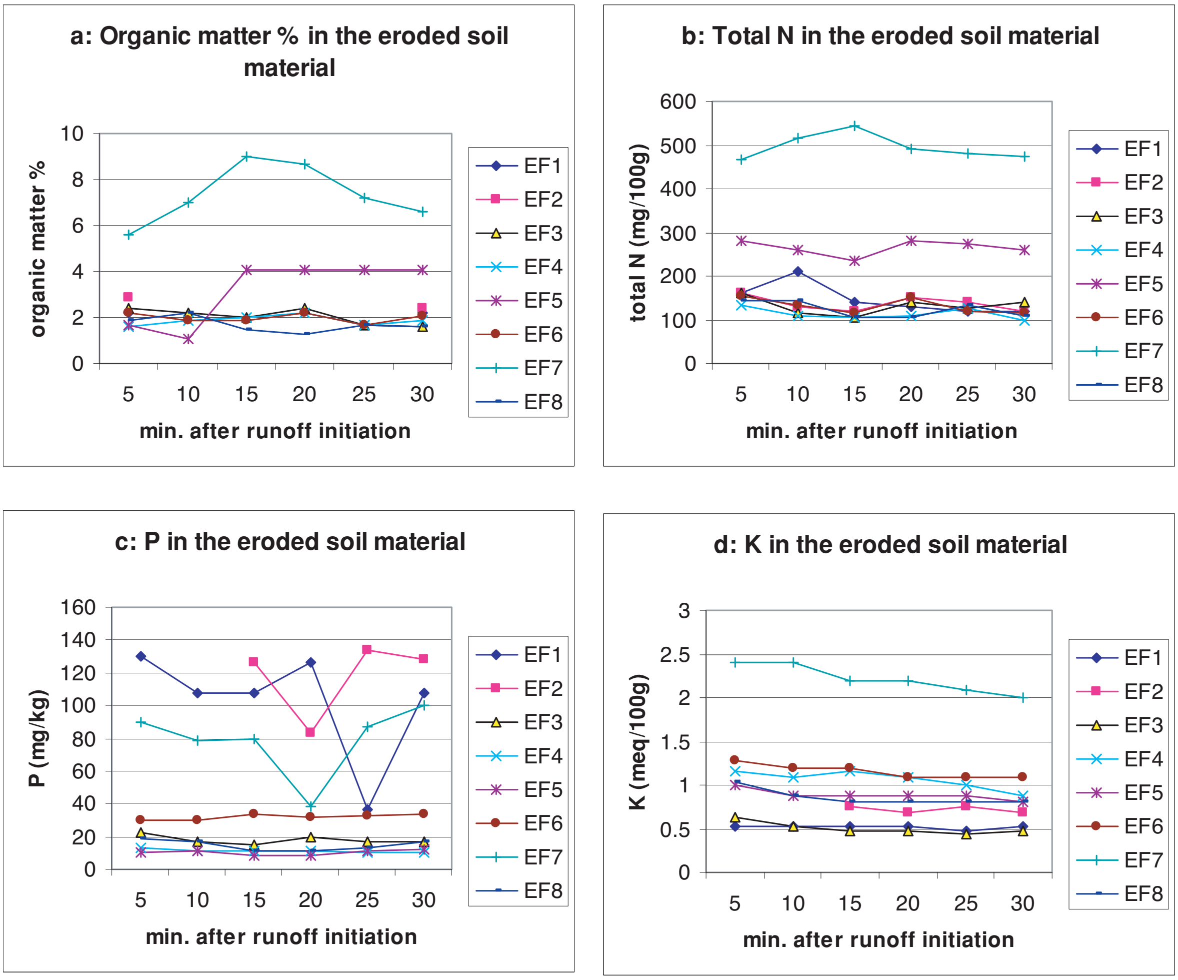


Figure 3: Concentration of organic matter, total N, P and K in the eroded soil material for 30 minutes duration of 80mm/h rainfall intensity

In Fig.4 are presented the concentration of nitrates and K in the runoff water during the experiment. The concentration of nitrates in the runoff water varied from soil to soil with concentrations varying from 5.3 to 68 mg/l (higher than the EU limit of 50mg/l for drinking water). The K (Fig.2b) in the runoff water varied from field to field, while a reduction was demonstrated with the rainfall duration or fluctuation, which varied from 4.25 to 10.92 mg/l.

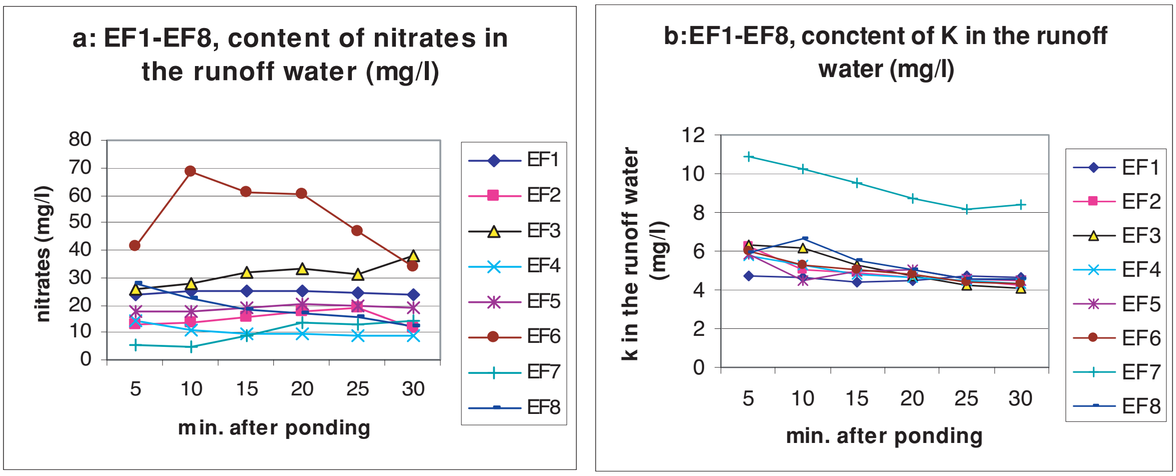


Figure 4: Average concentration of nitrates and K in the runoff water, in EF1-EF8, under 80mm/h rainfall intensity and for 30 minutes after runoff initiation (ponding)

In Fig.5 are presented the soil erosion losses and the runoff water in ploughed, unploughed and from wheat covered soil for rainfall intensities of 20 mm/h and 40 mm/h. Under 20 mm/h rainfall intensity the soil losses are higher in the unploughed soil, in all three fields and lower in the ploughed fields (Fig.5a). The average soil losses for 5 minutes varied from 2.6 (SD: 0.8) kg/ha in the ploughed fields, 15.0 (SD: 7.2) kg/ha in the wheat to 35.3 (SD: 7.0) kg/ha in the unploughed fields for the 20mm/ha-rainfall intensity.

For the higher rainfall intensity it was found that the lowest loss was observed in the wheat treatment in all fields studied (Fig.5b). For EF2 and EF8 the higher soil losses were observed in the ploughed soil and for EF1 in the unploughed soil. With 40 mm h-1 rainfall intensity the average soil losses varied from 14.6 (SD: 4.0) kg/ha for 5min under wheat to 62.9 (SD: 51.8) kg/ha for 5 minutes in the ploughed fields to 63.3 (SD: 32.7) kg/ha for 5 minutes in the unploughed fields (Fig.5b).

These data demonstrate that wheat, at a grown stage, provides sufficient protection for the soil under at least the two rainfall intensities studied in this experiment. These data could be explained by the fact that with the higher rainfall intensity the presence of grown wheat cover reduced more effectively the losses while in the lower rainfall intensity the ploughed soil increased infiltration and the microrelief and reduced the soil losses due probably to increased infiltration. The higher soil loss in the unploughed soil with the lower rainfall intensity could be explained by cap formation from previous rainfalls, which reduces infiltration and enhances runoff. It should be clarified here that under winter wheat most of the erosion takes place during autumn, and early winter when in Mediterranean areas occur heavy rainfalls and the soil is either ploughed or without plant cover.

In Fig.5c, d are presented the runoff percentage of rainfall for ploughed, unploughed and under wheat field for two different rainfall intensities. In these data it is shown that each field has each own pattern and behavior for different top management and rainfall intensity.

In Fig.6 are presented accumulated data from erosion plots for erosion losses and runoff water of the three treatments, in three replicates, fallow land, wheat, and bare (herbicide-paraquat treated soil). This figure shows that fallow land, i.e., soil with natural ungrazed vegetation on it, has less erosion and less runoff than wheat and bare soil. These data highlight the importance of no tillage, mulching and even coverage with wheat under natural conditions, in the reduction of the erosion.

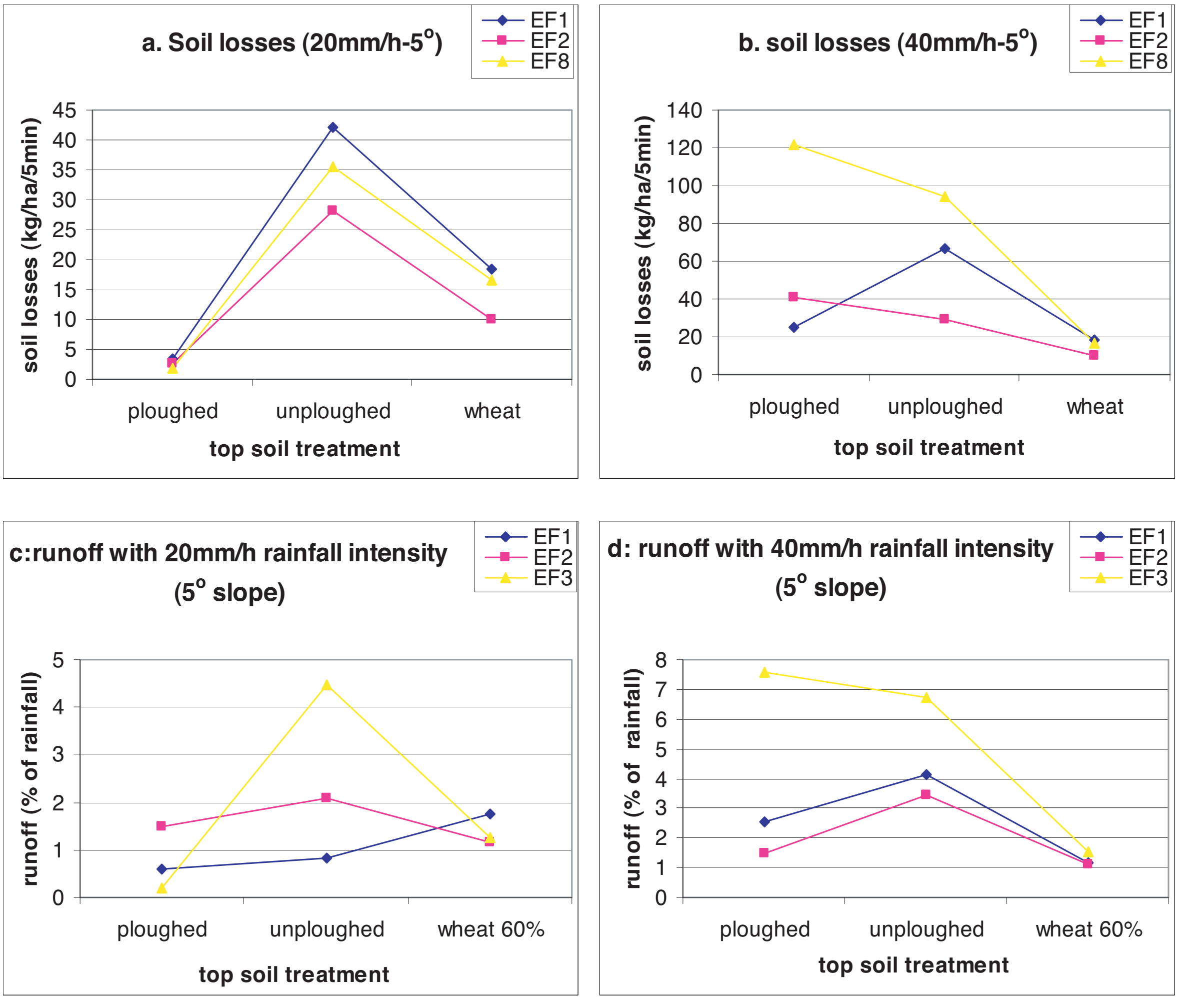


Figure 5: Average soil losses and runoff in EF1,EF2 and EF3 for different top soil treatment (ploughed, unploughed, and under wheat (60% coverage)

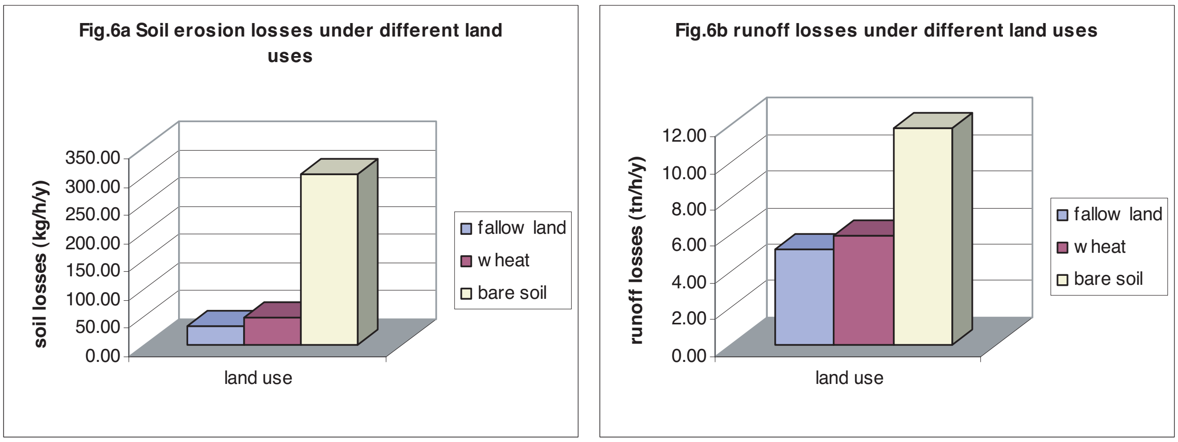


Figure 6: Soil erosion (a) and runoff (b) losses in erosion plots under wheat, fallow land and bare soil

In Fig.7 are presented the long term soil erosion data in a first order representative, catchment in Mouriki area, Viotia using the calibration models of Walling and He (2001), and more specifically the mass balance three model which incorporates soil tillage erosion (Theocharopoulos et al., 2003). In this figure, it is shown the effect of soil tillage on soil erosion as well as the importance of slope in relation to tillage.

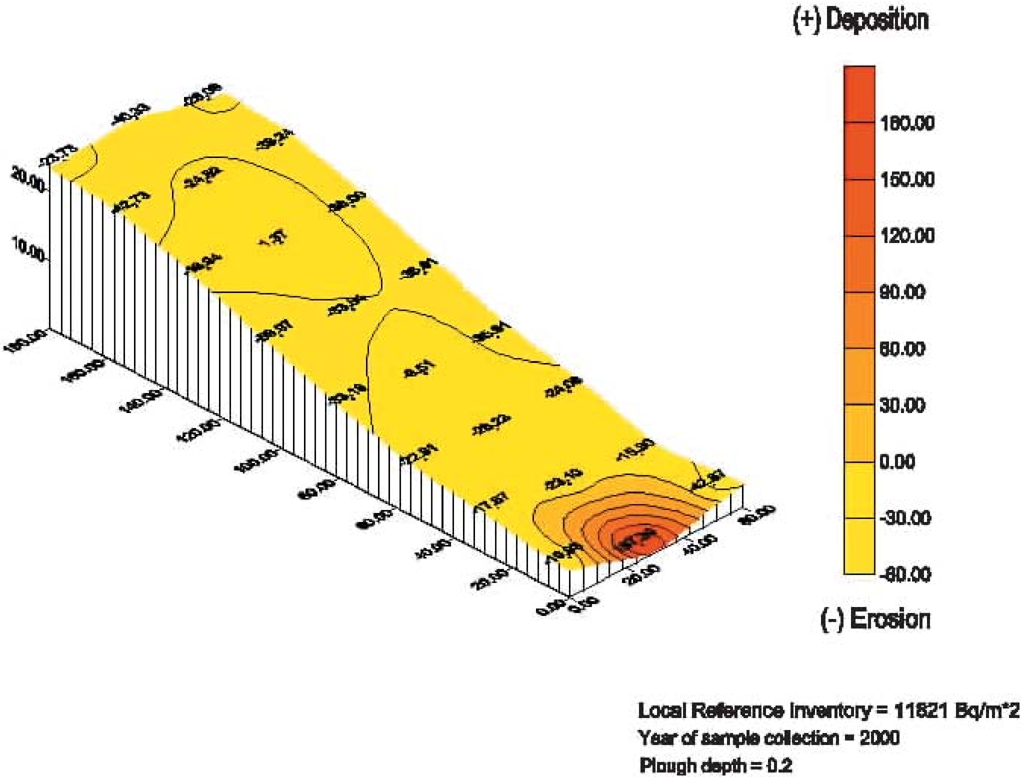


Figure 7: Soil erosion (-) and deposition (+) using the mass balance model 3 (t/ha/yr).(for coloured picture see annex #3, p.286).

Conclusions

From the above data the following conclusions related to soil management and soil erosion could be drawn:

i. Soil management and mainly ploughing highly affects soil erosion under Mediterranean condition.

ii. Each soil has its own behavior. The studied soils after ploughing are very sensitive to erosion, especially for the conditions of the experiments, with all its environmental implications.

iii. Soil losses and runoff water were affected by ploughing, soil slope, land use and soil surface management. Indicative erosion rates for different soil conditions are presented.

Acknowledgements

We are grateful to Mr. E. Pollalis and A. Papadopoulos for helping in editing this paper, Mr. D. Arapakis for the POSTER preparation, Mr. Tountas and Mr. Tsoutsikos for carrying out the experiments. Thanks are also expressed to the staff of the SSIA for their help in preparing this paper.

References

Bintliff J. 1992. Erosion in Mediterranean Lands: reconsideration of pattern, process and Methodology. In Bell, M. and Boardman (eds), Past and present soil erosion, Oxbow Monograph 22, Oxbow Books.

Bowyer-Bower T A S, Burt T P. 1989. Rainfall simulator for investigating soil response to rainfall. Soil Technology 2: 1-16.

Davidson D A, Theocharopoulos S P. 1992. A survey of soil erosion in Viotia, Greece. In Bell, M. and Boardman (eds), Past and present soil erosion, Oxbow Monograph 22, Oxbow Books.

Dumanski J, Peiretti R, Benites J R, McGarry D, and Pieri C. 2006. The paradigm of conservation agriculture. In Proceeding of World Association of Soil and Water Conservation, Paper No1-7.58-64.

Lal R, (ed) 1994. Soil erosion research methods, 2nd edition, SWCS, St Lucie Press.

Morgan R P C. 1979. Soil erosion. Longman Group Lmt, London.

Page A L. 1982 (ed). Methods of soil analysis. 2nd edition. Agronomy Monograph No 9.

Theocharopoulos S P. 1992. Soil Survey Report of Viotia District. Soil Science Institute. Scale 1:100,000, acreage 141,974 ha, (Gr).

Theocharopoulos S P. 1998. Modeling soil erosion in Greece. First annual report. NAGREF, Soil Science Institute of Athens, Athens (Gr).

Theocharopoulos S P, Florou E, Walling D E, Kalantzakos H, Christou M, Tountas P, Nikolaoy T. 2003. Soil erosion and deposition rates in a cultivated catchment area in central Greece, estimated using the 137 Cs technique. Soil & Tillage Research 69 (2003) 153-162.

Theocharopoulos S P, Christou M, Tsouloucha F, Tountas P, Petrakis P, Caramados V, Spyropoulou I, Ntoula M. 2004. Soil erosion studies in central Greece based on rainfall simulator: effect of soil type, rainfall intensity, soil slope and topsoil treatment. Int. Journal of Agricultura Mediterranea, Vol. 134, 3-4, 165-177.

Thornes J B. 1999. Mediterranean desertification: The issues. In P. Balabanis, D. Peter, A. Chazi, M. Tsogas (Eds), Mediterranean Desertification Research results and Policy implications. Proceedings of the International Conference 29 October to 1 November, 1996, Crete, Greece, EC, Volume I, pp9-15.

Walling D E, He Q. 2001. Modeling for converting Cs-137 measurements to estimates of soil redistribution rates on cultivated and uncultivated soils and estimating Cs-137 reference inventories (including software for model implementation).

Soil Biology as an Essential Component of Conservation Agriculture, with Particular Reference to Mycorrhizas and Legume Nodulation

Janet I. Sprent

Division of Applied and Environmental Biology

University of Dundee

DD1 4HN

Scotland, UK

Abstract

Although over 90% of bacteria and other microbes in soil have not yet been cultured, modern methods have shown that they include a very wide range of functional groups. Particularly relevant to Conservation Agriculture (CA) are those that control nutrient cycling, plant growth and nutrient uptake. Arbuscular mycorrhizas are found in nearly all plants and, as well as being important for nutrient uptake, are also significant in dry areas for helping plants to combat drought stress. Ectomycorrhizas are less common in crop species, but can be vital to the woody components of agro-forestry systems. Most legumes used in CA are able to fix nitrogen in association with soil bacteria, collectively known as rhizobia. In the last five years, the diversity of bacteria nodulating legumes has been greatly extended and some of the new nodulating genera may be particularly well adapted to low nutrient soils. Legumes in the Middle East are largely grown in the cool season and are species with a root hair infection process. Legumes that do not have this infection process may be more resistant to drought and salinity. Groundnut (peanut) and lupins are grown in some areas, but suggestions are made of other species that may be considered for use, especially when climate change is considered. However, if more carbon is to be sequestered in soils, then addition of nitrogen will also be necessary.

Introduction

Conservation Agriculture (CA) normally uses minimum tillage procedures and one of its prime aims is to use available water efficiently. These procedures are also likely to conserve the microbial flora, which are the subject of this paper. Although very important, invertebrate components of the soil biota are not considered here. The major emphasis is on mycorrhizas and legume root nodules. All legume names are those accepted by the International Legume Database and Information Service (ILDIS) and further information can be obtained from their web site.

Mycorrihizas.

There are two major forms of mycorrhiza, ecto- and endo. The first consists of modified roots and have a marked fungal sheath, but fungi do not enter host cells. Endomycorrhizas are now usually known as arbuscular mycorrhizas (AM). In these, roots are not modified, and fungal hyphae enter host cells where nutrients are exchanged between partners. Both forms of mycorrhiza have an extensive hyphal network ramifying throughout the soil, enabling the host plants to access a much larger soil volume than the root system alone. An excellent illustrated introduction to mycorrhizas can be found at the website ***www.ffp.csiro.au/research/mycorrhiza/intro.html***. In CA, ecto-mycorrihizal plants are not usually grown, as they are mostly woody shrubs and trees. However, in arid areas there are nodulated species of Acacia sub-genera Acacia and Aculeiferum and Faidherbia albida (formerly called Acacia albida) that may help in stabilising soil and providing fodder for cattle. These are AM, but many of the introduced Australian acacias (sub-genus Phyllodineae) can form both types of mycorrhiza (Sprent, 2001).

The best known benefit of AM to the host plant is assisting in the uptake of poorly available phosphorus, but many other nutrients, particularly ammonium and trace elements are also collected by mycorrihizal hyphae and passed to the host plant. The ability of AM to help plants withstand drought is also well documented (Read, 1999 reviews this and other processes), but other benefits are less well known. This applies in particular to their interactions with plant disease forming organisms. For example, Liu et al (2007) showed that AM infection of Medicago truncatula altered expression of genes associated with diseases and increase resistance to Xanthomonas campestris in shoots. However, from the point of view of Conservation Agriculture, which is associated with relatively undisturbed soils, perhaps the most important aspect of mycorrhizas is that they can form extensive networks that can transport nutrients between various donor and recipient plants. This may include transport of nitrogen both into and out of nitrogen fixing species (He, Critchley & Bledsoe, 2003). However, these functions may come at a cost to the host plant, as indeed do nitrogen fixing root nodules and other plant-microbe interactions (for example those where microbes supply the plant with hormones) in the rhizosphere (Morgan, Bending & White, 2005). In well-fertilised, tilled agricultural soils, symbioses are often suppressed, because soluble nutrients are freely supplied. In dryland, minimally-tilled soils, microbial interactions with plants are much more likely to play a significant role and need to be carefully conserved.

Legume root nodules

Other papers in this book highlight the value of legumes as cover crops and in rotations as part of CA. They are usually grown in the wet season, as legumes are generally perceived to need a good supply of water. This is certainly true of the common cool season legumes grown in the Middle East (chickpea, faba bean, lentils etc), all of which are infected by soil rhizobia through root hairs (Sprent, 2001). However, both salinity and drought impair root hair growth and hence may impede the infection process, resulting in poor nodulation and nitrogen fixation (Sprent & Zahran, 1988). Much less well studied are the estimated 25% of all legumes that do not have a root hair infection pathway (Sprent, 2007). There are two alternatives known, direct infection through epidermal cells (found in species of Lupinus) and cracks where lateral roots emerge (e.g. Arachis hypogaea, the groundnut or peanut). Both of these genera are grown to some extent in the Middle East, although there is very little research on the effects of stress on their infection by rhizobia. Of the very many genera of legumes endemic to the Middle East, two, Crotalaria and Lotononis lack hair infection and have potential for use as forage plants. These plants have been better studied in parts of Africa and some species have been found to be infected, not by typical rhizobia of the Proteobacteria, but by different species of another member of this group, the genus Methylobacterium (Sy et al 2001; Yates et al 2007 respectively). Even more recently legume nodules have been found to be formed, in this case through hair infection, by species of Burkholderia and Cupriavidus in the Proteobacteria (reviewed in Sprent, 2007; Sprent & James, 2007). These genera are closely related (and in some cases possibly the same as) well known plant, animal and human pathogens, and, in the case of

Burkholderia to endophytes of grasses. How widespread these novel bacterial symbionts are is not yet known, but they may be particularly advantageous in some harsh soils, such as those in the fynbos vegetation of South Africa, where they nodulate plants used to make honeybush tea (Cyclopia spp. Elliott et al 2007). Table 1 lists the currently recognised genera of legume nodulating bacteria. It should be emphasised that some bacteria may be isolated from legume nodules that are not capable of nodulating their host of isolation (e.g., Labrys neptunieae, Chou et al 2007) and are not therefore included. All the confirmed nodulating genera belong to the phyla and proteobacteria. In the former, all are grouped in the order Rhizobiales, that probably has 11 families, six of which have genera authenticated as legume nodulating. In the proteobacteria, the two genera known to have nodulating members are both included in the order Burkholderiales. With modern molecular methods, there is an ongoing process of re-classifying species of nodulating bacteria, for example changes between the genera Rhzobium and Sinorhizobium and it is certain the new genera will be added to the lists in both and proteobacteria. Fortunately there is an excellent website ***www.bacterio.cict.fr/p/proteobacteria.html*** that documents all changes accepted by the international microbial community and usually published in the International Journal of Systematic and Evolutionary Microbiology.

There is quite a bit of reclassification going on, merging both species and genera. Some genera have species that do not nodulate legumes. These are not included here. Some taxonomists put the genus Agrobacterium into Rhizobium, but this is highly controversial.

Table 1: Bacterial general known to nodulate legumes.

*** indicates that more species are likely to be described soon.**

** **indicates that the exact number of species is controversial.**

A-proteobacteria, order Rhizobiales
Family Rhizobiaceae
Rhizobium 13 spp, several with 2-3 biovars
Family Bradyrhizobiaceae
Bradyrhizobium 5** spp
Mesorhizobium 10 spp
Family Hyphomicrobiaceae
Azorhizobium 1 sp
Devosia 1sp
Family Methylobacteriaceae
Methylobacterium 2 spp
Family Brucellaceae
Ochrobactrum 2* spp
Sinorhizobium including Ensifer, no longer recognised as a distinct genus 13 spp
Family Phyllobacteriaceae
Phyllobacterium 1 sp

B-proteobacteria, order Burkholderiales
Family Burholderiaceae
Burkholderia 4 spp
Family Ralstoniaceae
Cupriavidus 1 sp

With the onset of climate change, it would be very worthwhile to think ahead and examine legumes in the native Middle Eastern flora that are tolerant of drought and salinity (the genus Sphaerophysa is particularly halo-tolerant) and their nodulating bacteria, with a view to future management of dry-land agriculture. Table 2 lists some genera that are known to be native in the region and which may have potential for use in CA. It is ironic that some of these, for example Biserrula pelecina, are being actively developed in Australia which has many similar soil and climatic characters (Howieson, Loi & Carr, 1995).

Table 2: Some genera from the Middle East region that could be considered for development in Conservation Agriculture.

Sub-family Papilionoideae

Genus	Comment
Astragalus	numerous spp., some toxic
Biserrula	pelecinus, developed in Australia for forage
Crotalaria	aegyptica has potential; juncea (sunnhemp) in limited use
Indigofera	three spp with potential
Lotononis	2 spp with potential
Lotus	several spp with forage potential
Lupinus	several spp, including angustifolius, that has been developed in Australia
Ononis	several spp with forage potential
Psoralea	some spp now transferred to Cullen Virtually unstudied for economic use. S.African spp nodulate freely.
Sphaerophysa	two spp, one, S. salsula very salt tolerant and has been used for forage and medicine.
Trifolium	many spp of this and related genera, have been screened for potential forage use in Australia.
Woody plants in sub-family Mimosoideae	
Acacia	several spp of potential, with good drought tolerance lowlands only
Faidherbia	only one species known, albida. Reverse phenology, lowlands only
Prosopis	farcta many potential uses and will grow in some highland areas

Although not included in aspects of CA covered in this book, the potential of certain woody species listed in Table 2 is worth considering. Faidherbia albida is thought by many to have originated in the Middle East and it has the unique phenology of shedding its leaves in the wet season and producing them in the dry season, a fact that has been exploited by African pastoralists for many years (Barnes & Fagg, 2003). There are numerous drought and salinity tolerant species of Acacia (sub genera Acacia and Aculeiferum) native to the lowland regions. They nodulate with a wide range of rhizobia, including some from the proteobacteria (James, Elliott & Sprent, unpublished data). Prosopis farcta is a tree that can grow on higher, as well as lower land and has been used for a variety of purposes, including forage and medicinal as well as wood.

Nitrogen fixation by non-legume systems

Much publicity has been given to nitrogen fixation in association with grasses. It is certain that nitrogen fixing bacteria, including some rhizobia can live within the xylem and other internal spaces of grasses. However, apart from certain sugar cane varieties grown in Brazil, the evidence that agronomically significant amounts of nitrogen are fixed is lacking (James 2000). Similarly, although the soil microflora may contain many organisms (e.g. Azotobacter and many as yet unculturable forms, Hurek & Reinhold-Hurek, 2005) that have the nitrogenase enzyme, and thus the potential to fix nitrogen, they do not contribute significantly to cropping systems, especially in drylands. Although cyanobacteria may form crusts on desert soils, the amount of nitrogen fixed can only support small local cryptogamic communities (Sprent 1993).

Soil carbon

Building soil carbon content is highly desirable for CA, but also, by sequestering carbon, some of the effects of climate change can be mitigated. However, most work has considered carbon on its own, whereas, in due course the next most common element in plants, N will become limiting. In an extensive study in southern Brazil, C and N contents of soil were investigated under conventional and zero tillage agriculture (Sisti et al 2004). Improvement of soil N varied with legumes used and with whether or not more N was removed with the crop than was fixed biologically. Grasslands with a legume component are particularly good at sequestering carbon (t'Mannetje, 2007). A more difficult problem will arise when soil P becomes limiting, although there are many plants, including nodulated legumes that are native to low phosphorus soils (Sprent, 1999).

CA and Soil Microbiology

Practices used in CA may have major implications for soil microbiology, particularly when minimum till procedures are used. This not only avoids the disruption of microrganisms that stabilise soil structure, but also maintains the integrity of mycorrihizal hyphae. Thus all the benefits of AM in particular (Read, 1999) are optimised. Another major effect of tilling is on nitrogen cycling, where nitrification is stimulated by aeration (Sprent, 1987). How important this is in sandy arid soils is less clear, as they are normally well aerated. However soil moisture itself differentially affects the processes of the nitrogen cycle (Sprent. 1987). Levelling of soils to facilitate use of machinery is likely to have an initial adverse effect, but once completed, mycorrihizal connections etc are likely quickly to be restored. In the specific case of permanent grasslands, with legume and grass components, lack of tilling enhances nitrogen fixation, even when low levels of nitrogen fertiliser are given. This is because the grass competes for the applied nitrogen, forcing the legume to fix its own (Carlsson, 1995). A similar situation occurs in African savannas, where grass competition has been shown to induce nitrogen fixing activity in species of Acacia (Cramer et al, 2007).

Conclusions and recommendations

In this book, other authors have reported great progress in optimising crop yield by developing current technologies. The essential role of soil invertebrates has been stressed, but less attention given to soils microbes. This paper has outlined some of the possibilities and constraints of using mycorrihizal and root nodule symbioses. While further development of crops and cropping systems using known technologies is needed, it is time to look ahead to a possible new generation of plant and microbial materials that can cope with continuing climate change, in particular desertification. In a desert area of the Indian Rajhastan, Gehlot (personal communication) has found numerous native nodulated legumes, from all three sub-families that appear to be adapted to dry conditions. The Middle East has a wealth of native legumes, well described in floras of the region, but almost entirely ignored for possible development as new crops for soil improvement, except for some forage species of interest to Australia. It is suggested that a wide, but targeted, search is conducted for species adapted to particular types of harsh environment and with characters such as non-root-hair infection, and nodulation with non-classical rhizobia. Some woody plants have also been suggested. These have the additional advantage of very deep root systems that can bring up water (and in some cases in dry areas nitrate) from deep in the soil (hydraulic lift).

In suggesting new lines of study, emphasis has been placed on the plant rather than the endosymbiont. Much research has been carried out into drought and salinity tolerance of rhizobia, in most cases concluding that their tolerance is considerable. This is hardly surprising, since these organisms have evolved to live in plant cells, which have osmolarities similar to those of many partially saline soils. Further, rhizobia can survive for years in desiccated nodules – indeed this method of storage may be more effective for some strains, than maintenance on agar slopes (Wang, Sutherland & Sprent, unpublished observations).

Acknowledgements.

My thanks to the organisers of this excellent meeting for making it possible for me to come to Syria and to Barbara Mackinder for helping me to access relevant floras at the Royal Botanic gardens, Edinburgh.

References

Barnes R D, Fagg C W. 2003. Faidherbia albida: monograph and annotated bibliography. Tropical Forestry Papers no 41. Oxford Forestry Institute, University of Oxford

Carlsson G. 2005. Input of Nitrogen from N2 Fixation to Northern Grasslands. PhD thesis, University of Umeå, Sweden

Chou Y-J, Elliot G N, James E K, Lin K-Y, Chou J-H, Sheu D-S, Sprent J I Chen W-M. 2007. Labrys neptunieae sp. nov. isolated from the root nodules of the aquatic legume Neptunia oleracea. International Journal of Systematic and Evolutionary Microbiology 57: 577-581.

Cramer M D, Chimphango S B M, van Cauter A, Waldram M S, and Bond W J. 2007. Grass competition induces N2 fixation in some species of African Acacia. Journal of Ecology 95: 1123-1133.

Elliott G N, Chen W-M, Bontemps C, Chou J-H, Young P W, Sprent J I, James E K. 2007. Nodulation of Cyclopia spp (Leguminosae, Papilionoideae) by Burkholderia tuberum. Annals of Botany in press.

He X H, Critchley C, Bledsoe C S. 2003. Nitrogen transfer between plants through common mycorrihizal networks (CMNs). Critical Reviews in Plant Sciences 22: 531-567.

Howieson J G, Loi A, Carr S J. 1995. Biserrula pelecinus L. – a legume pasture species with potential for acid, duplex soils which is nodulated by unique root-nodule bacteria. Australian Journal of Agricultural Research 46: 997-1009.

Hurek T, Reinhold-Hurek B. 2005. Molecular ecology of N2-fixing microbes associated with graminaceous plants: hidden activities of unknown bacteria. In Nitrogen Fixation in Agriculture, Forestry, Ecology and the Environment. pp173-198. Eds. D Werner and W E

Newton. The Netherlands, Springer.

James E K. 2000. Nitrogen fixation in endophytic and associative symbiosis. Field Crops Research 65: 197-209.

Liu J, Maldonado-Mendoza I, Lopez-Meyer M, Cheung F, Town C D, Harrison M J. 2007. Arbuscular mycorrihizal symbiosis is accompanied by local and systemic alterations in gene expression and an increase in disease resistance in shoots. The Plant Journal 50: 529-544.

Morgan J A W, Bending G D, White PJ. 2005. Biological costs and benefits to plant-microbe interactions in the rhizosphere. Journal of Experimental Botany 417: 1729-1739.

Read D J. 1999. The ecophysiology of mycorrihizal symbioses with special reference to impacts upon plant fitness. In Physiological Plant Ecology. pp133-152. Eds. M C Press, J D Scholes and M G Barker. Oxford, Blackwells and the British Ecological Society.

Sprent J I. 1987. The Nitrogen Cycle. Cambridge, Cambridge University Press. 151pp

Sprent J I.1993. The role of nitrogen fixation in primary succession on land. In Primary Successions on Land pp209-219. Eds. P J Grubb and J Miles. Special Publication No 12 of the British Ecological Society, London

Sprent J I 1999. Nitrogen fixation and growth of non-crop species in diverse environments. Perspectives in Plant Ecology, Evolution and Systematics 2:149-162.

Sprent J I 2001. Nodulation in Legumes Kew, Royal Botanic Gardens.146pp

Sprent J I 2007. Evolving ideas of legume evolution: a taxonomic perspective on the occurrence of nodulation. New Phytologist 174: 11-25.

Sprent J I James E K 2007. Legume evolution: where do nodules and mycorrhizas fit in? Plant Physiology 144: 575-581.

Sprent J I, Zahran H H 1988. Infection, development and functioning of nodules under drought and salinity. In Nitrogen Fixation by Legumes in Mediterranean Agriculture pp145-151 Eds. D P Beck & L A Materon. Dordrecht, Martinus Nijhoff/Dr W J Junk.

Sisti D P J, dos Santos H P, Kohhann R, Alves B J R, Urquiaga S, Boddey R M. 2004. Change on carbon and nitrogen stocks in soil under 13 years of conventional or zero tillage in southern Brazil. Soil & Tillage Research 76: 39-58.

Sy A, Giraud E, Jourand P, Garcia N, Willems A, deLjudie P, Prin Y, Neyra M, Boivin-Masson C, Dreyfus B. 2001. Methylotrophs in symbiosis with legumes. Journal of Bacteriology 183: 214-220.

t'Mannetje L 2007. The role of grasslands and forests as carbon stores. Tropical Grasslands 41: 50-54.

Yates R J, Howieson J G, Reeve W G, Nandasena K G, Law I J, Bräu L, Ardley J K, Nistelberger H M, Real D, O'Hara G W. 2007. Lotononis angolensis forms nitrogen fixing, lupinoid nodules with phylogenetically unique, fast-growing, pink-pigmented bacteria, with do not nodulate L. bainsii or L. listii. Soil Biology and Biochemistry 39: 1680-1688.

Impact of Conservation Agriculture on Soil Fertility in Dry Regions

Isam Bashour
Faculty of Agricultural and Food Sciences
American University of Beirut
Beirut-Lebanon

Abstract

Since the beginning of farming, the importance of soil fertility was recognized. To many scientists, conservation agriculture (CA) means sustainability. Direct sowing, reduced tillage, reduced surface incorporation of crop residues, and the establishment of cover crops are practices of CA. In dry regions, by applying CA methods in farming, soil erosion and water runoff are reduced while soil aggregation, organic matter content, soil moisture and biodiversity increase. In the long term CA makes soils of dry regions more fertile, less vulnerable to erosion, compaction, salinization and nutrient deficiency. Although CA seems to be the natural choice for farmers in dry regions, it has not been adopted by the majority of the farmers.

The reasons that are holding farmers back from practicing CA should be investigated. In the Middle East, farmers, teachers, economists, and decision makers do not have sufficient information about CA and therefore it has not been widely adopted although it may be the solution for many agricultural and environmental problems in the region.

Sufficient knowledge about CA should be obtained by conducting extensive field experiments to be the power behind making informed decisions. This research programme should aim at developing strategies and practices that enhance production, prevent degradation of soil and water, and at the same time are economically viable and socially acceptable.

Keywords: Conservation agriculture, erosion, tillage, land degradation.

Introduction

Man learned very early, since the beginning of land utilization, the difference in soil fertility and it's depletion by extensive cultivation. The principles of plant nutrition were not well known before the 19th century and soil productivity was evaluated by yield levels and visible soil properties. Later he was able to improve land production by reclamation, irrigation, drainage and applying fertilizer materials.

The nutrient supply potential was continuously reduced by extensive cultivation and man was obliged to incorporate in the cropping system periods without cultivation (fallow system) to give the soil time to rebuild the fertility level and release nutrients from the soil reserve through weathering and mineralization. Thus the fallow system became a universal practice for the maintenance of soil productivity in all agricultural regions of the world.

After Liebig formulated the first law of plant growth (Gardiner and Miller, 2007), the aspects of soil fertility were expanded by the knowledge that plant growth is based on mineral salts and not on humus or other soil contents. Then the soil was considered as a nutrient container with different storage capacities and a natural medium in which nutrients will be released by weathering and mineralization and added by fertilization. The effectiveness of fertilization became clear to farmers and was checked by benefit-cost ratio.

In the media and the classrooms, the importance of increasing agricultural productivity to secure sufficient food and fibre for a continuously growing population is stressed. The world's population has doubled over the last 40 years to more than 6 billion people, with over 9 billion projected by 2050. About 95-97% of the projected increase in population will occur in developing countries, primarily Asia and Africa.

It is estimated that only 10 to 20% additional new land can be put under cultivation by 2050 (Gardiner and Miller, 2007). This illustrates the need for increasing productivity per unit area and for securing sustainability of the new and the already farmed areas.

Tillage

For thousands of years the soil was tilled to grow crops. Early ploughs were forked or crooked sticks pulled behind people or animals. During the past 100 years, tillage has changed drastically. Heavy equipment was developed and used to farm large fields. Plant residues were mixed into the soil. Farmers would plough, disk and smooth the soil in one operation. Then, they would fertilize plant and spray pre-emergent herbicides in another pass (Havlin et al., 2005). Technical abilities exceeded good reasoning. Topsoil in fields subjected to intensive tillage for 30 to 50 years often lost about half the organic carbon of its original content (Fig.1).

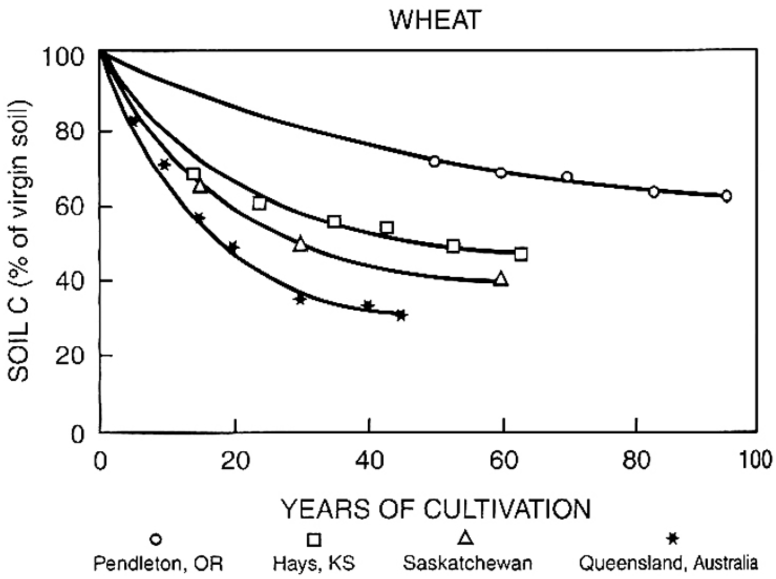


Figure 1: Decline in soil C with time since initial cultivation in wheat cropping (Havlin et al., 2005).

Increased energy costs have focused attention on reduced tillage, conservation tillage, and no-till.

Tillage is done in dry regions to prepare an adequate seedbed, control weeds, improve aeration, increase water infiltration, make furrows for irrigation, and to incorporate residues or fertilizers into the soil. Reduced tillage is any combination of tillage operations that do less soil disruption than conventional tillage. Reduced tillage requires less fuel (about 50%), less time, and causes less soil erosion and compaction. However, it requires the use of more chemicals (herbicides and pesticides) to control weeds and insects and may require heavier equipment for planting. The reduced tillage farmer must be a better farmer than the conventional-till farmer to produce the same yield. Many farmers, especially in dry regions, still question which system is better: no-till, reduced, or conventional tillage? Miller & Gardiner (1998) answered this question as follows:

1. Reduced tillage is more adaptable to various farming systems than no-till.
2. Seed varieties, with reduced tillage, should have quick emergence characteristics, cold tolerance, disease resistance, and the ability to perform with high plant populations.
3. Clean and uniform seedbed is needed for small-seeded crops such as tomatoes, lettuce, carrots, alfalfa and clovers.
4. Reduced tillage requires better management skills and planning than conventional tillage.
5. Crop rotations, rather than pesticides or tillage, as the primary defence against pests may be as good or better financially in the long run.

Research comparing different tillage methods is limited in the Middle East. Extensive research programs on tillage, reduced tillage, and no-till on various types of crops and orchards are needed in this region prior to giving recommendations to farmers.

Soil Erosion

Soil should be recognized as a treasured non-renewable resource. Soil erosion is the removal of soil by water and wind. When the topsoil erodes, farmers must cultivate the exposed B horizon, which is less fertile and harder to till than the top soil. Weesies et al., (1994) reported that in 10 years the eroded soils produced 9 to 18% lower maize yields and 17 to 24% lower soybean yields than slightly eroded soils in USA. In the last 100 years, more than 40% of original topsoil has been eroded from the rolling hills of eastern Washington and adjacent areas in Idaho and Oregon (Miller & Gardiner, 1998). Many mountains in the Middle Eastern countries have been exposed to severe erosion. The mountains of Lebanon have experienced severe erosion for a long time to leave the Eastern slope of Mount Lebanon and the Western slope of Anti-Lebanon almost completely barren. Some of the eroded materials formed the top layer of the fertile soil of the Beqaa alluvial plain. Stopping erosion and sedimentation is impossible, but both of these problems can be reduced by practicing conservation tillage systems.

In the United States, good progress was made between 1982 and 1992 in reducing erosion by taking marginal lands out of cultivation and by promoting conservation tillage (Fig.2). The average annual erosion is still above the maximum allowed level (11 kg /ha).

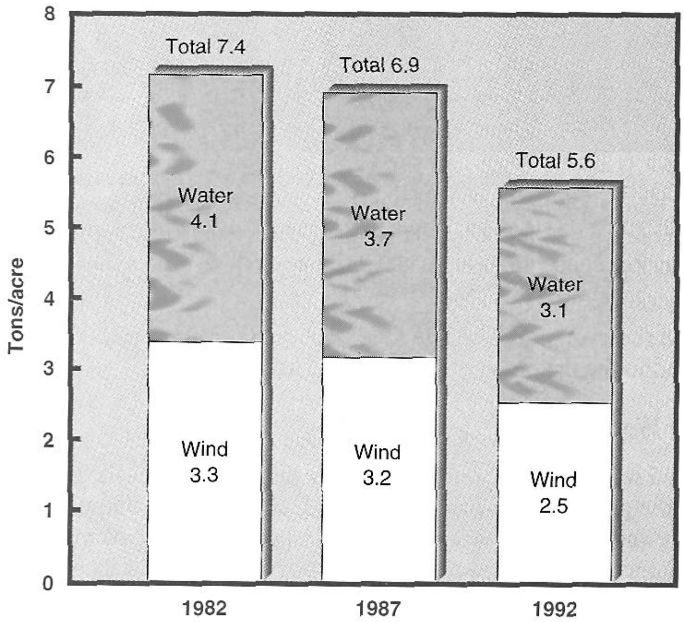


Figure 2: Average annual soil erosion from crop land in the United States by wind and water. (Miller and Gardiner, 1998) (Acre=0.405 Hectare)(1 ton/acre = 2.25 metric t/hectare)

The change needs to be made because an American ton is not the same as a metric tonne

In the Mediterranean area, soil erosion and degradation is severe. Water erosion can result in the loss of 20 to 40 t/ha of soil in a single storm, with more than 100 t/ha in extreme events greatly exceed the average rate of soil formation (< 1 t/ha/yr), increasing the risk of desertification in the region. Conventional agricultural intensification (increased mechanization and ploughing) over the past 50 years has largely contributed to this trend. The use of large amounts of fertilizers, pesticides, and irrigation help to offset the harmful effects of erosion, but if not utilized properly, may cause pollution and health problems.

In the Middle East it takes more than 1000 years to form three cm of top soil and farmers should try their best to utilize conservation tillage systems. They should avoid tillage during low moisture conditions which causes deterioration of soil structure and increases soil erosion. Terraces, contour cultivation, contour strip cropping and filter strips should be encouraged because they lead to a reduction in erosion and reduce transport of nutrients and pesticide-enriched sediments.

Cover Crops:

Cover crops, usually legumes or cool-season grasses, are planted to provide protection against erosion. Legumes also add nitrogen to the soil and reduce fertilization cost. In semi-arid regions, farmers refuse to use cover crops because they compete with cash crops for water which is the main limiting factor for plant growth.

Surface Residues:

The approximate quantity of surface residue remaining after one tillage operation depends on the crop type and the implement used for tillage, as explained in Table 1.

Table 1: Effect of tillage method on percent of crop residues remaining on soil surface following each tillage operation.

Tillage Implement	Maintained Surface Residue
Wide-blade cultivation	90%
Heavy duty cultivation	70%
One-way disk (tandem disk)	50%
Mouldboard, disk plough	10%

Ref.: Miller & Gardiner, 1998.

Effect of Tillage on Availability of Nutrients:

The applications of phosphorus and potassium fertilizers often result in higher concentrations of residual nutrients for several years after application. Few guidelines have been established for soil sampling fields in which P and K fertilizers (slightly mobile) have been band-applied. Soil testing is recommended every 3-5 years. Tables 2 and 3 show the effect of tillage on N, P, K, and soil pH.

Table 2: Influence of tillage on P and K status

Soil	Plough	Chisel	No-Till	Plough	Chisel	No-Till
Depth	Bray-1 P			KCl Extractable K		
In.	……	……	……	mg/kg ……	……	……
0-3	37	85	90	150	230	285
3-6	47	35	27	165	105	100
6-9	30	15	18	140	100	100
9-12	8	8	8	100	100	100

Ref: Havelin et al., 2005 (0.154 inch = 1 cm)

Table 3: Influence of tillage and N application rate on soil pH

Yearly N Rate lb/ac	No-Till		Plough	
	0-2 in.	2-6 in.	0-2 in.	2-6 in.
0	5.75	6.05	6.45	6.45
75	5.20	5.90	6.40	6.35
150	4.82	5.63	5.85	5.83
300	4.45	4.88	5.58	5.43

Ref: Havlin et al., 2005 (0.89 lb/ac = 1 kg /ha)

It is well documented that soil tillage may improve seed placement, germination, root growth and distribution (Fig. 3).

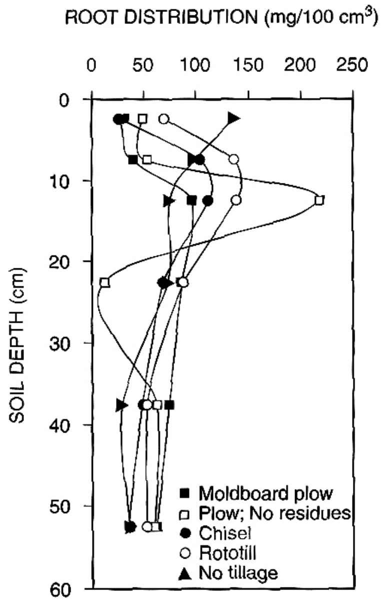


Figure 3: The effect of tillage on corn root distribution, (Barber, 1971).

In some soils, mainly heavy textured, no-tillage may cause some restricted root growth because of increased bulk density. This subject should be tested prior to recommending farmers follow restricted tillage in heavy calcareous soils of the Middle East.

Plants absorb nutrients mostly from moist soils; thus shallow application of nutrients may be less effective than deeper placement in dry regions. Generally nutrients should be placed where stimulation of root growth is desired; therefore deep placement may be necessary in soils of dry regions (Havlin et al., 2005). Determining proper placement of applied nutrients is as important as identifying the proper rate. In reduced tillage systems, more nutrients remain potentially inaccessible near the surface (Fig. 4). For some crops, increasing subsoil nutrient availability can enhance productivity.

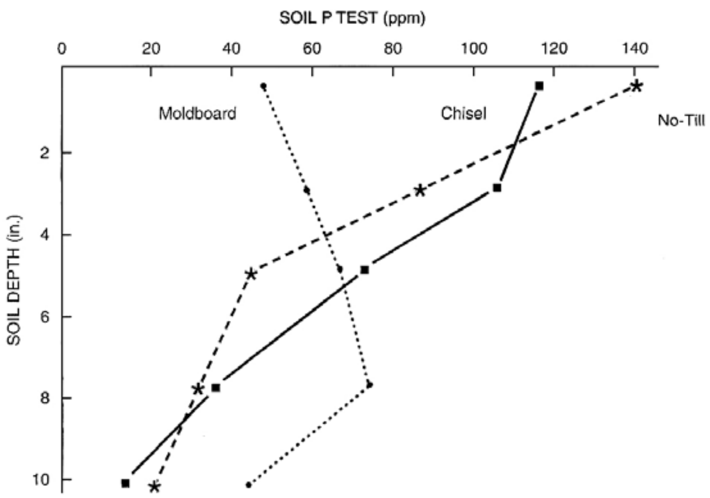


Figure 4: Tillage effect on distribution of soil-P after three years of P fertilization. (Havlin et al., 2005) (0.154 inch = 1 cm)

Conservation Agriculture (CA) and Nutrient Management:

In the following, the term conservation agriculture (CA) is applied for all reduced, conservation tillage and no-till systems.

Low fertility soils in dry regions may need to be increased medium/high fertility levels before establishing CA systems wherever feasible. In reduced and no-tillage systems, nutrients become concentrated mostly in the top 10 cm of the soil. Periodic tillage can partially distribute nutrients in the soil (Figure 4).

The increases in yield due to the application of N and K fertilizers on maize were generally greater under no-till system than under ploughed systems as shown in Figure 5.

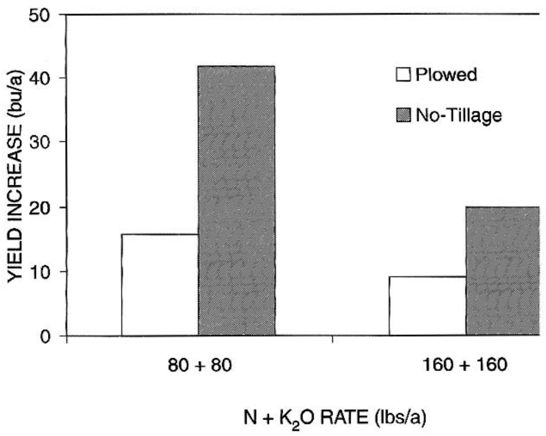


Figure 5: Influence of tillage on broadcast N + K2O on maize yield. (1 bu/acre = 0.06 tons/ha, 0.89lb/a = 1 kg/ha)

Knife application of N fertilizer on no-till sorghum gave much higher yield than when the same rate of N was broadcasted below surface crop residue (Fig. 6).

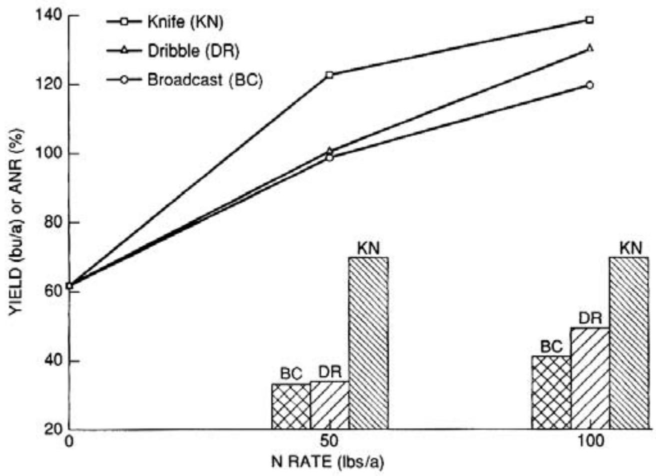


Figure 6: Influence of N rate and placement on no-till grain sorghum yield and apparent N recovery in the grain. (Havlin et al., 2005).

The utilization of nutrients from the subsoil depends on root depth, soil properties and soil moisture level. Deep rooted crops such as alfalfa and trees increase availability of P and K in surface layers because of upward movement of nutrients by roots from deep soil layers and accumulation on soil surface. In the majority of the calcareous soils in this region, K availability is usually medium to high in both surface and subsoil, but most subsoils are low in P and micronutrients. Phosphorus and micronutrient fertilizations of the surface soil are generally adequate to increase P and micronutrients' availability.

Utilizing Organic Sources:

Soil organic matter content is one of the critical factors that influence soil productivity because it influences biological, physical and chemical soil properties. Soil organic matter level depends on soil and crop management practices that affect carbon accumulation and losses in soils. Maintenance of organic matter levels for the sake of maintenance alone is not a practical approach and it is more practical to follow management procedures that will sustain production without reduction in organic matter levels in soils.

Animal manures are good sources of nutrients. Maximizing benefits of manuring depends on: manure type, nutrient contents, application method, time of application and its availability. In general, about 20-40% of the organic N will mineralize during the first year after application and decrease in subsequent years (Table 4 and Fig. 7).

Table 4: Estimated quantity of available N from organic N applied in manure over three years.

Manure Source	Year 1	Year 2	Year 3
	........................% N Mineralized........................		
Liquid manure	30	12	6
Solid manure	25	12	6
Compost	20	6	3

Ref: Havlin et al., 2005.

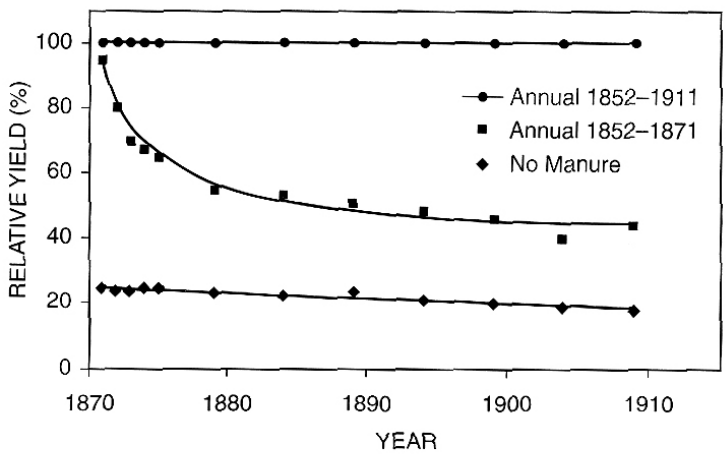


Figure 7: Barley yield influenced by long-term manure application. Havlin et al., 2005.

Composting is being adopted in arid and semi-arid regions. This approach has many benefits; reduction in mass and volume, decreasing weed seed viability, controlling fly breeding and also reducing odors from land where manure has been applied.

Governmental Intervention:

The United States is an example for positive governmental intervention for land conservation. As Americans moved westward, they exploited and depleted the soil. The damage to the depleted and eroded soil was clearly visible in wind and water erosion, and dam siltation (Schlebecker, 1978).

In his presidential campaign of 1932, Franklin D. Roosevelt proposed the creation of a Civilian Conservation Corps (CCC) to battle soil fertility depletion and erosion. In 1933, the U.S. Congress established it. Slowly but surely the land was saved. Farming practices changed, never to be reversed. The researchers found ways to make fertilizers restore soil fertility, halt erosion, cut down floods and renew large areas in the country. Simultaneously, the federal government brought advances to the farmers and established a long-term relationship between scientists and decision makers which in return conserved the land and assisted farmers. The USA has been the pioneer country in CA because of the strong support of subsequent USA administrations for CA system by issuing several farm bills supporting conservation system of farming. Other pioneer countries in CA are Australia, Canada, Brazil and Argentina, while CA is far less common in Europe. Unfortunately CA is hardly applied in the Middle East although farmers stand to gain from applying environmental friendly agricultural practices.

If conventional farming practices are to be converted to CA systems in the Middle East, farmers and decision makers need to be convinced that CA farming systems are better and more economical than the traditional systems which they and their fathers have been applying for decades. The methodology of the CA system needs to be learned and required equipment and machinery should be readily available. Therefore, extensive research programmes are essential and technology transfer efforts supported by policy makers and administrative levels are required.

The Middle Eastern countries need to join hands in supporting a serious, extensive CA research programme to help governments make informed decisions. The Arab Centre for the Studies of Arid Zones and Dry Lands (ACSAD) is the most capable agency in the region to shoulder this challenging responsibility. The mission of research programmes should be to maintain or enhance production, protect natural resources, prevent soil and water degradation, while being economically viable and socially acceptable.

References

Barber S A. 1971. Effect of tillage practice on corn (Zea mays L.) root distribution and morphology. Agron. J. 63:724–726.

NEED Initials of Authors Gardiner, R.W. and D.T. Miller 2007. Soils in Our Environment, 11th edition. Prentice Hall, New Jersey, USA (follow guidelines—you have not been consistent with italics and capital letters for books; the guidelines sent to you showed specific examples)

Havlin J, Beaton J, Tisdale S, and Nelson W. 2005. Soil fertility and fertilizers, 7th edition. Prentice Hall, Upper Saddle River, New Jersey, USA.

Hebblethwaite J F, Towery D. 1998. World wide trends in no- till farming - Competing with the competition. Proc. Northwest Direct Seed Intensive Cropping Conf., Jan 7- 8, 1998, Pasco, WA, USA, 1 – 8, In: http://www.rolf-derpsch.com

Miller R.W., and Gardiner D.T. 1998. Soils in our environment, 8th edition. Prentice Hall, New Jersey, USA. (Look at the difference how you have listed the title here and that listed above)

Pimentel D, Harvey C, Resosudarmo P, Sinclair K, Kurz D, McNair M, Crist S, Shipritz L, Fitton L, Saffouri R, Blair R. 1995. Environmental and economic cost of soil erosion and conservation benefits. Science 267: 1117-1123.

Schelebecker J. 1978. Preserving the soil, Governmental Intervention (1914-1945). In Whereby We Stand. The Iowa State University Press, Ames, Iowa, USA.

Koyoto protocol/United Nations. 1998. Framework conventions on climate change. http//www.un/ccc.de

Conservation Agriculture: for a better environment. <http://www.ecaf.org> (list year like for all other references

Weesies G A, Livingston S J, Hosteler W D and Schertz D L. 1994. Effect of soil erosion on crop yield in India: results of a 10- year study. J. Soil and Water Conservation 49: 597-600.

The Role of Crop Rotations in Conservation Agriculture

Ahmad Fares Asfary

Conservation Agriculture Program, The Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD), *P. O. Box; 2440, Damascus-Syria, Fax: 00963-11-5743063, E. mail: fasfary@acsad.org, fasfary@scs-net.org*

Abstract

Conservation Agriculture (CA) is a dynamic system, flexible, and is continuously developing to improve and sustain the use of land resources of forests, steppe, and cropping lands. It is considered the remedy to land degradation and desertification and to climate change impact on agricultural production.

During the last several decades a conservation cropping system (Commonly referred to as CA) based on three pillars; direct drilling, soil mulching, and crop rotations, have been developed to sustain and improve the productivity of cropping lands in any region and site. However CA implementation in dry areas where precipitation is erratic, low, and in short periods, and the ecosystems are harsh and fragile is critical and needs good knowledge of land and climate conditions to achieve the above mentioned goals. Cropping systems are also supposed to satisfy people's needs and compliment their eco-system services. Therefore this paper will only highlight briefly the impact of crop rotations in CA and the benefits we could get from other experiences to improve present crop rotations and provide more options to farmers especially in dry areas.

Crop rotations are sequences of crops over 2, 3, or 4 years or seasons, that have been developed over the years by farmers and agriculturists to improve production and sustain land resources to a certain extent similar to the natural vegetation of forests and steppe lands. Crops vary in their phenological and physiological characteristics, growth patterns and requirements. Accordingly their sequence in a rotation is designed to benefit from these differences to improve the efficient use of precipitation and irrigation water, soil moisture and nutrients; to sustain and improve soil OM, C: N ratio and biomass; to control weeds, pests, diseases, and to prevent soil erosion. However, natural vegetations are more efficient because they provide continuous and dense plant cover with a wider range of plants with different characteristics. Cropping systems require improvements to be more efficient in utilizing water and nutrients, increasing C sequestration, conserving water and soil nutrients, increasing soil OM and biomass, and controlling pests and pathogens

Key Lessons from International Experiences about Conservation Agriculture and Considerations for its Implementation in Dry Areas

R. Lahmar[1] **and B. Triomphe**[2]

*1- **CIRAD, UMR SYSTEM,** SupAgro Bâtiment 27, 2 place Viala F-34060 Montpellier cedex 1, rabah.lahmar@cirad.fr*

*2- **CIRAD, UMR INNOVATION,** TA C-85 /15, 73 rue Jean-François Breton F-34398 Montpellier cedex 5, bernard.triomphe@cirad.fr*

Abstract

Land scarcity and soil degradation in dry areas are increasingly recognized and being documented. Their impact on the livelihood of people and the resilience of ecosystems is a source of growing concern. Alternative land management practices and strategies are needed to mitigate/reverse current negative trends. Conservation agriculture (CA) may contribute to this goal. Indeed, CA emerged historically in response to soil erosion crises and their negative economic consequences.

The adaptation of CA in diverse situations, including small-scale farming, of rainfed and irrigated agriculture has given way to developing various CA systems spanning a wide array of practices ranging from reduced tillage (RT) to no-tillage (NT) with varying degrees and means of soil cover.

CA is perceived as a powerful tool of land management in dry areas. It allows farmers to improve their productivity and profitability especially in dry years while conserving and even improving the natural resource base and the environment. However, CA adaptation in drylands faces critical challenges linked to water scarcity and drought hazard, low biomass production and acute competition between conflicting uses including soil cover, animal fodder, cooking/heating fuel, raw material for habitat etc. Poverty and vulnerability of many smallholders that rely more on livestock than on green production are other key factors.

This paper builds on selected lessons from a wealth of international experiences with the development, fine-tuning and dissemination of CA-based systems, their known drivers, constraints and impacts, to address the potential and challenges of CA in dry areas. It suggests ways and means that may help in designing and shaping alternative programs, tools and strategies aimed at sustainable land management in dry areas.

Key words: Conservation agriculture, biomass, soil cover, dry areas, land management, innovation systems, livelihood, crop-livestock competition, sustainability, production costs, soil erosion, adoption.

1. Introduction

The current concept of Conservation Agriculture (CA) has been mainly shaped in the subtropical Brazilian large-scale market oriented farming conditions. While different authors have proposed different definitions, a definition largely used is that proposed by FAO[(1)] :

"CA is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. CA is based on enhancing natural biological processes above and below the ground. Interventions such as mechanical soil tillage are reduced to an absolute minimum, and the use of external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with, or disrupt, the biological processes".

From this definition, one can infer that conservation agriculture is not an actual technology; rather, it refers to a wide array of specific technologies that are based on applying one or more of what are widely regarded as the three main conservation agriculture "principles" (IIRR and ACT, 2005):

- Reduce the soil tillage, or suppress it altogether;
- Cover the soil surface adequately—if possible completely and continuously throughout the year;
- Diversify crop rotations.

In the international literature, terms such as conservation tillage (CT), zero-tillage (ZT), direct drilling (DD), direct sowing/seeding (DS), and Resource Conserving Technologies (RCTs) are also common, and usually refer to technologies or technology packages that may constitute specific sub-types of CA systems or intermediate systems. One can mention that CA frontiers with other technologies such as agroforestry, or soil and water conservation practices (SWC) such as terraces, zaï, half moon and other water harvesting practices are still not precise.

Whatever the label actually used, there is growing evidence of large-scale adoption of CA systems worldwide (Derpsch, 2005). However, the type of actual CA practices used in diverse agro-ecological and socio-economic environments is highly variable, and frequently departs from the simultaneous and rigorous local application of the three generic CA principles. (Erenstein, 2003; Harrington and Erenstein, 2005; Lahmar et al., 2007b). Only in limited areas are such principles applied simultaneously and consistently over time: such cases that one may call 'full conservation agriculture' are common, yet not systematic, in southern Brazil (do Prado, 2004; Bolliger et al. 2006) and a few other Latin American countries (Scopel et al. 2004; Ribeiro et al. 2007).

Historically, CA practices and systems emerged as a response to soil erosion and profitability crises in USA, Brazil, Argentina and Australia (Coughenour, 2000; Scopel et al., 2004)[(2)] . Their development was allowed by the discovery and availability of herbicides, which for the first time gave farmers a practical and economic option to control weeds other than by agronomic and mechanical means. The transition from conventional plough-based agriculture to conservation agriculture was neither fast nor without hurdles: in most places, it took several decades of hard work and trial-and-error by a variety of actors[(3)] to get to the point where CA systems were profitable and adapted to the specific local conditions that each user had to face.

Today, CA in its many forms covers about 100 million ha worldwide (Derpsch, 2005), versus 60 million in 2000 (Derpsch, 2001). This swift increase in acreage touches continents and countries very differently: CA occupies a large share of areas devoted to annual crops in the USA, Australia, Brazil and Argentina, but remains marginal in Europe (de Tourdonnet et al., 2007) and in Africa

(1) FAO conservation agriculture website: *http://www.fao.org/ag/ca/index.html*

(2) This paper does not with traditional/indigenous CA systems such as the Slash-and-Mulch systems practiced by smallholders throughout tropical America, even though they offer many interesting insights and lessons: see for example Thurston, 1997 or Triomphe and Sain, 2004.

(3) farmers-innovators, extension agents, researchers and input manufacturers were among the key ones.

(Harrington and Erenstein, 2005). In Asia, a swift increase of CA surfaces is occurring in the Indo-Gangetic plains (Gupta et al., 2007). In China and Central Asia, current CA acreage is expected to increase rapidly due to the growing interest in CA, existing favorable institutional and policy conditions, the involvement of machinery manufactures and national and international research institutions (Harrington and Erenstein, 2005). In most cases, farmers who have adopted CA until now are motorized and practice large-scale commercial, high-input, market-oriented agriculture on hundreds or even thousands of hectares. They usually have access to strong support services, including research, extension, input supply and credit. Furthermore, much of the adoption has occurred under favorable agroclimatic conditions: deep soils, humid or sub-humid climates in particular. Conversely, adoption of CA by smallholders in unfavorable areas has been the exception. Such differential adoption rates raise a number of questions, be it relative to the universal validity of the CA principles, or relative to the factors and conditions involved in the adaptation and adoption process.

The objective of this paper is to identify the potential benefits and challenges related to the application of CA experiences for the dry areas of the Arab region. It will also address a number of questions by drawing on recent international experiences with CA in diverse environments.

As for the main sources used for this paper, there is increasing evidence available worldwide about the many past and on-going experiences with CA, as reported for example during the first three World Congresses on Conservation Agriculture, held respectively in Madrid-Spain in 2001 (Garcia-Torres et al., 2001), in Foz de Iguassu-Brazil in 2003, and in Nairobi- Kenya in 2005. Yet little of this evidence has been systematized, and hence it is difficult to draw synthetic lessons. Also, the latest results of many on-going experiences have not been reported to the worldwide CA community[(4)].

Fortunately, the results of the EU-sponsored KASSA project (Knowledge Assessment and Sharing on Sustainable Agriculture[(5)]) are now available: it had the specific objective of synthesizing the validated scientific knowledge generated on CA in a number of regions: Northern and Eastern Europe, the Mediterranean, Latin America and Asia (Lahmar et al., 2007a). Other key sources for this paper are the results of a series of case studies conducted within the framework of collaboration between FAO and CIRAD (Triomphe et al., 2007a; Boahen et al., 2007, Baudron et al., 2007, Nyende et al., 2007; Kaumbutho and Kienzle, 2007, Shetto and Owenya, 2007). In addition, a number of reviews and syntheses about CA have also become recently available, such as West and Post (2002), do Prado (2004), Scopel et al. (2004), IIRR (2005), ACT (2005), and Bolliger et al. (2006). Finally, first-hand knowledge and contacts with many on-going CA projects were also extensively used to complete the picture whenever necessary.

2. Productivity and profitability of CA

CA is widely heralded for its effect on crop productivity. Yet they are far from uniform.

In Latin America, crop yield increases at the farm level when comparing NT systems to conventional plough-based systems were extensively reported (Ribeiro et al., 2007a). Conversely, in Northern Europe and the Mediterranean, CA does not appear to drastically change yields (de Tourdonnet et al., 2007a, Arrúe et al., 2007a). On average, yields in Northern Europe on poor and medium fertile soils do not change (+/- 10%) under CA; they actually decrease slightly on very fertile soils with a high intensive level of production. In the Mediterranean countries, most of the

(4) There have been many regional and national workshops and publications on CA over the world. As example three Mediterranean workshops on no-till took place respectively in Morocco in 2001, in Tunisia in 2004 and in Spain in 2006. See also Conservation agriculture status and prospects. Abrol, I.P. et al. eds, 2005.

(5) KASSA results are publicly available at http://kassa.cirad.fr/

studies carried out in Spain and in Morocco concluded that yields are generally 10-15% higher under no-tillage, especially in dry years. Similar observations have been reported in Latin America (Ribeiro et al., 2007b): yield effect tends to be stronger during relatively dry years, while productivity among contrasting management systems remains similar under normal climatic conditions. This makes CA a more interesting option in dry areas where drought is a continual hazard. The effect of CA practices on productivity is not uniform however, as different annual grain crops respond differently to different soil / tillage systems: the crop rotation increases and stabilizes yield more than continuous cropping.

In terms of profitability, large-scale farmers in Latin America and Europe gain significantly from using CA, due mostly to lower mechanization / motorization costs, including reduction in labor, fuel, lubricants, and maintenance and depreciation costs of agricultural machinery. A tractor lasts three to four years longer in NT systems than when used for hard tasks such as ploughing in conventional cropping systems. Savings allow increasing crop area and more efficient use of machinery and labor force. Small-farmers who depend on use or access to a tractor also benefit directly or indirectly from reduced machinery costs, and also from more autonomy from hired machinery entrepreneurs (Scopel et al., 2005). In Asia, savings ranging from US$ 70 to 140 per hectare accrue from a combination of less needs for irrigation (from 15-20% or even more under bed planting), and increased yields of 200-500 kg/ha.

While cost reductions are most common with the use of CA, savings may be offset by additional costs incurred for chemical weed and pest control. It is reasonably arguable that the rise of the cost of pesticides and/or heavy infestations of weeds, pests and diseases may affect farmers' decision with respect to the use of CA.

In small-scale farming throughout Latin America and Africa, CA reduces drudgery, especially for farmers depending on animal draught or human labor. Reduction in total labor use ranges from 11% to 46% depending on the crops grown. Reduction in labor peaks throughout the agricultural year is also an important aspect. Labor reduction allows farmers to increase their cultivated area or to undertake other activities generating additional incomes, or even to provide help for their neighbors, which is also socially relevant (Ribeiro et al., 2007b).

The short term socio-economic benefits that CA provides through the reduction of costs of production, the need to improve farms' competitiveness, the current trend of increase of the farm size, market globalization and the steady increase of fuel cost are seen likely sufficient to boost CA systems within Europe and possibly overcome farmers and societal reluctance due to socio-cultural barriers or environmental considerations. In many European regions the shift from conventional agriculture to CA is likely already ongoing (Lahmar et al., 2006).

Long-term socio-economic benefits are supposed to come about with the improvement of soil physical, chemical, and biological properties and soil fertility (Gupta et al., 2007a-b) which may also increase the profitability and attractiveness of CA. However, a recent study (Deen et al., 2006) showed that a change in yields occurs in the early years of NT adoption; the length of time under NT had a minimal impact on crop yield response to the NT system.

Taken together, these results show clearly that RT and especially NT greatly cut production costs in basically all types of agroecosystems. The increased global and regional competition will certainly urge more farmers to seek a reduction of their production costs and an increase of their productivity and profitability. CA has proven to be an effective means to achieve these goals. However, the magnitude of the increased profitability depends on many factors including soil, crop, rotation, machinery, cropping and farming systems, etc. Unfortunately, reliable long-term data related to input costs, and to socio-economic aspects of CA, remain scarce and do not allow drawing a comprehensive picture and a realistic comparison among countries, cropping systems, and farming conditions (Lahmar et al., 2006).

3. Potential of CA for soil and water conservation in dry areas

Changes induced by CA practices in soil properties related to soil water, fertility and erosion, and the erosion processes as affected by CA practices have been researched in many dry areas. Most of the studies were conducted at research stations, on a limited number of soil types and only few studies refer to long-term experiments or to on-farm designs. Number of properties have been investigated (soil structure and porosity; aggregates stability; soil infiltration and hydraulic conductivity; soil compaction; earthworm population; soil organic matter (SOM) and carbon (SOC)) but the studies rarely addressed all the properties simultaneously. This makes it difficult to understand the functioning of CA systems and to build a comprehensive knowledge base regarding the long-term impact of CA systems on soil and water in dryland agroecosystems. In this section we will focus mainly on research results obtained in the Mediterranean drylands (Arrúe et al., 2007b).

3.1. Soil physics and related water properties

Soil structure and porosity change when soil management shifts from tillage to RT or NT and soil cover. However, the magnitude and the significance of the changes seem to vary depending on soil texture, the climate, and the CA practice, i.e., RT or NT and the soil cover management. In many situations CA practices led to compaction of the topsoil (Gómez et al., 1999; Hernanz et al., 2002) and a decrease of soil porosity (Lampurlanés and Cantero-Martínez, 2006). As consequence, the hydraulic conductivity decreases (Lampurlanés and Cantero-Martínez, 2006; Moret and Arrúe, 2007). The negative effect of NT on infiltration can be counteracted by the presence of residues on the soil surface, resulting in lower evapotranspiration and greater water storage in the upper soil layer (Josa and Hereter, 2005; Lampurlanés and Cantero-Martínez, 2006), or by the increase in the population of earthworms, resulting in a greater number of vertical paths created by continuous worm burrows that maintain or increase hydraulic conductivity (Moreno et al., 1997). However, in the Mediterranean context, soil moisture as influenced by climatic conditions of the year is a determinant factor for the number of the earthworms during and between years (Ojeda et al., 1997).

3.2. Soil organic matter and aggregate stability

Changes in SOM and SOC under CA are intensively reported in the international literature. SOC generally increases, and the increase rate depends on the CA practices and the crop rotations (West and Post, 2002).

NT systems always accumulate more organic matter on the soil surface than RT systems. One particular feature of CA is that SOC accumulates near the surface of the topsoil which leads to a vertical stratification of the carbon (Hernanz et al., 2002; Moreno et al., 2006; Mrabet, 2002; Álvaro-Fuentes et al., 2007). This distribution of SOM and SOC improves the biological activity, enhances the physical properties of the topsoil, and reduces erosion risk.

Soil surface crusting is very common in dry areas. It plays a key role in runoff and erosion. Low aggregate stability favours soil surface sealing and erosion (Lahmar and Ruellan, 2007). CA practices seem to improve aggregate stability (Mrabet et al., 2001): the improvement is higher in NT systems compared to RT systems (Hernanz et al., 2002). The increase of aggregate stability is correlated to the increase of SOC (Hernanz et al., 2002). Nevertheless, soil sealing is a complex process involving many factors and in regions where crusting is a significant problem, soil cover plays a key role in preventing crust formation (Usón and Poch, 2000).

3.3. Erosion mitigation

Research focused on both water and wind erosion. Water erosion has been studied in annual crops in Spain (De Alba et al., 2001) and in perennial crops in Spain, Italy and Greece (olive orchards) (Gómez et al., 1999, 2005). Wind erosion has been studied in semiarid Spanish cereal/fallow lands (López et al., 2001; López and Arrúe, 2005). In Andalusia several studies focused on the development of simulation models and expert systems to predict the effect of tillage systems on water erosion under different climatic conditions and to design site-specific agricultural implements (Simota et al., 2005; De la Rosa et al., 2005). As results, in dryland olive crops, reduced tillage and soil cover seem to be effective in reducing water erosion (De la Rosa et al., 2005). In cereal/fallow lands, reduced tillage, with chiselling as primary tillage, could be a viable alternative to mouldboard ploughing for wind erosion control (López et al., 1998, 2000).

From these results, it is very clear that the combination of soil cover and NT or RT plays a key role in controlling water runoff. However, it is not yet clear to what extent CA systems can mitigate soil erosion under the aggressive Mediterranean climate. Empirical observations and actual measurements of the drastic reduction of soil erosion by NT practices in Brazil led to the general thought that NT systems by themselves were strong enough to control erosion. Consequently, farmers neglected complementary conservation practices and eliminated terracing systems. Recent results showed that the protection of soil surface by crop residues in NT systems is not always followed by a reduction of runoff. In addition to leaching of nutrients and pesticides, sheet and rill erosion developed even on sites where NT systems have been used for along time. A new conservation technique, called "vertical mulching" (Denardin et al., 2005) is being developed in southern Brazil in NT systems. The combination of NT, terraces and tree plantations in northern Catalonia-Spain seem to be the best way to preserve soil, water and the landscapes.

4. Development, adaptation and dissemination of CA

As already highlighted, the shift to CA practices has historically largely been driven by economic considerations such as decreasing production costs, and especially the cost savings associated with the reduced use of machinery. This has been the case in Europe, in the U.S., and recently in the Indo-Gangetic Plains (Soane and Ball, 1998; Coughenour, 2000; Gupta et al., 2007b). Other factors which also relate broadly with economic factors include decreasing work load especially during seasonal peaks. To a large extent, ecological crises are a driver for CA adoption. Examples are the extreme erosion affecting Southern Brazil, and the complex agro-environmental sustainability crisis affecting the dominant intensive rice-wheat irrigated cropping systems of the Indo-Gangetic Plains. These were perceived and acted upon mostly because of their direct economic consequences in terms of the threat they posed to farmers' livelihoods, even though of late, environmental concerns and the perceived role of CA in achieving a more harmonious relationship with nature have become more prominent.

But the road to CA adoption is not straightforward. In many places, unforeseen technical problems drove many initial adopters back to conventional farming. This has, for example, been the case in Europe and the Mediterranean because of problems with weeds, pests, and crop residue management (Rasmussen, 1999; Arrúe et al., 2007b), or to excessive topsoil compaction (Munkholm et al., 2003). Lack of knowledge and technical advice (or access to them) has also discouraged farmers from adopting CA in many cases. Changes in economic circumstances have also had a large influence on adoption. In France, for example, the attractiveness of CA to farmers has been highly dependent on the types and amounts of subsidies in place under the Common Agricultural Policy which have fluctuated over time. In the Indo-Gangetic Plains, the retention of soil cover is still difficult because of the demand for crop residue for cooking fuel and animal feed is high in the region and many farmers are use to burning rice residue in the field to enable timely sowing a wheat crop. More generally, the use of a cover crop and diversified crop rotations is still hardly practiced in many places due to climate and soil limitations, lack of adapted cover crop varieties, difficult management of crop residue in wet and dry conditions, competition for crop residue, and general market conditions. In turn, the difficulty of introducing cover crops means that farmers are often left to opt for chemical control under CA as the only alternative to ploughing if they do not have the labor resources necessary to control aggressive weed growth. This is especially true in manual agriculture in Africa (Boahen, 2007; Baudron et al., 2007).

Such difficulties may explain why some farmers around the world return partly or entirely to ploughing after years of practicing CA, even though they perceive the effectiveness of CA practices in increasing soil organic matter, enhancing earthworm activity, reducing soil erosion, and improving water infiltration and productivity under dry conditions. In the absence of systematic, unbiased monitoring of actual CA practices, and notwithstanding available estimates, the true current extent and type of CA adoption remain unclear. It seems, however, that RT is more common than NT in many places, and that areas listed as NT may correspond to fields managed in NT only for a part of the rotation, whereas the other crops of the rotation are managed using RT or ploughing. Such is, for example, the case of CA adoption in the Indo-Gangetic Plains (Gupta et al., 2007a), or in many areas across Europe (de Tourdonnet et al., 2007). Said differently, diverse tillage practices may follow one another in time and may coexist within the same farmland, as illustrated by the situation of small farmers in Southern Brazil, who while claiming to practice NT, resort periodically to tillage to handle difficult situations with respect to weed infestations, soil compaction or simply to incorporate lime (Ribeiro et al., 2005, Bolliger et al., 2006, Triomphe et al., 2007b).

5. Drivers and constraints for CA adoption

Process-wise, adoption seems to depend a lot on who is involved in the adaptation and dissemination process, and especially the role played by farmers and their organizations in leading multiple stakeholder consortia. Southern Brazil is well known for the fact that large-scale farmers and their associations have been at the forefront of CA adaptation and diffusion (through farmers' groups such as the Clubes da Minhoca, or Earthworms clubs) since the 1970s, taking advantage initially of experiences and NT equipment imported from the U.S. in the 1970s (Ekboir, 2003). The adoption process was catalyzed by a close interaction and collaboration among a number of stakeholders, including farmers, input and equipment manufacturers, local governments, and to a lesser degree, research and extension services. Many of the same dynamics are true for the large-scale farmers of Argentina, under the leadership of AAPRESID[(6)], a farmer-led society. In their case, CA adoption was strongly facilitated by the seemingly perfect fit between CA and the introduction of genetically-modified crops highly suited to management under NT, such as the "Round-up ready" soybean varieties.

Similar dynamics are at play at a more modest scale in the CA adoption processes observed elsewhere. In the Indo Gangetic Plains (Gupta et al., 2007), researchers and their partners developed and

(6) AAPRESID: Asociación Argentina de Productores en Siembra Directa. http://www.aapresid.org.ar/

disseminated in a participatory manner a wide basket of Resources Conserving Technologies(7) (RTCs), as a result of the emergence and consolidation over 2 decades of continuous efforts of an effective and dynamic innovation system assembling efforts of public and private sectors, national and international research institutions, extension services and innovative farmers. In France, farmers, initially discouraged by the lack of interest of formal research, created their own associations, such as BASE(8) and FNACS(9) to exchange, develop and promote CA practices suited to their conditions (Triomphe et al., 2007b). Today, many more stakeholders and formal institutions have joined the on-going efforts, including research. Spain is the country with the longest experience with CA around the Mediterranean. The true development of CA practices began in earnest in the 1980s with the involvement of technical advisers from agricultural services, farmers' cooperatives and multinational and national companies and scientists, many years after the initial efforts to introduce CA were made. Nowadays, across Spain there are many research groups on CA organized within the Spanish conservation tillage research network, collaborating with many farmers' societies and consortia and developing basic and applied research linked to farmers' concerns including long-term experiments to develop and assess CA-based systems. It is worth mentioning that the first world congress on CA took place in Madrid in 2001 (García-Torres et al., 2001) and the third Mediterranean meeting on no-tillage took place in Zaragoza in 2006 (Arrúe and Cantero-Martínez, 2006). In Italy, no-tillage trials started in 1968, but CA expansion began only in the 1990s. It was driven by the need to reduce cropping costs and the availability on the Italian market of sowing equipment and adequate herbicides (De Vita et al., 2006). In Tunisia adoption has increased markedly, as a result of collaboration between mostly educated large-scale farmers, a Tunisian high education and research school, the Tunisian Technical Center for Cereals (CTC), equipment manufacturers and providers under the auspices of an externally-funded project (Ben-Salem et al., 2006). Conversely, in Morocco, despite more than 20 years of successful CA research (Mrabet, 2007), farmers' adoption of CA practices remains still incipient, most probably due to the fact that the CA agenda has for the most part remained a research agenda, with no or weak linkages with farmers and other stakeholders.

While large-scale farmers, easily able to take risks in investing resources and to enroll allies, have adopted CA relatively swiftly to the point where conventional farming has almost disappeared. Adoption by small-scale farmers has been a much more tedious and delayed process. When it occurred, it was the result of systematic, well-funded, wide-ranging public efforts aiming at CA development. Such has been the case in Southern Brazil, within the context of the well-funded micro-watershed projects implemented in Parana and Santa Catarina States (do Prado, 2004; Bolliger et al., 2006). Research has been pivotal in the development of animal-drawn and manual CA equipment (Ribeiro et al., 2007a), a condition which was also key in the Andean valleys of Bolivia (Wall et al., 2003), and has recently been observed throughout Eastern and Southern Africa (Shetto and Owenya, 2007; Baudron et al., 2007). Developing or making CA equipment available to farmers is indeed critical, as availability of jab planters, NT drills, herbicide sprayers and "knife-rollers" induce huge reductions in labor requirements and drudgery, constituting major driving forces for CA adoption by small-scale farmers, despite the constraints such farmers face with weed control.

Overall, the dynamics of CA adaptation and adoption varies from country to country and from region to region within a country; as well as with time, depending on the specific circumstances farmers face. Table 1 offers a list of some of the key factors acting as drivers to CA adoption both

(7) Resource-Conserving technologies constitute a diverse set of practices including zero and reduced tillage, surface seeding, bed planting, real time N management using leaf colour chart, residue management, paired row planting, single deep placement of fertilizers, laser levelling, controlled traffic. They can be applied simultaneously, but also as single components, or as part of a step-wise adoption process.

(8) BASE Bretagne Agriculture Sol et Environnement.

(9) FNACS Fondation Nationale pour une Agriculture de Conservation des Sols.

at the farm and regional levels. Most of these factors are reversible: drivers can become constraints and vice versa. While not all factors are necessary for CA adoption to take place, Table 1 makes it clear that CA does not have the same probability of being a suitable option in all agroecosystems and socioeconomic contexts.

Indeed, the development of CA systems and their socio-economic and ecological sustainability are highly site specific. The fine tuning of CA systems requires a continuous adjustment which calls for permanent knowledge generation and sharing among the stakeholders. The success in the shifting process requires: (i)- substantial research efforts on CA systems to generate knowledge needed to develop, adapt, and improve site specific attractive CA technologies and options, and to assess/anticipate their long-term impacts; (ii)- creating favorable conditions allowing a significant involvement of leader farmers and farmers organizations, private companies and extension services in the shifting process and the improvement of their knowledge and management skills; (iii)-a favorable institutional and policy environment allowing all the stakeholders to interact within an effective innovation system able to generate, improve and disseminate knowledge (Lahmar et al., 2007b).

6. Drivers and constraints for CA development in Arab region dry areas

In dryland areas of the Arab region[10], CA development faces specific challenges. Evidence abounds in the semi-arid Mediterranean about the ability of CA to improve water productivity and soil protection against degradation and erosion. However, there are many obstacles that prevent farmers from applying CA. They include water scarcity, unreliable precipitation, and drought that result in low biomass production. The acute competition that omnipresent livestock provide for available biomass, not to mention the high incidence of poverty among rural smallholders that exposes farmers, mainly smallholders, to risks of crop and livestock failures during the transition period is a further constraint. Hence, it is important to ponder what might make CA a viable option for this region.

Almost the whole Arab region territory is arid. Furthermore, the per capita arable land is among the lowest of the world (0.19 ha/person) (FAO, 2006a) and it will decline even further given the steady increase of the population. Livestock is ubiquitous; it is considered as a major economic activity in the Mediterranean cereal zones (Cantero-Martinez and Gabiña, 2004). The Arab region is suffering from a number of interrelated problems including poverty and undernourishment (FAO, 2006b), extensive soil degradation caused partly by agricultural land mismanagement (overgrazing, excessive/non-adapted soil tillage, bad management of irrigation and drainage) (Lahmar and Ruellan, 2007), and significant loss of agricultural land due to the expansion of urban areas (ACSAD, CARME and UNEP, 2004). These problems must also be considered in context of a growing population that is expected to double from its current 315 million by 2050 (FAO, 2006b). Consequently, the livelihoods of rural people and ecosystems' resilience are under growing threat in the region as a whole. This assessment is far from new. Indeed, the debate on the impact of ploughing on land degradation began in the 1950s. Several attempts were made to mitigate this situation, such as introduction of the Australian-born ley farming, and the early introduction of a series of mechanical measures to control soil erosion. However, neither of these interventions was very successful (Chatterton and Chatterton, 1996, Roose and de Noni, 1998; Lavee et al., 2004).

Hence the need for alternatives agricultural practices to sustain Mediterranean dry areas farming systems is increasingly evident. The development of CA practices has been suggested, and in some cases, worked on by a number of researchers (Pala et al., 2000; Dixon et al., 2001; Mrabet, 2001; Cantero-Martínez and Gabiña, 2004; Lahmar and Ruellan, 2007).

10-Refers in this text to the 22 countries of the league of Arab States.

CA is promoted in the Mediterranean region mostly because it is perceived as a powerful production and protection land management tool. However, CA adaptation in dry areas faces specific challenges (Mrabet, 2001; Pratap Narain and Praveen Kumar, 2005; Wani et al., 2005), including water scarcity and, rain unreliability and drought hazard, low biomass production and the acute competition for its use as soil cover, animal fodder, cooking/heating fuel, row material for habitat etc., and, the poverty and vulnerability of many smallholders that rely more on livestock than on green production. Success of CA in these conditions remains weak in absence of substantial institutional, financial, research and learning support.

7. Discussion

In the absence of specific enabling policies and other material incentives, farmers' adoption of CA remains mainly driven by economic considerations; i.e., the short-term reduction of production costs it provides. This explains why the large-scale farms are always the pioneers in CA adoption. Environmental considerations or natural resources degradation do not seem critical in the farmers' decision whether or not to shift towards CA, except probably when they are economically threatened by acute environmental crises. Overall, owing to current CA experiences, practices and knowledge, CA can hardly be considered as a stabilized set of components, but rather as a basket of technical and managerial options to be used in a flexible way, according to specific targeted objectives and correlative constraints and opportunities.

Lessons from the international experiences with the development, fine-tuning and dissemination of CA-based systems; their drivers, constraints and impacts may help in designing and shaping alternative programs, tools and strategies aiming at sustainable land management in dry areas. To avoid wasting precious resources, the following issues must be given due consideration:

i) - Development and sustainability of CA-based systems are highly site-specific. It is sensitive to, and dependent on, local biophysical, social, cultural, technological, institutional, market and policy environments. Thus, simply transferring a model from one to another place is not a viable option;

ii) - Shifting towards CA is not a simple matter of technical change. It is about an innovation process which calls for a thorough change in management and adequate knowledge and skills, from the field to the farm and beyond, allowing a continuous adjustment and integration of the new systems into local agriculture;

iii) - The process is knowledge consuming. It calls for a continuous generation and upgrading of knowledge, skills and capacities related to the development, functioning and performance of the systems. This requires the use of participatory, systemic and multidisciplinary research and development approaches, as well as significant investments in training and education;

iv) - Effective innovative learning processes depend heavily on the active sharing of the knowledge generated and experiences acquired, including successes and failures, between farmers and other stakeholders at the local, regional and international scales.

v)- The success of the whole process calls for setting up and maintaining dynamic and effective innovation systems over extended periods of time. Such systems allow multiple stakeholders to interact in real time and adapt, correct and improve the performance and sustainability of the suited CA-based/related systems. Farmers and their societies have to be prominent players in these systems. Other vital stakeholders include research; policy makers; service, input and implement manufacturers and providers. Ensuring effective coordination of such networks is essential to avoid the process aborting prematurely and to make sure the concerns and needs of the weakest stakeholders (usually the smallholders) are addressed.

Eventual success of CA projects in these conditions relies on the capacity to develop systems able to produce enough biomass (i.e., crop residue or cover crops that allow covering soil, feeding livestock and providing fuel and raw material for households), while simultaneously improving household livelihood in the short-term. This may also imply creating adequate enabling environments over sufficient periods of time to support the transition to CA and limit the associated risks.

8. Conclusions and perspectives

Land scarcity and soil degradation in the Arab region dry areas are increasingly recognized and being documented. Their impact on food production, environmental quality, people livelihood and ecosystems' resilience is a growing concern. CA may prove to be an alternative land management tool able to mitigate/reverse land degradation and to improve farmers' livelihood. Lessons from the international experience in CA tend to show that where it is suitable and when it is properly implemented, CA may fulfill these dual objectives. However, the development, the fine tuning and the dissemination of CA-based systems in the dry areas face many specific challenges; among them, especially low rainfall and drought hazard, low biomass production and competition for its uses from livestock and households, and rural poverty.

There is ample evidence that transition to CA-based farming is not a simple matter of technical change but rather a complex innovation process which calls for adequate enabling environments, values and attitudes favoring the involvement and capacity-building of the relevant stakeholders including small-scale/poor farmers and pastoralists/transhumants. Acceptability of future locally-adapted CA-based systems will depend on their ability to integrate harmoniously with livestock-related concerns and constraints and to contribute effectively to poverty alleviation over the short-term. Their long-term sustainability requires continuous technical and managerial adjustments that call for substantial participatory, systemic and multidisciplinary research and development efforts and effective education, training and dissemination strategies. More than a policy support, a paradigm shift is needed.

Table 1: Drivers and constraints for CA

Source: Lahmar et al., 2007b

Drivers/constraints for conservation agriculture (not ranked)	
Farm and market conditions	Reduced/ increased production costs
	More/ less flexibility and improved timeliness of operations
	More/ less diversification and enterprise selection
	Use/ lack of cover crops
	Use/ lack of suitable rotations for integrated pest, weed, disease control
	Suitable / scarcity or excess amounts of residues
	Strong/ weak crop-livestock interactions
	Reduced/ increased soil erosion and resource degradation
	Improved/ reduced water productivity (apply to water-scarce agroecosystems)
Biophysical conditions	Favourable/ unfavourable climate
	Favourable/ unfavourable soils
Social, cultural, technological, institutional, and policy environments	Presence/ absence of a crisis mentality
	Absence/ presence of socio-cultural barriers
	Leadership/ lack of leadership from farmers and farmer organisations
	Ready availability/ lack of conservation agriculture implements
	Presence/ absence of dynamic and effective innovation system
	Availability/ lack of knowledge regarding conservation agriculture
	Presence/ absence of policies for training, communication and support for farmers' initiatives
	Policies affecting farm size, agrarian structure and land tenure
	Appropriate/ inappropriate agricultural research policies
	Favourable/ unfavourable macroeconomic policies
	Favourable/ unfavourable agricultural sector policies
	Presence/ absence of suitable subsidies and credits to facilitate conservation agriculture
Impact of conservation agriculture on health and on the environment	Reduced/ increased pressure of weeds, pests and disease
	Reduced/ increased pollutions
	Impact of conservation agriculture on human health known/ not known

References

Abrol, I.P., Gupta, R.R. and Malik, R.K., Eds. 2005. Conservation agriculture status and prospects. New Delhi, Centre for the advancement of sustainable agriculture. 232p.

ACSAD, CAMRE and UNEP, 2004. The state of desertification in the Arab world. Updated study. Damascus, 21p.

Álvaro-Fuentes, J., Cantero-Martínez, C., Arrúe, J.L., Gracia, R. and López, M.V., 2007. Management impacts on soil organic C sequestration in Mediterranean dryland agroecosystems. In Chabii A. (Ed). Organic matter dynamics in agroecosystems. INRA, Poitiers, 480-481.

Arrúe, J.L., Cantero-Martínez, C., Cardarelli, A., Kavvadias, V., López, M.V., Moreno, F., Mrabet, R., Murillo, J.M., Pérez de Ciriza, J.J., Sombrero, A., Tenorio, J.L., and Zambrana, E., 2007a. Comprehensive inventory and assessment of existing knowledge on sustainable agriculture in the Mediterranean platform of KASSA. In Lahmar, R., Arrúe, J.L., Denardin, J.E., Gupta, R.K., Ribeiro, M.F.F, and de Tourdonnet, S., (eds). Knowledge assessment and sharing on sustainable agriculture. CD-Rom, CIRAD, Montpellier-France. ISBN 978-2-87614-646-4. 24p.

Arrúe, J.L., Cantero-Martínez, C., Cardarelli, A., de Benito, A., Fernández, J.E., Kavvadias, V., López, M.V., Moreno, F., Mrabet, R., Murillo, J.M., Onorati, A., Paschalidis, C. Pérez de Ciriza, J.J., Sombrero, A., Tenorio1, J.L. Zambrana, E. and Zervakisn, G., 2007b. Prospects for sustainable agriculture in the Mediterranean platform of KASSA. In Lahmar, R., Arrúe, J.L., Denardin, J.E., Gupta, R.K., Ribeiro, M.F.F, and de Tourdonnet, S., (eds). Knowledge assessment and sharing on sustainable agriculture. CD-Rom, CIRAD, Montpellier -France. ISBN 978-2-87614-646-4. 27p.

Arrúe, J.L., Cantero-Martínez, C., (eds.), 2006. Third Mediterranean meeting on no-tillage. Options mediterranéennes, Série A, n°69, IAMZ, Zaragoza, 210pp.

Baudron, F., Mwanza, H. M., Triomphe, B. and Bwalya, M. 2007. Conservation agriculture in Zambia: a case study of Southern Province. Conservation agriculture in Africa series, African Conservation Tillage network, CIRAD and FAO, Nairobi-Kenya, 28 p.

Ben-Salem, H., Zaibet, L., and Ben-Hammouda, M., 2006. Perspectives de l'adoption du semis direct en Tunisie. Une approche économique. In Arrúe J.L and Cantero-Martínez C, eds. Third Mediterranean meeting on no-tillage. Zaragoza (Spain): CIHEAM. Serie A, 69: 69-75.

Boahen, P., Addo Dartey, B., Delali Dogbe, G., Asare Boadi, E., Triomphe, B., Daamgard-Larsen, S., Ashburner, J., 2007. Conservation agriculture as practiced in Ghana. Conservation agriculture in Africa series, African Conservation Tillage Network, CIRAD and FAO, Nairobi-Kenya, 45 p.

Bolliger, A, Magid, J., Carneiro Amado, T.J., Skorra Neto, F., dos Santos Ribeiro M.F., Calegari, A., Ralisch, R., de Neergaard, A., 2006. Taking stock of the Brazilian 'zero-till revolution': a review of landmark research and farmer's practice. Advances in Agronomy 91: 48–110.

Cantero-Martínez, C. and Gabiña, D., 2004. Evaluation of agricultural practices to improve efficiency and environment conservation in Mediterranean arid and semi-arid production systems: MEDRATE project. In Cantero-Martínez, C. and Gabiña, D. eds. Mediterranean rainfed agriculture: Strategies for sustainability. Zaragoza (Spain): CIHEAM- EC Europe Aid. Serie A, 60: 21-31.

Chatterton, L. and Chatterton, B., 1996. Sustainable dryland farming. Combining farmer innovation and medic pasture in a Mediterranean climate. Cambridge University Press, Great Britain. 339p.

Coughenour, C.M., and Chamala, S., 2000. Conservation tillage and cropping innovation: constructing the new culture of agriculture. Iowa State University Press, Ames, 360p.

De Alba, S., C. Lacasta, G. Benito, and A. Pérez-González. 2001. Influence of soil management on water erosion in a Mediterranean semi-arid environment in Central Spain. In: García-Torres, L., Benites, J., Martínez-Vilela, A. (Eds.), Conservation agriculture, a worldwide challenge. ECAF and FAO, Spain, vol. II, pp.173-177.

Deen, B., Janovicek, K., Vyn, T., and Lapen D., 2006. Effect of intermittent tillage on yield and soil quality in a maize/soybean/wheat rotation. In Fotyma M. and Kaminkska B. eds. Proceedings of the IX ESA Congress. Part II. Bibl. Frag. Agronom. Warsaw. Vol.11, 525-526.

De la Rosa, D., Diaz-Pereira, E., Mayol, F., Czyz, E.A., Dexter, A.R., Dumitru, E., Enache, R., Fleige, H., Horn, R., Rajkay, K., Simota, C., 2005. SIDASS project Part2. Soil erosion as a function of soil type and agricultural management in Sevilla olive area, southern Spain. Soil Till. Res. 82, 19-28.

Denardin, J.E., Kochhann, R.A., Flores, C.A., Ferreira, T.N., Cassol, E.A., Mondardo, A. and Schwarz, R.A., 2005. Manejo de enxurrada em sistema plantio direto. Porto Alegre: Fórum estadual de solo e água. 88p.

Derpsch, R., 2005. The Extent of CA Adoption worldwide: Implications and Impact. Keynote paper presented at the III World Congress on Conservation Agriculture, Nairobi, Kenya, October 3-7, 2005.

Derpsch R., 2001. Conservation Tillage, No-tillage and related technologies. In Garcia-Torres, L., Benites, J., Martinez-Vilela, A. (eds). Conservation Agriculture, a worldwide challenge. Vol. 1, ECAF and FAO, 161-170.

De Vita, P., Di Paolo, E., Fecondo, G., Di Fonzo, N., Pisante, M., 2006. No-tillage and conventional tillage effects on durum wheat yield, grain quality and moisture content in southern Italy. Soil Till. Res. 92, 69-78.

de Tourdonnet, S., Nozières, A., Barz, P., Chenu, C., Düring, R.A., Frielinghaus, M., Kõlli, R., Kubat, J., Magid, J., Medvedev, V., Michels, A., Müller, L., Netland, J., Nielsen, N.E., Nieves Mortensen1, C., Picard, D., Quillet, J.C., Saulas, P., Tessier, D., Thinggaard, K., and Vandeputte, E., 2007a. Comprehensive inventory and assessment of existing knowledge on sustainable agriculture in the European platform of KASSA. In Lahmar, R., Arrúe, J.L., Denardin, J.E., Gupta, R.K., Ribeiro, M.F.F, and de Tourdonnet, S., (eds). Knowledge assessment and sharing on sustainable agriculture. CD-Rom, CIRAD, Montpellier-France. ISBN 978-2-87614-646-4. 55p

de Tourdonnet, S., Barz, P., Bolliger, A., Düring, R-A., Frielinghaus, M., Kõlli, R., Kubat, J., Laktionova, T., Magid, J., Medvedev, V., Michels, A., Netland, J., Novakova, J., Picard, D., Simon, T., Thinggaard, K., Vandeputte, E., Werrity, J. and Willms, M., 2007b. Prospects for sustainable agriculture in the European platform of KASSA. In Lahmar, R., Arrúe, J.L., Denardin, J.E., Gupta, R.K., Ribeiro, M.F.F, and de Tourdonnet, S., (eds). Knowledge assessment and sharing on sustainable agriculture. CD-Rom, CIRAD, Montpellier-France. ISBN 978-2-87614-646-4. 23p

Dixon J., Gulliver, A. and Gibbon, D. (2001). Farming systems and poverty. Improving farmers' livelihoods in a changing word. FAO and World Bank. Roma and Washington D.C. 409p.

do Prado Wildner, L., Hercilio de Freitas, V.M., McGuire, M. 2004. Use of green manures / cover crops and conservation tillage in Santa Catarina, Brazil. In Eilitta M, Mureithi, J., Derpsch, R., (eds.). Green manure / cover crop systems of smallholder farmers. experiences from tropical and subtropical regions. Dordrecht-Netherlands: Kluwer Academic Publishers. 1–36.

Ekboir, J.M., 2003. Research and technology policies in innovation systems: zero tillage in Brazil. Research Policy 32:573–586.

Erenstein, O., 2003. Smallholder conservation farming in the tropics and sub-tropics: a guide to the development and dissemination of mulching with crop residue and cover crops. Agriculture, Ecosystems and Environment 100:17–37.

FAO, 2006a. The state of food and agriculture. FAO, Rome. 168p.

FAO, 2006b. The state of food insecurity in the world. FAO, Rome, 38p.

Garcia-Torres, L., Benites, J., Martinez-Vilela, A. (eds), 2001. Conservation Agriculture, a worldwide challenge. Vol. 1&2. Spain, ECAF and FAO.

Gómez, J.A., Giráldez J.V., Fereres, E., 2005. Water erosion in olive orchards in Andalusia (Southern Spain): a review. Geophysical Research Abstract, Vol. 7, 08406, 7 pp.

Gómez, J.A., Giráldez J.V., Pastor, M., Fereres, E, 1999. Effects of tillage method on soil physical properties, infiltration and yield in an olive orchard. Soil Till. Res. 52, 167-175.

Gupta, R.K., Abrol, I.P., Ha Dinh Tuan, Hussain, I., Sangar, S., and Tripathi, S.C., 2007a. Comprehensive inventory and assessment of existing knowledge on sustainable agriculture in the Asian platform of KASSA. In Lahmar, R., Arrúe, J.L., Denardin, J.E., Gupta, R.K., Ribeiro, M.F.F, and de Tourdonnet, S., (eds). Knowledge assessment and sharing on sustainable agriculture. CD-Rom, CIRAD, Montpellier-France, ISBN 978-2-87614-646-4. 60p.

Gupta, R.K., Abrol, I.P., Ha Dinh Tuan, Hussain, I., Sangar, S. and Tripathi, S.C., 2007b. Prospects for sustainable agriculture in the Asian platform of KASSA. In Lahmar, R., Arrúe, J.L., Denardin, J.E., Gupta, R.K., Ribeiro, M.F.F, and de Tourdonnet, S., (Eds). Knowledge assessment and sharing on sustainable agriculture. CD-Rom, CIRAD, Montpellier (France), ISBN 978-2-87614-646-4. 21p.

Håkansson, I., 1994. Soil tillage for crop production and for protection of soil and environmental quality: a Scandinavian viewpoint. Soil Till. Res. 30, 109-124.

Harrington, L. and Erenstein, O., 2005. Conservation agriculture and resource conserving technologies- a global perspective. In Abrol, I.P., Gupta, R.K. and Malik, R.K. eds. Conservation agriculture- Status and prospects. Centre for Advancement of Sustainable Agriculture, New Delhi. 1-12.

Hernanz, J. L., López, R., Navarrete L. and Sánchez-Girón, V. 2002. Long-term effects of tillage systems and rotations on soil structural stability and organic carbon stratification in semiarid central Spain. Soil Till Res. 66, 129-141.

IIRR and ACT (International Institute of Rural Reconstruction and Africa Conservation Tillage Network), 2005. Conservation agriculture: a manual for farmers and extension workers in Africa. Nairobi-Kenya.

Josa, R., Hereter, A., 2005. Effects of tillage systems in dryland farming on near-surface water content during late winter period. Soil Till. Res. 82, 173-183.

Kaumbutho, P., and Kienzle, J., (eds.), 2007. Conservation agriculture as practiced in Kenya: two case studies. Conservation agriculture in Africa series, African Conservation Tillage network, CIRAD and FAO, Nairobi-Kenya, 108p.

Lahmar, R., Ruellan, A., 2007. Dégradation des sols et stratégies coopératives en Méditerranée : la pression sur les ressources naturelles et les stratégies de développement durable. Cahiers Agricultures, 16 : 318-323.

Lahmar, R., Arrúe, J.L., Denardin, J.E., Gupta, R.K., Ribeiro, M.F.F, and de Tourdonnet, S., (eds). 2007a. Knowledge assessment and sharing on sustainable agriculture. CD-Rom, CIRAD, Montpellier-France. ISBN 978-2-87614-646-4.

Lahmar, R., Arrúe, J.L., Denardin, J.E., Gupta, R.K., Ribeiro, M.F.S., and de Tourdonnet, S., 2007b. Knowledge assessment and sharing on sustainable agriculture - Main lessons. In Lahmar, R., Arrúe, J.L., Denardin, J.E., Gupta, R.K., Ribeiro, M.F.F, and de Tourdonnet, S., (eds). Knowledge assessment and sharing on sustainable agriculture. CD-Rom, CIRAD, Montpellier-France. ISBN 978-2-87614-646-4. 6p.

Lahmar, R., de Tourdonnet, S., Barz, P., Düring, R.-A., Frielinghaus, M., Kolli, R., Kubat, J., Medvedev, V., Netland, J., Picard, D., 2006. Prospect for Conservation Agriculture in Northern and Eastern European Countries. Lessons of KASSA. In: Fotyma, M. and Kaminkska, B. (Eds.), Proceedings of the IX ESA Congress. Part III. Bibl. Frag. Agronom. Warsaw. Vol.11, pp 77-88.

Lampurlanés, J. and Cantero-Martínez, C. 2006. Hydraulic conductivity, residue cover and soil surface roughness under different tillage systems in semiarid conditions. Soil Till. Res. 5, 13-26.

López, M.V. and Arrúe, J.L., 2005. Soil tillage and wind erosion in fallow lands of Central Aragaon, Spain: An overview. In: Faz, A., Ortiz, R., and Mermut, A.R. (Eds.), Sustainable Use and Management of Soils: Arid and Semiarid Regions. Advances in GeoEcology, Catena Verlag 36, 93-102.

López, M.V., Gracia, R., and Arrúe, J.L., 2001. An evaluation of wind erosion hazards in fallow lands of semiarid Aragon (NE Spain). J. Soil Water Cons. 56, 212-219.

López, M.V., Gracia, R., Arrúe, J.L., 2000. Effects of reduced tillage on soil surface properties affecting wind erosion in semi-arid fallow lands of Central Aragon. European Journal of Agronomy 12, 191-199.

López, M.V., Sabre, M., Gracia, R., Arrúe, J.L., Gomes, L., 1998. Tillage effects on soil surface conditions and dust emission by wind erosion in semi-arid Aragon (NE Spain). Soil Till. Res. 45, 91-105.

Lavee, H., Calvo-Cases, A., Sarah, P., Boix –Fayos, C., Ben-Shmuel, M., Arnau-Rosalen, E. 2004. Lessons and experiences gained from 20 years of measuring soil erosion and related data in the Mediterranean: Future challenges and the way ahead. In: Van Asselen, S., Boix-Fayos, C., and Imeson, A., eds. Briefing papers of the second SCAPE workshop in Cinque Terre (Italy). 23-36.

Moreno, F., Murillo, J.M., Pelegrín, F., Girón, I.F., 2006. Long-term impact of conservation tillage on stratification ratio of soil organic carbon and loss of total and active CaCO3. Soil Till. Res. 85, 86-93.

Moreno, F., Pelegrín, F., Fernández, J.E., Murillo, J.M., 1997. Soil physical properties, water depletion and crop development under traditional and conservation tillage in southern Spain. Soil Till. Res. 41, 25-42.

Moret, D., Arrúe, J.L., 2007. Dynamics of soil hydraulic properties during fallow as affected by tillage. Soil Till. Res. (in Press).

Mrabet, R., 2007. No-tillage research in rainfed areas of Morocco. In Lahmar, R., Arrúe, J.L., Denardin, J.E., Gupta, R.K., Ribeiro, M.F.F, and de Tourdonnet, S., (eds). Knowledge assessment and sharing on sustainable agriculture. CD-Rom, CIRAD, Montpellier -France. ISBN 978-2-87614-646-4. 19p.

Mrabet, R. 2002. Stratification of soil aggregation and organic matter under conservation tillage systems in Africa. Soil Till. Res. 66,119-128.

Mrabet, R. 2001. Le semis direct : potentiel et limites pour une agriculture durable en Afrique du Nord. Centre de développement sous-régional pour l'Afrique du Nord de la Commission économique des Nations Unies pour l'Afrique (CDSR-AN/CEA). 30p.

Mrabet, R., Saber, N., El-Brahli, A., Lahlou, S. and Bessam, F., 2001. Total, particulate organic matter and structural stability of a Calcixeroll soil under different wheat rotations and tillage systems in a semiarid area of Morocco. Soil Till. Res. 57, 225-235.

Munkholm, L.J., Schønning, P., Rasmussen, K.J. and Tandrup, K., 2003. Spatial and temporal effects of direct drilling on soil structure in the seedling environment. Soil Till. Res. 71, 163-173.

Nyende P., Nyakuni, A., Opio, J. P., Odogola, W., 2007. Conservation agriculture: a Uganda case study. Conservation agriculture in Africa series, African Conservation Tillage network, CIRAD and FAO, Nairobi- Kenya, 29 p.

Ojeda, I., Blanco, R., Cantero-Martínes, C., 1997. Influencia del sistema de laboreo sobre la población de la familia Oligochaeta (Lumbricidae) en zonas de secano semiárido. II Congreso Nacional Agricultura de Conservación. AELC/SV. Burgos.

Pala, M., Harris H.C., Ryan, J., Makboul, R. and Dozom, S. (2000). Tillage systems and stubble management in a Mediterranean-type environment in relation to crop yield and soil moisture. Experimental Agriculture 36(2): 223-242.

Pratap Narain and Praveen Kumar, 2005. Prospects and limitations of reduced tillage in arid zone. In Abrol, I.P., Gupta, R.K. and Malik, R.K. eds. Conservation agriculture- Status and prospects. Centre for Advancement of Sustainable Agriculture, New Delhi. 191-198.

Rasmussen, K.J., 1999. Impact of ploughless soil tillage on yield and soil quality: A Scandinavian review. Soil Till. Res. 53, 3-14.

Ribeiro, M.F.S., Denardin, J.E., Bianchini, A., Ferreira, R., Flores, C.A., Kliemann, H.J., Kochhann, R.A., Mendes, I.C., Miranda, G.M., Montoya, L., Nazareno, N., Paz, C., Peiretti, R., Pillon, C.N., Scopel, E., and Skora Neto, F., 2007a. Comprehensive inventory and assessment of existing knowledge on sustainable agriculture in the Latin American platform of KASSA. In Lahmar, R., Arrúe, J.L., Denardin, J.E., Gupta, R.K., Ribeiro, M.F.F, and de Tourdonnet, S., (eds). Knowledge assessment and sharing on sustainable agriculture. CD-Rom, CIRAD, Montpellier - France. ISBN 978-2-87614-646-4. 58p.

Ribeiro, M.F.S., Denardin, J.E., Bianchini, A., Ferreira, R., Flores, C.A., Kliemann, H.J. Kochhann, R.A., Mendes, I.C., Miranda, G.M., Montoya, L., Nazareno, N., Paz, C., Peiretti, R., Pillon, C.N., Scopel, E. Skora Neto, F., 2007b. Prospects for sustainable agriculture in the Latin American platform of KASSA. In Lahmar, R., Arrúe, J.L., Denardin, J.E., Gupta, R.K., Ribeiro, M.F.F, and de Tourdonnet, S., (eds). Knowledge assessment and sharing on sustainable agriculture. CD-Rom, CIRAD, Montpellier -France. ISBN 978-2-87614-646-4. 31p.

Ribeiro, F., Triomphe, B., Benassi, D., and Hubert, B., 2005. Do smallholders in Southern Brazil practice Conservation Agriculture as recommended or as suits them? Preliminary evidence from Parana State. Proceedings, Third World Congress on Conservation Agriculture, Nairobi-Kenya 3-7 October 2005.

Roose, E. et De Noni, G., 1998. Apport de la recherche à la lutte antiérosive. Bilan mitigé et nouvelle approche. Etude et Gestion des sols, 5 : 181-194.

Scopel E., Triomphe, B., dos Santos Ribeiro, M.F., Séguy, L., Denardin, J.E., Kochhann, R.A., 2004. Direct seeding mulch-based cropping systems (DMC) in Latin America. Proceedings, 4th international Crop Science Congress, Brisbane, Australia, 26-Sept to 1-Oct 2004.

Scopel, E., Triomphe, B., Goudet, M., Valadares Xavier, J. H., Sabourin, E., Corbeels, M. and

Macena da Silva, F. A. 2005. Potential role of Conservation agriculture in strengthening small-scale farming systems in the Brazilian Cerrados, and how to do it. Proceedings, Third World Congress on Conservation Agriculture, Nairobi-Kenya 3-7 October 2005.

Shetto, R. and Owenya, M. (eds.), 2007. Conservation agriculture as practiced in Tanzania: three case studies. Conservation agriculture in Africa series, African Conservation Tillage network, CIRAD and FAO, Nairobi-Kenya, 146 p.

Simota, C., Horn, R., Fleige, H., Dexter, A.R., Czyz, E.A., Diaz-Pereira, E., Mayol, F., Rajkay, K., de la Rosa., D., 2005. SIDASS project Part1. A spatial distributed simulation model predicting the dynamics of agro-physical state for selection of management practices to prevent soil erosion. Soil Till. Res. 82, 15-18.

Soane, B.D., Ball, B.C., 1998. Review of management and conduct of long-term tillage studies with special reference to a 25-yr experiment on barley in Scotland. Soil Till. Res. 45, 17-37.

Thurston, H.D., 1997. Slash/ Mulch systems: sustainable methods for tropical agriculture. Intermediate Technology Publications, London.

Triomphe, B. and Sain, G., 2004. Mucuna use by hillside farmers of Northern Honduras. In Eilitta, M., Mureithi, J. and Derpsch, R. (eds.), Green Manure / Cover crop systems of Smallholder Farmers. Experiences from Tropical and Subtropical regions, Dordrecht- Netherlands, Kluwer Academic Publishers, 65-97.

Triomphe, B., Kienzle, J., Bwalya, M. and Damgaard-Larsen, S., 2007a. Case Study project background and method. In Baudron, F., et al. Conservation agriculture in Zambia: a case study of Southern Province. Conservation agriculture in Africa series, African Conservation Tillage network, CIRAD and FAO, Nairobi, Kenya.

Triomphe, B., Goulet, F., Dreyfus, F., de Tourdonnet, S., 2007b. Du labour au non-labour : Pratiques, innovations et enjeux du sud au nord. In Bourrigaud, R and F. Sigaut : Nous Labourons. Actes du Colloque « Techniques de travail de la terre, hier et aujourd'hui, ici et là-bas », Nantes, 25–28 octobre 2006, Centre d'Histoire du travail, France. 369-382.

Usón, A., Poch, RM., 2000. Effects of tillage and management practices on soil crust morphology under a Mediterranean environment. Soil Till. Res. 54, 191-196.

Wall, P., Ekboir, J.M. and Hobbs, P.R., 2003. The role of international cooperation networks to promote Conservation Agriculture. In Producing in harmony with nature, II World congress on Sustainable Agriculture proceedings, Iguaçu, Brazil, 10-15 August.

Wani, S.P., Pathak, P., Sachan, R.C. and Pandle, Suresh., 2005. Conservation tillage for enhancing productivity and protecting environment: ICRISAT experience. In Abrol, I.P., Gupta, R.K. and Malik, R.K. eds. Conservation agriculture- Status and prospects. Centre for Advancement of Sustainable Agriculture, New Delhi. Pp. 179-190.

West, T.O., Post, W.M., 2002. Soil organic carbon sequestration rates by tillage and crop rotation: A global data analysis. Soil Sci. Soc. Am. J. 66, 1930-1946.

Experiences with Conservation Agriculture in Semiarid Regions of the USA

Bobby A. Stewart
Director Dryland Agriculture Institute, and Distinguished Professor of Agriculture
West Texas A&M University, Canyon, Texas, USA, 79016
bstewart@mail.wtamu.edu

Abstract

The Great Plains, the Pacific Northwest, and parts of the Southwest and intermountain areas constitute the major dryland farming areas of the USA. These areas support one of the six food and fiber production systems that developed historically in the U.S. Listed in chronological order, the six systems were woodland, prairie, ranch, irrigated, dryland, and leftover farming. This is a natural progression that is typical of other regions in the world as agriculture expands to more and more marginal lands. In the USA, as settlers pushed west from the subhumid eastern edge of the Great Plains, they found that crop production became more erratic and precarious. Most indigenous soil and water conservation practices have tillage as their focus, and this was also true in the USA. A picture of the moldboard plow is at the center of the seal for the U.S. Department of Agriculture and tillage is ingrained as part of our culture. The sharp increase in energy prices in the 1970s coupled with the growing dissatisfaction of farming land with terraces because of increasing size of machinery led to increasing interest in conservation tillage and no-tillage. These practices started in the Cornbelt region of the USA to control water erosion, but it was soon noted that these practices conserved water in semiarid regions. Conservation agriculture has become widely practiced, although still not dominant, in USA dryland areas and particularly so where fallow periods of 9 to 16 months are practiced between crops. Keeping mulch on the soil surface controls wind and water erosion, increases stored soil water by increasing infiltration and reducing evaporation, halts and often reverses soil organic matter decline, and usually increases yields of subsequent crops. Small increases in seasonal water use by plants, particularly grain crops, can increase yields significantly.

Introduction

The Great Plains, the Pacific Northwest, and parts of the Southwest and intermountain areas constitute the major dryland farming areas of the USA. The Great Plains, however, make up the largest region and this paper will be limited to the Great Plains, and most of the examples will be from the Southern Great Plains. Geographically, the Great Plains is an immense area as shown in Figure 1. It reaches from Mexico across the entire US from and far north into Canada. Before much of the land was broken by the plow in the late 1800s, most of the land from north Texas northward was treeless grassland. The only trees present were along the floodplains of streams and on the few mountain masses in the northern Great Plains. The grasslands were productive and often lush and served as grazing lands for immense herds of bison that were indigenous to the area. Many American Indians lived in the Great Plains until the beginning of agricultural settlement around 1870. The herds of bison moved up and down the Great Plains periodically grazing the grasslands. South of the grasslands, shrubs were mixed with the grasses. The general lack of trees was because of a lack of moisture. Nearly all of the Great Plains receives less than 600 mm of annual precipitation, and much of the area receives less than 400 mm. The amount of annual precipitation is relatively similar from south to north, but increases from west to east. The temperature increases from north to south, so the dryness of the region varies with the driest part of the Great Plains being in the southwest part and the most humid region in the northeast.

The Ogallala aquifer (Figure 2) underlies much of the US Great Plains and has played a major role in the agricultural production of the region particularly since the 1950s. However, there is little or no recharge of the aquifer from precipitation so the aquifer is essentially being mined. There is much more water in the northern part of the aquifer than in the southern part so the sustainability of the aquifer varies greatly. In the Texas High Plains, some lands that were converted from dryland farming to irrigated farming in the early 1950s have already reverted to dryland because the aquifer has been so seriously depleted. In other areas of the aquifer, most notably in parts of Nebraska, ground water supplies will likely be sufficient for hundreds of years. This paper will deal only with the dryland farming in the semi-arid Great Plains which accounts for considerably more than half of the cropland. In the Texas High Plains, one of the most highly concentrated irrigated areas in the US Great Plains, the irrigated portion of cropland accounted for about 50 percent during the peak irrigation years but has since declined to around 40 percent.

Early History of Agriculture Development in US Great Plains

The US Great Plains was considered by most early explorers as an area similar to the Sahara and was designated on early maps as the "Great American Desert." However, dryland agriculture began in the area in the late 1800s. The development of railroad transportation and the passage of the Homestead Act of 1862, which provided free land to settlers, led to vast areas of native grasslands being converted to croplands. The settlers brought their tools and knowledge from the humid regions. In the early days, these practices worked well because the newly cultivated grassland soils were highly fertile and had good physical properties because of relatively high soil organic matter contents. Annual cropping and intensive cultivation were widely practiced by the early farmers. Deep plowing was advocated to provide a reservoir for water storage; and a dust mulch, resulting from pulverizing the surface soil, was recommended to reduce evaporation.

Following World War 1 of 1914-1918, high wheat prices, coupled with the development of power machinery, led to the rapid expansion in cultivated land and large-scale cropping. Settlers pushed west from the sub-humid eastern edge of the Great Plains because there were vast acreages of land that had not been developed. Early-day conservationists had warned of the erosion that would take place in many parts of the Great Plains if the land were cultivated. As agriculture expanded, however, the semi-arid Great Plains was opened to homesteading, land was broken from sod, and large-scale farming developed. This expansion largely occurred during the decade of 1915-1925 when the average annual precipitation was higher than the long time average. The more favorable precipitation, coupled with more than adequate plant nutrients coming from the decomposition of soil organic matter from the newly plowed grassland soils, resulted in high wheat yields and prosperous farmers. Unfortunately, the decade of higher than average precipitation was followed by drier years and the decade of the 1930s became known as the “Dust Bowl” era. The soil organic matter content of the soils declined rapidly after cultivation began. The decline was hastened by the fact that much of the land was fallowed for 15 or more months between wheat crops to store water in the soil profile for the subsequent crop. During the fallow period, the land was often tilled 10 to 12 times for weed control. The long and severe drought of the 1930s resulted in wind erosion that was so severe that national attention was focused on the Great Plains.

Burnett et al. (1985) reported that 43% of the area had serious erosion damage. It was estimated that about 2.6 million ha in the Southern Plains were removed from cultivation because of erosion. In retrospect, it is clear that much of the land should never have been cultivated. The most important decision that should be addressed for a semi-arid region is not only how to farm, but how much to farm, and whether or not to farm. Short-term gains, however, nearly always take precedent over long-term consequences and this generally results in the cultivation of marginal lands that cannot be sustained long-term. The history of crop production in the Great Plains offers much to be learned about the sustainability of crop production in semi-arid regions.

Even though the region had become devastated during the 1930s, favorable rainfall years returned during the 1940s when wheat prices were again high because of World War II and the interest in plowing grasslands resumed. Again, droughts followed and wind erosion in some areas became almost as serious in the 1950s as in the 1930s. The economy of the region, however, was much better because irrigation development increased rapidly during the 1950s. Dryland farmers also adopted new practices. Although the “Dust Bowl” of the 1930s did not return, the fragility of the region was reaffirmed.

Development of Tillage Practices to Control Wind Erosion in the US Great Plains

The Dust Bowl era clearly showed that the practices and tools that farmers used so successfully in humid areas were simply not appropriate for dryland areas like the US. Great Plains. Following the Dust Bowl years, two practices emerged that allowed farmers to cope with the erratic climate that dominates the regions. These practices were stubble-mulch tillage, and increased used of fallow. Stubble mulch tillage, also called mulch tillage is any tillage system that retains a high percentage of crop residues on the surface of the soil. It was developed during the Dust Bowl era to control the ravishing wind erosion. Stubble-mulch tillage basically uses v-shaped sweeps that are pulled about 10 cm below the soil surface following harvest of a crop. Generally, this tillage operation only incorporates about 15 percent of the crop residues with the soil. The crop residues remaining on the soil surface are usually sufficient to control wind erosion. It was also found that stubble mulch tillage increased the amount of water stored in the soil profile and this led to a small, but significant, increase in yields. Fallowing is the practice of allowing cropland to remain idle during a major portion of the season or the entire season when a crop would normally be grown. The usual goal is to increase water storage in the soil for the next crop. This is vitally important in the US Great Plains because growing season precipitation for essentially all the region is less than even half of the growing season potential evapotranspiration. Therefore, it was essential for reducing risk and obtaining suitable yields in the region that a substantial amount of plant available water is stored in the soil profile at time of seeding a crop to supplement the growing season precipitation. The use of fallow led to increased yields that also resulted in more crop residues, and stubble mulch tillage left sufficient crop residues on the soil surface to control wind erosion even though as many as four stubble-mulch tillage operations were commonly used during the fallow period.

Conservation Agriculture Practices in the US Great Plains

The most successful sustainable agroecosystems are those that use some form of conservation agriculture. The goal of conservation agriculture is to conserve, improve and make more efficient use of natural resources through integrated management of available soil water and biological resources combined with external inputs (FAO, 2002). Conservation agriculture contributes to environmental conservation as well as to enhanced and sustained agricultural production. It can also be referred to as resource-efficient agriculture. Conservation agriculture is based on three principles:

- Avoiding mechanical soil disturbance
- Maintaining a permanent soil cover, by crop residues and crops
- Crop rotation.

The greatest problem with applying conservation agriculture concepts in dryland regions is the lack of crop residues. Crop residues are lacking because the sparse and highly variable precipitation limits biomass production. In many cases, the situation is made even worse because of the use of crop residues for animal feed and fuel. The removal of crop residues accelerates the already fast decline of soil organic matter common in dryland areas. This lowers the soil water holding capacity and fertility and results in even lower yields and a downward spiral of crop productivity and soil quality.

The long-term future of many dryland regions depends on stopping, or reversing, the downward spiral of crop productivity and soil quality. This is a particular challenge in many of the developing countries where yields are low and the demand for crop residues is great. FAO (1996) reported that the 1988-1990 average yields of wheat (Triticum aestivium L.), maize (Zea mays L.), and sorghum (Sorghum bicolor) in developing countries in semi-arid regions were 1100, 1130, and 650 kg/ha, respectively. These low grain yields result in relatively low amounts of crop residues.

There are numerous studies, however, that show even small amounts of crop residues can be beneficial for controlling wind erosion and increasing soil water storage. Fryrear (1985) established the relationship between soil loss by wind erosion and the percent of soil cover. Covering 20% of the surface reduced soil losses by 57%, and a 50% cover reduced soil losses by 95% compared to soils with no cover. Fryrear concluded that the cover could be any non-erodible material such as large clods, gravel, cotton (Gossypium hirsutum L.) gin trash, or any diameter stick between 3.1 mm and 25.4 mm in size. For 50% groundcover, approximately 1Mg/ha of wheat straw is required (Van Doren and Allmaras, 1978). To achieve the same rate of cover, however, an estimated 3 Mg/ha of sorghum stalks, and 9 Mg/ha of cotton stalks, is required (Unger and Parker, 1976). Therefore, under semi-arid conditions when grain yields are only in the range of 1 Mg/ha, wheat or other small grain crops are likely to be the only crops that will furnish sufficient crop residue to significantly impact wind erosion. Vertically oriented residues are also more effective for controlling wind erosion than flat oriented residues. Water erosion is also a problem in semi-arid regions and Bilbro et al. (1994) reported a similar relationship between soil cover and water erosion as for wind erosion.

Residue cover can increase the efficient use of limited precipitation in several manners. Plant residues on the soil surface can cause a reduction in runoff, principally by protecting soil surfaces that are prone to crusting from raindrop action. Cornish and Pratley (1991) reported that fallow efficiencies for a number of clay soils in Queensland, Australia were increased from about 21% to 29%, almost entirely because of reduced runoff when some surface residues were left on the soil surface. Fallow efficiency is the percent of precipitation occurring during the fallow period that is stored in the soil profile at the end of the fallow period. Crop residues on the soil surface also reduce evaporation of water from the soil. The residues reduce the energy available for evaporation because of its poor thermal conductivity. It also increases the resistance to vapor transfer from the soil to air. These conditions have the greatest effect when there are frequent rains so that the soil surface does not totally dry between precipitation events. This allows movement of water deeper into the soil where it is much less subject to evaporation. Observations by the authors also suggest that on soils where there is sufficient cracking that a major advantage of no-till is that the cracks are not destroyed and relatively small precipitation events can result in rainfall rapidly moving 30 cm or deeper into the soil compared to only 5 to 10 cm in tilled soil where the cracks have been destroyed. Most of the water retained near the surface will be evaporated in a few days unless additional precipitation occurs.

The amount of crop residues remaining on the surface depends on several factors. Assuming that the residue is not utilized for animal feed or household fuel, the most important factor is the kind and number of tillage operations. Moldboard tillage will bury approximately 95% of the residue with one operation. In comparison, disk tillage will bury about 90%, chisel plows about 50%, and under cutters (sweeps 50 to 75 cm wide) about 25%. Even the sweep plows that are often used during long fallow periods will bury most of the crop residues because there are usually three or more tillage operations during the fallow period when tillage is used exclusively for weed control. The greatest amounts of crop residue are left on the soil surface when herbicides are used for weed control and tillage can be greatly reduced or completely eliminated.

Greb et al. (1979) were among the earliest researchers to clearly show the benefits of reduced tillage on water conservation in semi-arid regions. In a wheat-fallow system that included a 15 to 16 month fallow period, they found water storage in the soil profile during the fallow period increased every time the number of tillage operations decreased (Table 1). This is due to two factors. The first is that the soil is dried to the depth of tillage each time it is tilled. The second is that the less the soil is tilled, the greater the amount of mulch that remains on the surface to reduce the evaporation potential. More importantly, Greb et al. showed that only a few mm of additional soil water storage at time of seeding increased wheat grain yields dramatically. An increase of 55 mm of soil water storage at seeding doubled the grain yield of wheat from 1.07 to 2.16 Mg/ha (Table 1). The 55 mm increase was achieved by increasing the fallow efficiency from 19 to 33%. The reason that such a small increase of soil water increases grain yield so much is because the threshold amount of evapotranspiration required for grain production is already met and the additional water increases grain production directly.

Unger (1978) also showed that relatively small amounts of wheat residue left on the soil surface could significantly increase soil water storage during fallow (Table 2). Although the greater the amount of wheat residue left on the surface, the greater the amount of soil water storage, there was a significant increase in both soil water storage and subsequent grain sorghum yield from only 1 Mg/ha. This amount of wheat residue is commonly available even when grain yields are as low as 500 kg/ha. Therefore, even though there are not nearly as many crop residues available in semi-arid regions as desired, some benefits can be achieved by properly managing them. An upward spiral of crop productivity and soil quality can result but significant progress will take years, or even decades. In contrast to irrigation where dramatic increases can be achieved immediately, increasing yields in semi-arid regions by increasing the efficient use of limited precipitation is a long-term process. Policy makers must recognize this and more importantly, they must be willing to commit resources and develop strategies to promote soil and water management practices in semi-arid regions.

Although research involving conservation agriculture practices began soon after the development of herbicides, interest and adoption were limited because it was generally less expensive to use tillage. However, there was a great change beginning about 1973 as a result of the formation of the Organization of Petroleum Exporting Countries (OPEC) that resulted in dramatic increases in petroleum costs. These increases had an immediate effect on farmers in the US Great Plains and they began to look for ways to reduce the amount of fuel and the most immediate and effective way was to reduce both intensity and number of tillage operations. The research efforts devoted to developing limited-tillage, conservation tillage, and no-tillage systems increased dramatically and continue to this day.

Unger and Baumhardt (1999) summarized more than 50 yr of research studies conducted at Bushland, TX that is located in the Texas High Plains where the average annual precipitation is 470 mm and the annual potential evapotranspiration about 1880 mm (Stewart, 1988). Unger and Baumhardt (1999) compared the amounts of plant available water stored in the soil profile at the time of seeding grain sorghum from 1956 to 1997 (Figure 3). They further compared the average amount from 1956 to 1970 to the average of 1970 to 1997. As already stated, limited-tillage systems (herbicides and some tillage) and no-tillage (herbicides exclusively) systems became widely used in the early 1970s. On average, plant available water stored in the soil at time of seeding increased from 102 mm to 173 mm for these different time periods. Sorghum grain yields also increased significantly over the years (Figure 4). Yields increased 139 percent during the 1956 to 1997 period, or about 50 kg/ha annually. The authors attributed 46 of those percentage units to the use of improved hybrids, base on results of a uniformly managed 40-yr study. The remaining 93 percentage units were attributed to other factors, primarily to soil water at time of planting. The increases in soil water at planting, as stated above, were mainly due to the adoption of improved crop residue management practices after about 1970. Growing-season precipitation averaged 270 mm and total annual precipitation averaged 475 mm, but both were highly variable among years. For example, growing-season precipitation ranged from 76 mm in 1940 to 503 mm in 1960 and total precipitation ranged from 240 mm in 1970 to 828 mm in 1941.

Stone and Schlegel (2006) recently summarized yield and water supply relationships of grain sorghum and winter wheat from 1973 to 2004 at Tribune, KS, located in the central part of the US Great Plains where the annual precipitation is somewhat less than at Bushland, TX, but the potential evapotranspiration is also less. The relationship between grain sorghum yield and growing season precipitation is shown in Figure 5. Although the yield increases as precipitation increases, the relationship is poor and this is basically due to the fact that in most years there is not sufficient growing season precipitation to produce good yields. As already discussed, crop production in the US Great Plains is highly dependent on having a good supply of plant available water stored in the soil profile at time of seeding. The relationship between grain sorghum yield and plant available soil water at time of plant emergence is presented in Figure 6 and this relationship is considerably better than the one with growing season precipitation. The best relationship, however, is when grain yield is plotted as a function of field water supply (plant available soil water at emergence plus growing season precipitation) and this relationship is shown in Figure 7. Although there is a lot of scatter in Figure 7, the relationship is very positive. Much of the scatter is due to when precipitation events occurred because precipitation events can occur at critical plant growth stages or at times when additional water has little or no effect on grain yield.

In Figure 8, Stone and Schlegel (2006) compared the relationships between grain sorghum yield and field water supply for dryland conventional tillage and no-tillage treatment groups. These relationships are of great interest and show that increased residue amounts associated with no-tillage increased the amount of precipitation stored in the soil profile during fallow. Perhaps even more important, the increased residue resulted in more efficient use of growing season precipitation. These combined effects of no-till that is perhaps the ultimate conservation agriculture practice had a dramatic effect on increasing grain sorghum yield, and while no data are shown regarding soil physical properties, there is little doubt that these properties were also improved.

A final example of the benefits that can accrue over a long time from improved water management practices is the data shown in Figure 9. These are farmer yields of wheat grain for Deaf Smith County, Texas. The average annual precipitation for the county is about 450 mm and the annual potential evapotranspiration is about 1800 mm. Therefore, drought is a very common occurrence and severe water stress occurs every year. The yearly precipitation amounts show a range from less than 200 mm to more than 800 mm. A 10-yr moving average (each yearly point is the average precipitation amount for the year shown plus the nine previous years) line of annual precipitation is also shown and although there is some variation, the average annual amount has remained relatively stable. The county average wheat yields for each year are also shown in Figure 2 and there is also a line showing the 10-yr moving averages. It is noteworthy that the moving yield average and moving precipitation average closely paralleled each other until the early 1970s. Since that time, the moving average grain yield increased essentially every year and the average yield has more than doubled. No single factor is responsible because improved cultivars and management practices have all played a role. However, Figure 9 clearly shows that the use efficiency of the precipitation has dramatically increased. Water management is the first factor that must be addressed in dryland regions because other improved technologies such as improved cultivars and fertilizers are usually not beneficial without improved water management. The early 1970s was when the cost of oil and other energy sources increased rapidly and there was a concerted effort by researchers, extension personnel, and industry representatives to promote less tillage and more herbicide usage. This increased the amounts of crop residues remaining on the soil surface resulting in more soil water storage during fallow periods and higher crop yields. There is little doubt that reduction in tillage has been a significant factor in the increasing yield of wheat illustrated in Figure 9. The trend toward less tillage continues so it is anticipated that crop yields will also continue to increase, but at a slow rate. The quality of the soil resource base will also be enhanced if this trend continues because more crop residues will be produced and with reduced tillage, a higher percentage of the carbon in the crop residues will be retained in the soil as organic matter. The increased level of soil organic matter will improve soil physical properties and continue the upward spiral of crop production and soil quality.

Conclusion

Conservation agriculture is based on the principles of avoiding mechanical soil disturbance, maintaining a permanent soil cover by crop residues or growing crops, and crop rotation. While conservation agriculture has been highly successful in humid areas, its suitability for dryland regions has been questioned. However, there is ample evidence that shows some of the principles of conservation agriculture can be applied to dryland regions and crop productivity and soil quality can be enhanced as a result. The US Great Plains was a highly productive dryland region in the early years following conversion of the fertile grasslands to croplands. However, intensive tillage and cropping caused a rapid decline in soil organic matter levels and deterioration of soil physical properties. These changes, coupled with succeeding years of drought, resulted in the infamous Dust Bowl of the 1930s considered by many to be one of the greatest ecological disasters ever caused by human activities. Recovery of the area required a change in tillage practices that would leave some crop residues on the soil surface to control wind erosion. In the early 1970s, energy prices increased significantly and this led to a rapid increase in the development and adoption of conservation agriculture practices such as reduced-tillage (herbicides and some tillage) and no-tillage (exclusively herbicides). These practices have increased yields, improved soil physical properties, and controlled wind erosion. Adoption is still less than desired. Higher management skills and increased input costs are required, both of which are often lacking in dryland regions. Practices that work well one year may not work nearly as well the next because of differences in climatic conditions. Therefore, continued success in getting producers to adopt conservation agriculture practices in dryland regions like the US Great Plains will not be easy, and certainly not quick. The greatest constraint is that water is so limiting in these areas that the amount of crop residues is insufficient to maximize water use efficiency and quickly change soil organic matter content. In developing countries, residues are often removed from the soil for use as animal feed or household fuels and this further complicates the situation. The long-term sustainability of dryland soils, however, can be significantly enhanced by reduced tillage that leaves more crop residues on the soil surface. Researchers, change agents, and policy makers must promote these principles to the fullest extent feasible and develop strategies and policies that can be implemented successfully by the farmers.

References

Bilbro, J.D., B.L. Harris and O.R. Jones. 1994. Erosion control with sparse residue. p. 30-32. In: B.A. Stewart and W.C. Moldenhauer (eds.), Crop Residue Management to Reduce Erosion and Improve Soil Quality. Conservation Research Report No. 37, Agricultural Research Service, United States Department Agriculture, Washington, D.C.

Burnett, E., B.A. Stewart and A.L. Black. 1985. Regional effects of soil erosion on crop productivity _ Great Plains. p. 285-304. In: Soil Erosion and Crop Productivity. American Society of Agronomy, Inc., Crop Science Society of America, Inc., Soil Science Society of America, Inc., Publishers. Madison, WI.

Cornish, P.S. and J.E. Pratley. 1991. Tillage practices in sustainable farming systems. p. 76-101. In: V. Squires and P.G. Tow (eds.), Dry Farming – Australia. Sydney University Press.

Food and Agricultural Organization (FAO). 1996. Prospects to 2010: agricultural resources and yields in developing countries. P. 26-36. In: Volume 1 Technical Background Documents 1-5. World Food Summit, Food and Agriculture Organization of the United Nations, Rome.

Food and Agricultural Organization (FAO). 2002. Intensifying crop production with conservation agriculture. http://www.fao.org/ag/ags/AGSE/main.htm Food and Agriculture Organization of the United Nations, Rome.

Fryrear, D.W. 1985. Soil cover and wind erosion. Transactions American Society Agricultural Engineers 28:781-784.

Stewart, B.A. 1988. Dryland farming: the north American experience. p. 54-59. In: P.W. Unger, T.V. Sneed, W.R. Jordan, and R. Jensen (eds.), Challenges in Dryland Agriculture_A Global Perspective. Proceedings of the International Conference on Dryland Farming, August 15-19, 1988, Amarillo-Bushland, TX. Texas Agricultural Experiment Station, College Station, TX.

Stone, L.R. and A.J. Schlegel. 2006. Yield-water relationships of grain sorghum and winter wheat. Agronomy Journal 98:1359-1366.

Unger, P.W. and R.L. Baumhardt. 1999. Factors related to dryland grain sorghum yield increases. Agronomy Journal 91:870-875.

Unger, P.W. and J.J. Parker, Jr. 1976. Evaporation reduction from soil with wheat, sorghum, and cotton residues. Soil Sci. Soc. Am. J. 40:954-957.

Van Doren, D.M., Jr., and R.R. Allmaras. 1978. Effects of residue management practices on the soil physical environment, microclimate, and plant growth. p. 49-83. In: W.R. Oschwald (ed.), Crop Residue Management Systems. American Society of Agronomy Special Publication 31. American Society of Agronomy, Madison, WI.

Figure 1: The Great Plains extends from Mexico on the south well into Canada on the north.(for coloured picture see annex #3, p.286).

Figure 2: The Ogallala aquifer is one of the largest aquifers in the world and underlies a large part of the US Great Plains.

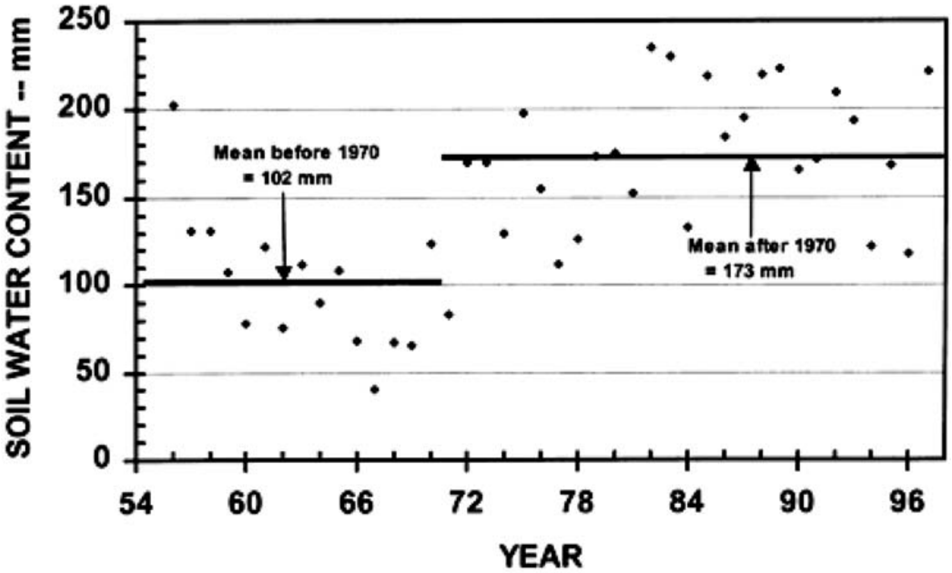


Figure 3: Average annual volumetric soil water content at planting time for dryland grain sorghum in studies conducted from 1956 to 1997 at the USDA-ARS Conservation and Production Research Laboratory, Bushland, TX (Unger and Baumhardt, 1999).

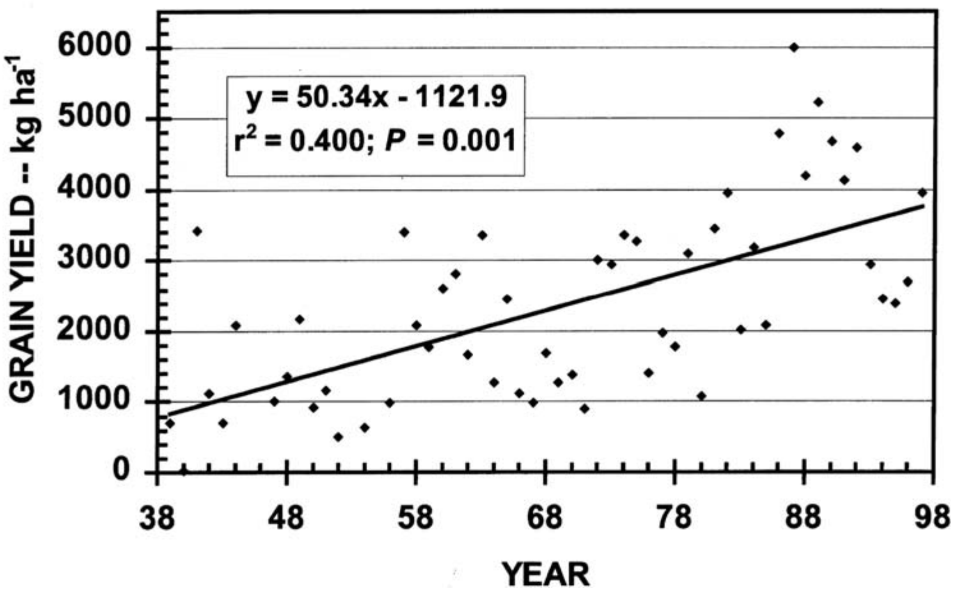


Figure 4: Average annual grain yields for dryland grain sorghum in studies conducted from 1939 to 1997 at the USDA-ARS Conservation and Production Research Laboratory, Bushland, TX (Unger and Baumhardt, 1999).

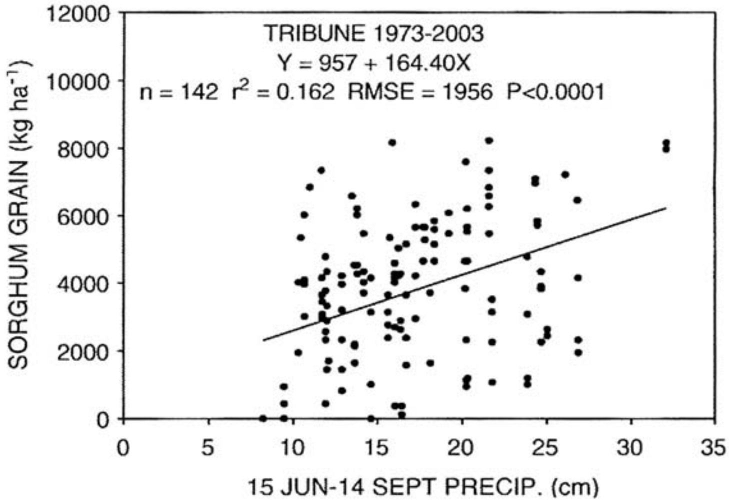


Figure 5: Grain sorghum yield at Tribune, KS associated with growing season precipitation (June 15 to September 14) (Stone and Schlegel, 2006).

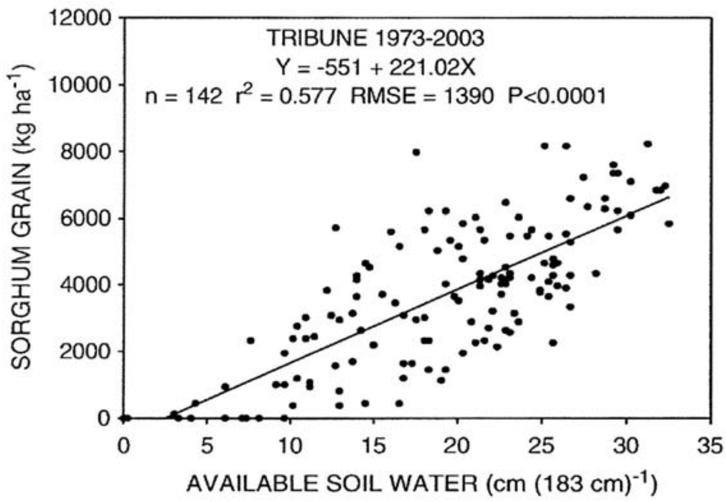


Figure 6: Grain sorghum yield at Tribune, KS associated with plant available soil water at emergence (Stone and Schlegel, 2006).

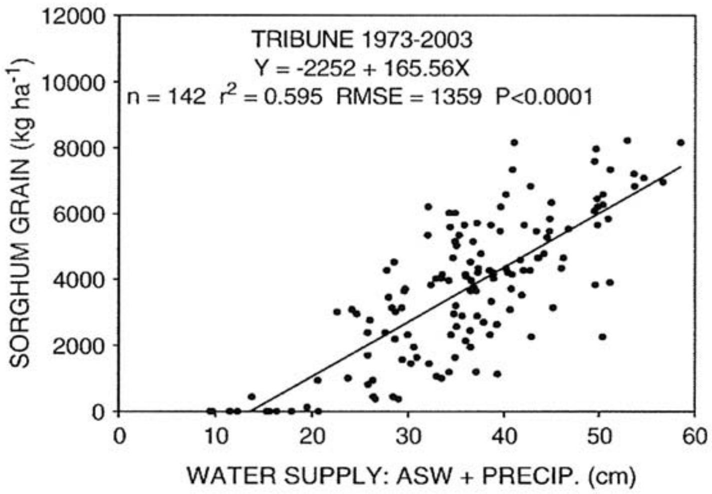


Figure 7: Grain sorghum yield at Tribune, KS associated with plant available soil water at emergence plus growing-season precipitation (Stone and Schlegel, 2006).

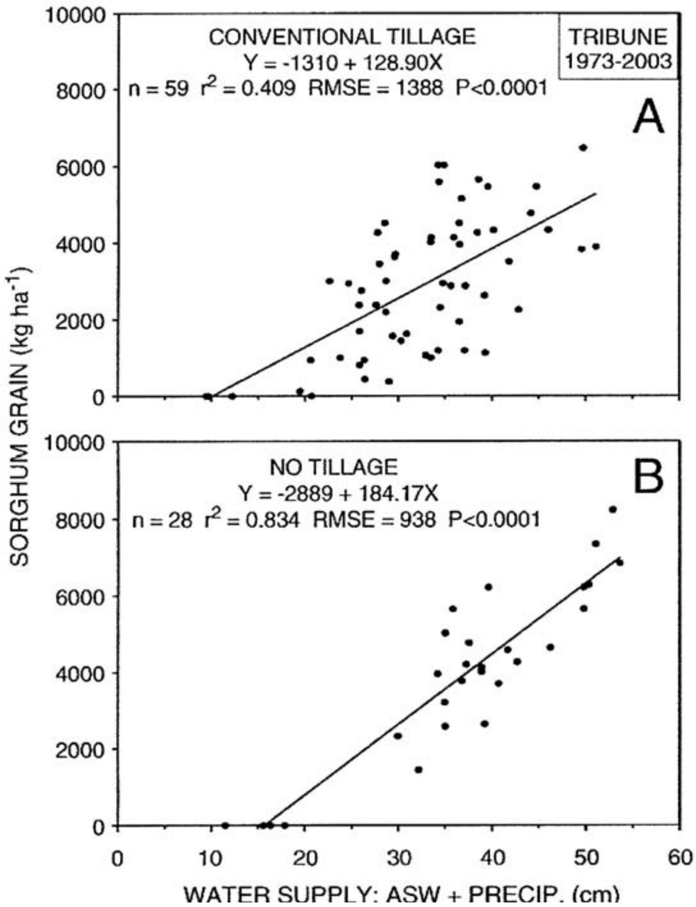


Figure 8: Grain sorghum yield at Tribune, KS associated with water supply (plant available soil water at emergence plus growing-season precipitation) for dryland conventional tillage (Section A) and for no-till (Section B) treatment groups (Stone and Schlegel, 2006).

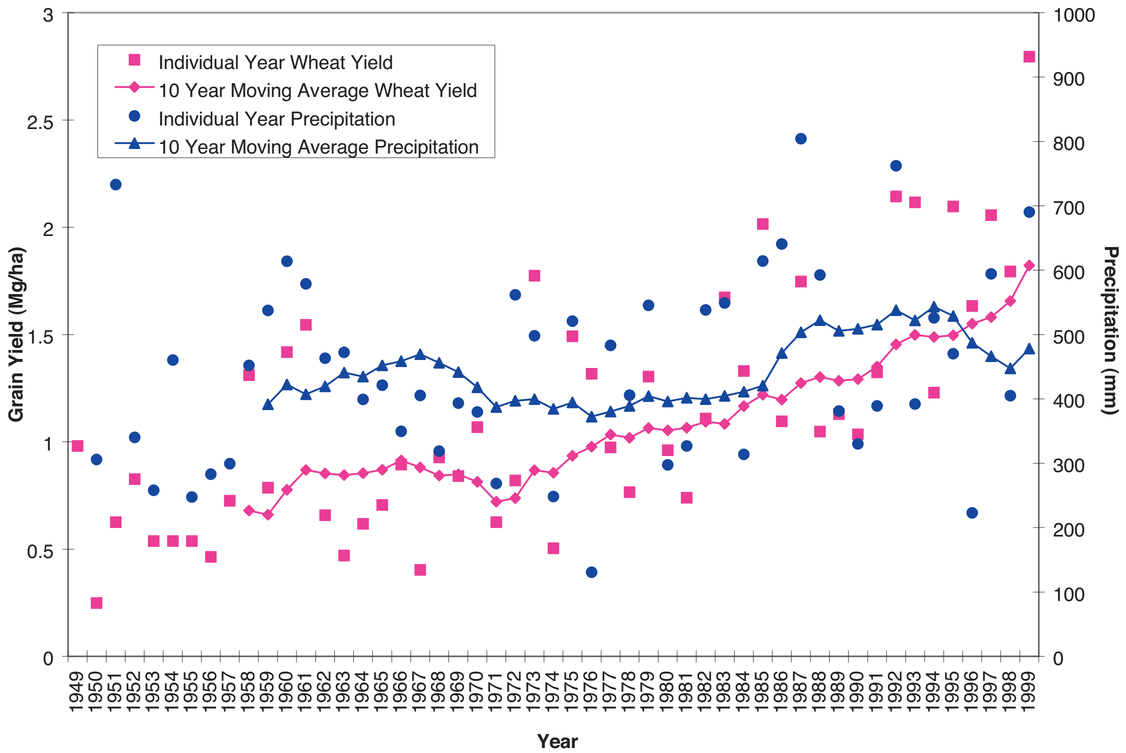


Figure 9: Relationship between annual precipitation and average wheat yields for Deaf Smith County, Texas, showing gradual increase in yield and improved precipitation use efficiency (Unpublished data, Zhen Wu, W.A. Colette, and B.A. Stewart, West Texas A&M University).

Table 1: Progress in wheat-fallow systems at Akron, Colorado (Greb et al., 1979).

Years	Tillage	No. tillage operations	Fallow water (mm)	Fallow efficiency (%)	Wheat yield (Mg ha^{-1})
1916-1930	Maximum tillage, plow and harrow	7 to 10	102	19	1.07
1931-1945	Shallow disk, rodweeder	5 to 7	118	24	1.16
1946-1960	Begin stubble mulch in 1957	4 to 6	137	27	1.73
1961-1975	Stubble mulch, herbicides in 1967	2 to 3	157	33	2.16
1976-1990	Minimum till, projected no-till	0 to 1	183	40	2.69

Table 2: Straw mulch effects on soil water storage during an 11-month fallow, water storage efficiency, and dryland grain sorghum yield at Bushland, TX.

Mulch rate (Mg ha^{-1})	Water storage[1] (mm)	Storage efficiency[2] (%)	Grain yield (Mg ha^{-1})	Total crop water use[3] (mm)	WUE [4] (kg m^{-3})
0	72 c[5]	22.6 c	1.78 c	320	0.56
1	99 b	31.1.b	2.41 b	330	0.73
2	100 b	31.4 b	2.60 b	353	0.74
4	116 b	36.5 b	2.98 b	357	0.84
8	139 a	43.7 a	3.68 a	365	1.01
12	147 a	46.2 a	3.99 a	347	1.15

1-Water use determined to 1.8-meter depth; precipitation averaged 318 mm during the fallow period.

2- Storage efficiency is percent of precipitation occurring during the 11-month fallow period that was stored in the soil at the end of the fallow period.

3- Growing season precipitation plus change in soil water during the growing season.

4- Water use efficiency (WUE) based on grain produced, growing season precipitation, and soil water change during the growing season.

5- Column values followed by the same letter are not significantly different at the 5% level (Duncan's multiple range test).

(Adapted from Unger, 1978.)

Evaluation of Conservation Agriculture Technology in Mediterranean Agricultural Systems

C., Cantero-Martínez[1], D. Gabiña[2], J.L. Arrúe[3]

*1- **Universidad de Lleida, Crop and Forestry Sciences Dept.***
Rovira Roure, 191. 25198 Lleida, Spain
email. Carlos.cantero@pvcf.udl.es

*2- **CIHEAM-IAMZ,** P.O. Box 202, 50080 Zaragoza, Spain*
Email: gabina@iamz.ciheam.org

*3- **Estación Experimental de Aula Dei (CSIC), Soil& Water Dept.***
Av. Montañana 1005, 50059 Zaragoza, Spain
Email: arrue@eead.csic.es

Introduction

Rainfed agriculture has been practised over large arable crop areas in the Mediterranean basin. In these areas, soils and water availability for crops and animals are the main limiting constraints. Soil conservation and efficient use of water are vital to stable and sustainable agricultural production. Both arable and livestock production that is developed around the Mediterranean Sea has been and will continue to be the main base of economic activity in these areas. The maintenance and efficiency of the farming practices, based on soil and water conservation, are therefore basic conditions for the sustainability of the rural population and to mitigate their migration to urban areas. Sustainable development of agricultural technologies also has to be considered to avoid the environmental degradation of these fragile agroecosystems. Conservation agriculture (CA) is a promising technology for these Mediterranean agricultural systems and has been proven effective for the conservation of soil, water, soil organic matter, and biodiversity. To provide farmers with timely access to this technology, linking research, advice and previous local knowledge is necessary. However, research, experimentation and development of this technology have been conducted with low intensity in the Mediterranean basin, with large differences between countries and areas.

This paper will present different activities carried out recently by CIHEAM-IAMZ, including studies, research and experimentation projects, showing the possibilities and constraints for the development of Conservation Agriculture technologies in the Mediterranean area. The activities include the development of the MEDRATE project (Cantero-Martínez and Gabiña, 2004) and the conclusions of the Third Mediterranean Meeting on No Tillage (Arrúe and Cantero, 2006). Because they concern the Mediterranean region, we will also describe the main findings and conclusions of the EU-funded KASSA project (Knowledge Assessment and Sharing on Sustainable Agriculture – *http://kassa.cirad.fr/*). Finally, we will show the present situation and prospects for future development of Conservation Agriculture in the Mediterranean region.

MEDRATE Project: (Evaluation of agricultural practices to improve efficiency and environment conservation in Mediterranean arid and semi-arid production systems)

Objective and Methodology

The MEDRATE project was aimed to assess the impact and degree of adoption of agricultural technologies specifically adapted to rainfed agriculture. The project was carried out from 2001 to 2003, coordinated by the Mediterranean Agronomic Institute of Zaragoza (IAMZ) and funded by the European Union (EC DG I – CIHEAM Cooperation Project, 1998-2002 Regional Action Programme "Rainfed agriculture" RAP-RAG) (www.iamz.ciheam.org/RAG2003.htm; Cantero-Martínez and Gabiña D., 2004).

Fourteen agricultural technologies were evaluated in the degree of the research, experimentation and farmer adoption in specific areas of eight countries (Algeria, Egypt, Italy, Morocco, Spain, Syria, Tunisia and Turkey). These technologies were aggregated in three specific groups of techniques: Land and water management technologies, Crop production technologies, and Animal production technologies.

Conservation Agriculture was the first technology assessed within the Land and Water technologies group. CA has been considered in this project as a crop production system that conserves physical, chemical and biological soil properties; protects against erosion; improves the soil-plant water balance; reduces crop and farm inputs through reduced tillage intensity; increases the use of conservation tillage systems, including no-tillage; and maintains crop-plant residues for mulching. In all cases, conservation agriculture was defined as (1). Reduced Tillage or Minimum Tillage consisting of one or two shallow harrowings before sowing that keeps enough crop residues; or (2) No Tillage and Direct drill, where there is a minimal soil disturbance. Residues are maintained on the soil surface or in some cases they are removed totally or partially. Weed control is carried out through spraying a non-selective-non-residual herbicide before sowing. A special no-till drill is used for sowing annual field crops.

Conventional or traditional tillage system was defined in all selected areas, as which is used by the farmer including a high level of soil disturbance in a cycle of operations such as subsoiling or mouldboard ploughing, following several passes of disking, harrowing, chiselling or other tillage methods. In orchard crops, the tillage system considered was spading in autumn to plough under fertilisers and skim ploughing (1-2) in summer for weed control.

Assessment was done at three levels: (1) research on the basis of available data coming from research centres in the area and country; (2) experimentation networking using the available data from the research centers and (3) farmer adoption analysed on the basis of surveys in the selected area among a number of farmer practising or not the possible different conservation agriculture techniques.

Several criteria were used to evaluate the impact of conservation agriculture in the region. Points that included this evaluation were: yield, yield stability, resources use and efficiency. (i.e., water, nutrients, etc.), quality of the product (i.e., fruit weight, protein content, oil content, etc. specified for each case), economical features, production cost and economical margin, environmental impact: loss of biodiversity, soil loss, soil organic matter, leaching, crop residues, etc., technical feasibility, need for training, gender impact and general social acceptance.

Results of MEDRATE project

In the selected areas of the region, at research and experimentation levels, several short and medium term experiments were carried out under different conditions. In most of the field crops experiments, treatments compared the performance of traditional/conventional tillage systems with that of reduced or no tillage systems. In some cases, where experiments involved trees (olive, almond or vineyards), a comparison between conventional (deep or shallow tillage) and no tillage, maintaining a live or dead cover on the soil was planned. Several experiments included treatments of nitrogen or phosphorus fertilisation rates, tillage time, sowing time, sowing rate, or performance of the system under different crop rotations.

In general yield was not always affected by tillage reduction but in some areas there was an increase of 70 % using conservation tillage systems. High variations were found between and within selected areas due to the specific cropping systems and environmental factors. More important than yield is its stability that is very positive when this alternative technology is used.

Water use by crop is not generally higher when conservation tillage technology is used. Nevertheless, information from queries shows that there is an improvement of WUE up to 30 % when conservation tillage technologies are used. Grain weight increased when conservative technologies are applied.

Weed control meant an increase in the production cost when reducing tillage. However, reduction in fuel and labour compensate these expenses, making these technologies much more beneficial.

There is a general agreement that soil loss is dramatically reduced when conservation agriculture technology is used. More crop residues and more soil cover from this residue are commonly found when reduced and no tillage systems are used; but there is some variation depending on the total biomass production. Reduction of leaching and improvement of soil organic matter have been appreciated as normal in some farming systems. Impact of pest and diseases is highly variable and dependent on the particular insect or disease. It could be an increment of use of agrochemicals when conservation agriculture technology is used, commonly due to more difficulties for weed control.

According to researchers and technical advisers, social acceptance of these techniques is highly positive. Feasibility is good in most of the crops, with the exception of tree crops where more specific training is needed. Indeed, there is a general recognition that the use of reduced and especially no tillage-direct drilling needs some training for producers and farmers.

At farmer level, a high irregularity of adoption was detected between countries and within some countries. Farmers have never used conservation agriculture in some areas, but in other cases (countries and areas) there are farmers that have been practising conservation agriculture technologies without interruption for the last 25 to 30 years. They recognize the high value of CA because of the reduction of labour (50 % of the time), reduction of mechanisation power (up to 30 %) and reduction of inputs (up to 25 %). Farmers are also concerned about the environmental impact, and 82 % of them recognise the positive environmental impact when tillage is reduced.

There are differences between users of CA regarding the amount of investment for equipment that is needed (medium to high). The general opinion is that there is 20 % less investment required for conservation tillage in comparison with conventional tillage. The access to technology has been easy for farmers, mainly by diffusion from farmer to farmer, and they also found a high assistance level from Extension and Research Services. They recognise a medium level of need for training in CA. between CA users, there is an acceptance to recognise the positive impact on the well-being of the community.

Non-users had a lower level of instruction, and only 15 % of the farmers reached secondary school and 15 % are illiterate. Disadvantages of the CA technology for non-users are high investment, high inputs (herbicides), technological difficulty, and low to medium degree of knowledge of the technology.

General conclusions of MEDRATE project regarding Conservation Agriculture

The results showed CA as one of the main promising technologies to develop for the Mediterranean Region. However, there is still a general low level of adoption by the farmers. This would indicate that there may be problems in the adaptation of the technologies to farmers' conditions, especially the small farmers in some Mediterranean countries, or that the relations between research and extension services may not function adequately. The number of demonstration projects should be increased, Networks of long-term experiments established, and more investment in research on training and extension work.

At the end of the MEDRATE project improvements, limitations and conditions of use for development of CA in Med regions are summarised.

Improvements. The use of CA in the Med Region can improve crop productivity. The water balance can be improved through increased infiltration rates, and a reduction of runoff and evaporation resulting in an increase of soil moisture, crop water availability and finally water use efficiency. The increased amount of crop residues that cover the soil surface is advantageous for erosion control and for the increase of soil organic matter content. Economical margin is improved due to less fuel and labour utilised in this alternative technology.

There are disadvantages and limitations for CA, but they are usually detailed for given cropping systems. Incidence of pest, diseases and weeds has been reported. It needs specific application of herbicides and higher rates in some cases. In some circumstances, infiltration has been reduced due to compaction of the soil surface. In particular conditions, continuous addition of crop residues lead to stubble and residue accumulation, making planting operations and seedling emergence more difficult. With the use of these techniques that are based on maintaining crop residues, less of this material can be used for livestock feeding and bedding. Stubble grazing is also reduced.

Regarding machinery, a specific drill is needed, and farmers have difficulties acquiring this machinery. Some chisels and specifically direct drill machines are not available. The supplies do not arrive and the price of the machinery is high. This situation makes CA technology not accessible to farmers. The problem is more important when the landholding is small. Sometimes the power of the tractor is low and unsuitable for the new equipment.

Soil compaction is another very common limitation in clay and heavy textured soils and also when sheep grazing is practised under wet conditions. Furthermore, high accumulation of residues can produce physical and allelopathic problems.

Several conditions of use should be taken into account. Maintaining all crop residues chopped on the soil surface is needed for optimum crop residue management. In high yield areas and when crop residues exceed decomposition, some amount of the crop residues should be removed to facilitate seedbed preparation. Otherwise, it is important to change the sowing date, earlier or later sowing, depending on weeds and diseases situations. For adoption and recommendation within a farming system perspective, crop rotation, forage crop production and livestock management should be taken into account at farm level.

Conservation technology can be widely recommended in the soils of these areas; however it should be experimented locally to determine the best conservation tillage system. In some cases, minimum tillage is a better option than no-till to conserve soil and water. There is a need for specific research to identify farms and their socio-economical characteristics that could adopt the system. There is also a need for specific transfer of technology programmes to promote knowledge and development.

Third Mediterranean Meeting on No Tillage

Introduction

Three international meetings on No Tillage have been organised in the last few years in the western part of the Med Region. The first was held in Settat (Morocco) in October 2001. The second was in Tabarka (Tunis) in January 2004, and the last one was in Zaragoza (Spain) under the auspices of the Mediterranean Agronomic Institute of Zaragoza (International Centre for Advanced Mediterranean Agronomic Studies).

In all of them, researchers, agriculturalists and farmers, all interested in No Tillage, were working together sharing experiences on the development and limitations of CA technology. In all cases the conclusions coincided in the high interest of this promising technology and showed the benefits and particularities for solving problems related with several aspects of this cropping production system.

Third Mediterranean Meeting on No Tillage: Conclusions and Recommendations

This meeting was organised in four sessions and a field trip and welcomed more than 150 people coming from nine countries of the Med Region. Specialists on different topics of the No Tillage technology showed and discussed the benefits of CA on agronomic, environmental and socio-economic aspects for the sustainability of the Mediterranean Agriculture. Soil protection, improvement of water availability for crops, and enhancement of the biological aspects of the soil and global biodiversity were highlighted in the meeting. Particular attention was pointed out on the socio-economic aspects and in the mechanisms for technology transfer. Previous meetings and projects such as MEDRATE and after described KASSA, detailed the scarce resources used for the training and transfer of the knowledge from the research and experimentation, as one of the main limitations to develop CA.

Conclusions from the experiences presented from the researchers coincide in the positive improvement in yield and yield stability offered by No Tillage. Production costs are lower when tillage is reduced. Environmental aspects such as soil protection, water accumulation and biodiversity were enhanced by no tillage. However aspects such as weed control, crop residue management, allelophatic effects, and livestock interactions are still to be improved and need particular treatment depending on the cropping system. No Tillage in wet and irrigated systems and use of crop cover in tree crops (olive, almond, etc) requires more information and development.

Finally, an integrated approach to joint research programmes with users of No Tillage was strongly recommended, taking into account the socio-economic value for the sustainability of the Med Region. Training programmes at research and farmer level should be designed in the forthcoming years. A network of long-term experiments should be established to make a holistic analysis and evaluation of the integrated approach of technology focused on the conservation agriculture production system. Farmers associations should be established and activities for dissemination of this technology encouraged.

KASSA Project (Knowledge Assessment and Sharing on Sustainable Agriculture)

Objectives and Methodology

The KASSA project was a specific Support Action –SSA funded by the EC FP6 within the research priority Global Change and Ecosystems. KASSA was focused on conservation agriculture with the participation of 28 partners in 18 countries in Europe, North Africa, South-East Asia and Latin America.

The main objective was to assess the existing knowledge on conservation agriculture in the areas of the participants. Work analysis was distributed in four regional platforms: Asia, Europe, Latin America and the Mediterranean. This structure allowed comparison of conservation agriculture practices and experiences across agroecosystems within a large diversity of climates, soils, crops and farming and cropping systems and socio-economic conditions. KASSA partners spent 18 months analysing the information available on CA at the research level. Also, partners paid attention to the information obtained from technical, advisers and farmers involved in CA. Several workshops within the platforms and coordinating meetings were held to share the findings among the different platforms. This iterative process has resulted in a comprehensive knowledge base on practices, conditions and challenges related to CA. Finally a general meeting was organized with all partners in February 2006 to detail the general and particular conclusion and recommendations for further development of CA.

Main findings and conclusion of CA from KASSA partners.

Conservation agriculture is spreading in Latin America and Asia but is its adoption in Europe and North Africa is scarce and irregular. Its impacts on agricultural productivity and the quality of the natural resource base are not well understood.

Reduction of costs in machinery and fuel and time-saving is the main reason for the introduction and adoption of conservation agriculture technologies. Other factors that contribute to adopting CA are: flexibility of field operations, possibility to grow more than one crop, reduction of soil erosion and water budget for the crops.

When problems with weeds, pest and diseases make the technology less profitable for farmers, an integrated management strategy regarding sowing date, plant density, fertilization and other cropping technology is necessary and not always available. Besides this main limitation, there is also the problem of lack of knowledge between farmers and technicians or cultural barriers discriminating against their use. Sometimes suitable implements are not available. Biophysical conditions are not always favourable as in several cold and wet soils where the use of soil cover and no-till result in cooler soil temperatures, delayed sowing, and depressed yields. No-till is sometimes not suitable for soils prone to compaction. Conservation agriculture technologies are generally unsuitable where soil cover from crop residues is either inadequate (dry lands conditions, livestock competition for biomass) or in excess (wheat straw in temperate climate, rice straw in rice-based systems).

The major gaps in knowledge arise from the impact of conservation agriculture technologies on soil biological processes, on the impact of agro-chemicals, on farm incomes and costs, employment, rural development in both small scale and large scale farming taking into account the conditions of market, policy and institutional change.

There is a need for better information and decision support tools on site specific suitability of conservation agriculture based on climate, soils and technologic and socio-economic conditions.

Particular aspects of the Mediterranean Regions. Conclusions of the Mediterranean platform.

Conservation agriculture is irregularly distributed throughout the Mediterranean. Adoption in European Mediterranean countries has been greater than in North African countries.

The main reason for adoption was the necessity for input reduction of fuel, machinery and labour. No-tillage and cover crops are used between rows of perennial crops such as olives, nuts and grapes. Conservation agriculture is widely used for field winter crops. Occasionally it is used for traditional rotations with legumes, sunflower and canola, and much less in field crops under irrigation.

In the Mediterranean dryland areas, the agronomic and environmental objectives of CA have been related with soil and water conservation. In irrigated areas, conservation agriculture aims to optimise irrigation system management to conserve water, energy and soil quality and to increase fertilizer use efficiency.

The major reasons for shifting to CA can be summarised as: (1) better farm economy (reduction of costs in machinery and fuel and time-saving in the operations that permit to develop other agricultural or non agricultural complementary activities); (2) flexible technical possibilities for sowing, fertilizer application and weed control; (3) yield increase (10% to 15% higher) and greater yield stability; (4) soil protection against water and wind erosion; (5) greater nutrient-use efficiency; and (7) better water economy in dryland areas.

Some limitations have arisen for weed control, soil compaction, local pest and diseases and crop residue management. The adoption of conservation agriculture leads to the need to revise the whole management process. The gaps in knowledge in crop and soil management under conservation agriculture are related with the lack of specific data to which extent conservation agriculture helps to improve water-use efficiency in these water-scarce ecosystems. In rainfed agroecosystems, residue management questions are significant (residue scarcity by low production for mulch and competition with their use for livestock fodder). Farmer use of conservation agriculture is limited and follows the traditional control for weeds, pests or diseases without considering integration of different possibilities. Information on strategies to introduce conservation agriculture into irrigated agriculture is rare.

The lack of farmer information and training regarding CA is an important constraint. There is a concern about the time needed to reach a complete adaptation or stabilisation of CA and on crop rotation performance. There is little research conducted to date solely on sociological and economic factors concerning the evolution and the social impact of conservation agriculture systems. There is a gap in knowledge regarding methods for helping policymakers reach prudent, sensible decisions on topics touching on conservation agriculture.

Challenges for development of CA in Med Region

The main challenge in the Med Region is to develop CA site-specific tactics to the dry farming practices that are leading to resource degradation, including soil losses, soil organic carbon and fertility decline, which favour desertification.

CA is very attractive and should be adopted in Med Region through the enhancement and the maintenance of soil cover which reduce soil erosion and water losses and improve soil fertility. These should be addressed through an increase in biomass production by the use of drought-tolerant varieties with high water use efficiency and the introduction of new drought-tolerant cover crop species, and by the improvement of crop residue management, by improving water productivity in water-scarce rainfed agroecosystems, and thereby improving food safety and quality.

For CA adoption, another challenge is the development of innovation systems by information dissemination and training of farmers and technicians. Subsidy and credit programmes for the purchase of implements may serve as drivers of conservation agriculture adoption particularly by small-scale farmers. Policies should be addressed to support conservation agriculture research and development.

References

ARRÚE JL., CANTERO-MARTINEZ C. (Eds.) 2006. Third Mediterranean Meeting on No Tillage. Options Méditerranéennes, Serie A, No. 69, 210 pp. (ISBN. 2-85352-343-8).

CANTERO-MARTÍNEZ C. 2002. Evaluation of agricultural practices to improve efficiency and environment conservation in Mediterranean arid and semi-arid production systems. An example for conservation tillage. Workshop on Research for development. VII Congress of the European Society for Agronomy. Córdoba, July 2002.

CANTERO-MARTÍNEZ C. 2003. Evaluation of water management and crop production technologies in Mediterranean arid and semiarid systems. Seminar on Optimization of water use by plants in the Mediterranean. Association of Applied Biologist. Mallorca. March 2003.

CANTERO-MARTÍNEZ C., GABIÑA D. (Eds.) 2004. Mediterranean Rainfed Agriculture: Strategies for Sustainability. Options Méditerranéennes, Serie A, No. 60, 335 pp. (ISBN 2-85352-294-6).

CANTERO-MARTINEZ C. 2005. Evaluation of agricultural practices to improve water use and water use efficiency in Mediterranean arid and semi-arid production systems; MEDRATE project. Workshop: Improving Water Use Efficiency in Mediterranean agriculture: what limits the adoption of new technologies? Rome. September 2005.

KASSA PROJECT (Knowledge Assessment and Sharing on Sustainable Agriculture); http://kassa.cirad.fr/.

MEDRATE PROJECT (Evaluation of agricultural practices to improve efficiency and environment conservation in Mediterranean arid and semi-arid production systems); www.iamz.ciheam.org/RAP-RAG/research.htm

Challenges and Opportunities for Conservation Cropping: Icarda Experience in Dry Areas

M. Pala, A. Haddad and C. Piggin

International Center for Agricultural Research in the Dry Areas (ICARDA)

P.O. Box 5466, Aleppo, Syria

Abstract

Conservation agriculture is the integration of natural resources management with sustainable and economic agricultural production. As the concept was being developed in countries such as the UK, America and Australia in the 1970s, ICARDA also developed a program to serve the West Asia and North Africa (WANA) region, where natural resources were strained to meet the food needs of its burgeoning populations. ICARDA initially focused its research on the fundamental elements of the natural resource base, soil and water, and how these interacted with climate, to define existing cropping and animal production systems, and on breeding of stress resistant, high yielding cereal and legume crops. Agriculture in the WANA region is primarily based on rainfed cropping during the relatively cooler late fall to early spring, where rainfall ranges generally between 200 to 600 mm per year. Dry area crops are mainly wheat, barley, food legumes (lentil, chickpea, and faba beans) and forage legumes (medics, vetch, and lathyrus). Increasing human and livestock populations have led to increasing natural resource degradation in the region. The improved understanding of the biophysical processes set the scene for more of a “systems approach” through a series of long-term cereal-based rotation trials in the mid 1980’s embracing soil, crop, and animal components of the farming system in a manner simulating real-farm conditions. Conservation cropping revolves around the concepts of minimal soil disturbance, organic matter retention and diverse rotation, as well as good agronomy/crop management, and has many benefits including: savings in time, fuel and machinery wear; better soil structure; better soil-water dynamics (organic matter, porosity); improved traffic ability and more timely sowing; higher yield potential; and less erosion. The development of zero-till direct sowing has allowed conservation cropping to flourish around the world. An important global benefit is better sequestration of carbon for a more sustainable environment. Results from ICARDA and the region have shown the benefits of minimum- and zero-tillage over deep-tillage systems, especially in terms of increases in crop yields, soil organic matter, water use efficiency and net revenue. They also show the importance of crop diversification, with legumes providing improved soil quality, N-fertilizer use efficiency and water use efficiency in the system. Inclusion of oilseed crops in rotations has potential to enhance productivity, efficiency and sustainability and address widening deficits in supply and demand of vegetable oils in the region.

Keywords: Crop rotation, zero-tillage, conservation cropping, C sequestration, sustainability

Introduction

The availability and quality of land and water resources are of great importance across dry areas, where ICARDA serves, with scarcity of water a major factor limiting agricultural production. Sustainability of these resources is under pressure from high population growth rates which increase the demand for food, feed, and other agricultural products (Whitman et al., 1989). Production increases from more favourable lands are also declining, forcing people to use marginal lands. Thus, both marginal and fertile lands are currently suffering from various forms of degradation, including nutrient depletion, soil erosion, and reduction of soil water retention because of mismanagement of the natural resources and improper application of production practices.

Dry areas occupy over 85% of the areas receiving between 200 and 600 mm mean annual rainfall with high temporal and spatial variability. All winter sown crops, with their small canopy and low evaporative demands in winter months, are increasingly exposed to drought in the spring or early summer when evaporative demand is high, mostly at flowering and grain filling stages, and are largely dependent on stored soil moisture to complete their growth cycles (Cooper et al., 1987a). A small proportion of the available water is actually transpired by the crop with major water losses related to factors such as surface runoff, deep drainage, evaporation from the soil surface and deep cracks, and transpiration by weeds. Farm-level techniques are needed to reduce these losses and increase the proportion of available water transpired by the crop.

Increasing populations and higher demand of food and feed force us to increase productivity of water through increased crop yields. Improved soil and crop management practices combined with improved crop cultivars are needed to reduce water losses and increase transpiration efficiency of the cropping systems for sustainable productivity increases. Soil quality, soil fertility, water supplies and crops all need to be managed effectively and conserved through sustainable husbandry of natural resources and through investments in land improvement. Effective soil, water, and nutrient management require actions not only at the farm level, but also at community, regional, and national levels to achieve conservation cropping.

Conservation agriculture (CA) is the integration of natural resources management with sustainable and economic agricultural production (Dumanski et al., 2006) providing beneficial ecosystems services such as 1) food and fiber and biofuels, and 2) less erosion, less pollution, clean water, fresh air, healthy soil, natural fertility, C sequestration, sustainability and higher production (FAO, 2002). It is gaining a common acceptance in many parts of the world as an alternative to conventional agriculture which can cause high soil density, low organic matter through oxidation and mineralization, high erosion, severe drought effects on crops, low soil fertility, low responsiveness to fertilizers and environmental degradation (FAO, 2002).

Conservation cropping (CC) is a major part of CA, and is based on the principles of: improving the soil; efficient and effective use of crop production inputs such as water, fuel, fertilizer, pesticides and labor; and optimizing profits by employing improved agronomic practices as an integral part of production systems. However, conventional farmers' practices are still commonly applied because of traditional knowledge developed locally over thousands of years, and are difficult to replace in a short period of time. Nevertheless, we need to persist with the development and promotion of CC systems which are cheaper, more productive and more environmentally friendly and sustainable compared with the conventional cropping.

The important components of conservation cropping are minimal soil disturbance through zero tillage or direct sowing; timely sowing; balanced application of fertilizers; diverse crop rotations with legumes and oilseeds; and integrated pest management with less chemical use. These promote more sustainable production systems through reduced soil erosion with less soil and water pollution;

reduced input use; improved water use efficiency; and increased C sequestration with reduced emissions of greenhouse gases.

As production systems varied from one ecosystem to another, agronomic management practices have to be carefully tailored to those conditions and applied with farmers' participation from planning and implementation to evaluation for successful results. The objective of this paper is to summarize the present status of ICARDA research with respect to important components of conservation cropping with a specific emphasis on zero-till direct sowing.

Conservation Cropping Practices

In the rainfed production systems of dry areas, seasonal rainfall often defines the upper boundaries of crop yield potential under improved management practices. Research has been carried out by ICARDA in collaboration with national agricultural research services to overcome constraints limiting productivity and sustainability of cropping systems through improved soil quality, water use efficiency a and water productivity. Zero-till mulch-based direct sowing, early planting, improved crop varieties, efficient use of fertilisers, pesticides, and herbicides, and diverse crop rotations can assist in both conserving natural resources and increasing productivity through increasing available water , increased transpiration and decreased evaporative losses (Harris et al., 1991a).

Crop Rotations

There is increasing concern about the deterioration of integrated crop/livestock systems because of increased continuous cereal cropping resulting from increasing demand for food and feed. Cereal-fallow and continuous cereals are the common crop rotations of the dry areas, particularly in WANA region, but including legumes in the rotation has proved to be beneficial for sustainable crop production (Harris et al., 1991b; Harris, 1995). In addition, wheat-legume systems can result in higher soil organic matter content (and hence higher soil quality) than continuous wheat and wheat-fallow (Ryan, 1998). The decline in yield under continuous barley is a problem, but the causes of the poor productivity are not clear (Harris, 1994). The major effect of legumes is generally attributed to N fixation and improved soil physical conditions (Masri et al., 1998).

The overall effects of rotations on cereal yields after 14 years under seven crop rotation cycles (Ryan et al., 2008) were similar to those observed by Harris (1995) after only 7 years. Rotation effects seem to express themselves with respect to cereal yields in a relatively short period of time for simple 2-course rotations. The highest wheat (Cham 1) yield (2.43 t/ha) was obtained from a wheat-fallow rotation, and the lowest yield (1.08 t/ha) was found under continuous wheat. Percentage yield increases of wheat following other crops in the rotation compared with that of continuous wheat were 47, 73, 90, 100, and 112% after chickpea, medic, lentil, vetch and melon, respectively.

Clearly, continuous yearly cropping with cereals is an unsustainable practice. Fallowing is equally unattractive, especially economically as a crop is harvested only once in every two years and the land lies idle in the alternative fallow year. Legumes grown in a cereals-legume rotation improve the water-use efficiency of the system because, with their usually shorter growing period, some water is left in the soil profile to be used by the subsequent cereal crop, increasing the latter's productivity (Karaca et al., 1991; Harris, 1995). The major contribution of the trial was in showing the merits of food and forage legumes as alternatives to either fallow or continuous cereal cropping. Of the forage legumes, vetch emerged as the most attractive alternative to fallow or monoculture since it produces a valuable animal feed, either grazed or cut for hay, in the alternative year, in addition to acceptable cereal yields.

In order to get the maximum sustainability benefit of the cropping systems with proper crop rotation, improved varieties which are well adapted to specific conditions with efficient soil water use, tolerance to abiotic stresses such as cold, drought, and heat and biotic stresses such as diseases and insects, and increased crop yield levels, have to be an integral part of the management practices for conservation cropping.

Early Sowing

As water resources are limited, water conservation should focus on increasing water transpiration by crops relative to the evaporation from the soil surface in a given cropping season. Directing biomass production into periods of lowest atmospheric demand confers an advantage (Gregory 1991; Gupta 1995). In the winter rainfall dry environments, despite temperature limitations to growth, early sowing allows the major part of the crop's growth cycle to be completed within the cool, rainy winter/early spring period (Cooper & Gregory 1987). Attempts made to persuade WANA farmers to move from spring to winter sowing of chickpeas gave 30-70% yield increases (Silim and Saxena 1991; Pala & Mazid 1992a; Erskine & Malhotra, 1997). Similarly, grain yield increases of 20-25% were obtained by early sowing of lentil in mid-November instead of sowing in early January (Silim et al. 1991; Pala & Mazid 1992b). Winter sowing produces plants with a larger vegetative frame capable of supporting a bigger reproductive structure, leading to greater WUE and increased productivity (Cooper and Gregory 1987).

Early sowing depends on the tillage/crop rotation system employed. In highland areas of the WANA region, proper fallow tillage practices as well as sufficient precipitation will permit timely stand establishment of early sown crops and result in higher yield by extending the period of vegetative growth under cereal-fallow rotation systems (Pala, 1991). Delaying sowing date will delay crop germination and seedling establishment because of a rapid drop in air temperature in November. Supplementary irrigation of about 50 mm applied at sowing can increase water and crop productivity significantly by allowing earlier emergence and establishment before cold season (Tavakkoli & Oweis, 2004; Ilbeyi et al., 2006).

In the lowlands of the Mediterranean regions, where continuous cropping of pure cereal or cereals-legume rotations prevails, mid-November was found to be an optimum sowing date for cereals (Keatinge et al., 1986; Acevedo et al., 1991) with 200-250 kg/ha yield decrease for every week delay from the optimum. Sometimes the time required for tillage applications may create the difference in sowing date, as reported by Pala et al. (2000), where wheat grain yield was increased by 14% averaged over 10 years by early sowing in November compared with late sowing in December with a range from none to 109% increase. Lentil was more responsive than wheat, with a mean yield increase averaged over 10-years of 61% when planted in mid October compared with mid December planting with a range from none to 12 folds increase. Mean WUE of wheat increased by about 10 % and that of lentil by 48% (Pala et al., 2000).

Soil Fertility Management

Nitrogen (N) and phosphorus (P) deficiencies are common in dry areas (Matar et al., 1992). These strongly contribute to the uncertainty of crop production (Cooper, 1991). Improved soil fertility increases productivity and, consequently, WUE (Cooper et al. 1987b; Cooper, 1991). On-station and on-farm fertility research has resulted in appropriate recommendations for fertilizer use in the region (Cooper et al. 1987a; Harris et al. 1991a; Jones and Wahbi 1992; Matar et al. 1992; Pala et al. 1996; Ryan 1997) and demonstrated the benefits of appropriate fertilization on WUE through increasing water transpiration by crops, especially wheat and barley.

In deficient soils, P applied together with a small dose of N at planting enhances the rate of leaf expansion, tillering, root growth, and phenological development, ensuring more rapid ground cover and canopy closure, and earlier completion of the growth cycle before the vapour pressure deficit increased with rising temperature in spring (Gregory 1991). The results also confirmed the observation that, in the WANA region, responses to N are more important under favourable conditions, while responses to P are higher under dry conditions (Cooper, 1991; Jones & Wahbi 1992; Pala et al. 1996a).

Tillage

In the past, ICARDA has given special emphasis to the assessment of tillage systems for efficiency, enhanced productivity and sustainability together with partners from the NARS (Harris et al., 1991; Harris, 1995; CIMMYT and ICARDA, 2000; Pala et al., 2000 & 2005; Suleimenov et al., 2001a & 2001b; Ryan et al., 2004). Over much of the region, it is the usual practice to cultivate with a disc or mouldboard plough to a depth of 20 to 30 cm each year and then prepare the seedbed with either disk harrow or ducks-foot type implement, which leaves the soil bare and loose, increasing the risk of erosion by water and wind. The choice of tillage system must accommodate the need to conserve soil and water. When the land is untilled since the previous harvest, in all but the lightest soils, it is necessary with traditional implements to wait until early rains have moistened the soil sufficiently to permit soil penetration. Research-derived recommendations to cultivate after harvest or before the next rains to assist infiltration are often inapplicable because the soil is too dry and hard and implements are not powerful or robust enough. More recently developed direct drill (zero tillage) machinery with narrow tines or discs does permit penetration and opens up many options for changed crop establishment and tillage methodology, but has not been widely researched nor taken up by farmers in the region, as discussed below.

Currently, most staple cereals (overwhelmingly the predominant crop) continue extracting soil moisture beyond the end of the rainy season, so that after harvest many soils are unworkable until the next season. One solution is to give priority to the basic needs of the tillage operation, and to increase the flexibility of the cropping system by introducing new varieties and species of shorter growth cycle, or forage for hay production for early harvest. The underlying logic in all cases should be soil management to optimise the provision of water to crops most able to utilize it productively (Harris et al., 1991a).

In the long-term, tillage can be expected to cause breakdown of the surface structure and increased crusting. In soils where the surface structure is inherently weak, cultivation rapidly leads to surface degradation, reduced infiltration, and failure of crops to emerge through the solid crusts (Cooper et al. 1987a). Where arable land in dry areas is cropped every year, inter-season management may significantly affect soil moisture. Post-harvest control of weeds, by tillage or grazing, is important whenever residual moisture is left in the soil by a shallow-rooted, short-cycle, or early harvested crop such as legumes. In other areas, systems utilizing zero-tillage, reduced-tillage and/or crop residue retention treatments have been credited with reducing evaporative loss of water, as well as improving infiltration and reducing erosion (Bolton 1991; Papendick et al. 1991). In studies reported by Pala et al, (2000), general trends in soil water change were the same for all tillage practices. Although zero-tillage and minimum tillage treatments left more water at harvest compared with the deep tillage practices and were more energy efficient, no yield differences were observed.

FAO (2002) reported the factors affecting C sequestration potential of soils, listing irrigation water management (6%), land use change (7%), land restoration (13%), improved cropping systems (25%) and, most importantly, conservation tillage and residue management (49%). Conservation tillage and zero-tillage direct drilling systems are given specific emphasis below.

Conservation Tillage and Zero-till Mulch-based Direct Sowing:

Alternatives to conventional tillage mentioned above include 'zero-till' and other 'conservation tillage' systems. The zero-till system is a useful approach to solving the problems of soil erosion, soil fertility and soil with low water-holding capacity (FAO, 2002). Conservation tillage retains plant residues from previous crops on the soil surface (stubble retention) that can increase infiltration and reduce losses of soil or water relative to conventional tillage. Zero tillage is a 'cornerstone' of Conservation Cropping (CC), and can be practiced in both large and small farming systems. With zero-till direct drilling the only tillage operations is low-disturbance seeding techniques with narrow tynes or discs for application of seeds and fertilizers directly into the stubble of the previous crop. Gradually, organic matter of the surface layers of zero tilled land increases with an organic mulch developed on the soil surface, and this is eventually converted to stable soil organic matter because of reduced biological oxidation compared to conventionally tilled soils (Dumanski et al., 2006).

Most of the benefits of zero tillage relate to increased organic matter and available water in the soil with major overall effects of less erosion, more healthy soil, natural recycling of fertility, higher sustainability and higher production (FAO, 2002). In dry years, the improved moisture, aggregation and organic matter status of the zero till soils often ensure yield where conventionally tilled soils do not. Profit margins with zero tillage are normally better than under conventional tillage systems, and this enhances the sustainability and future continuity of the CC systems (Dumanski et al., 2006; Ibno Namr and Mrabet, 2004). Stability of the soil organic matter under zero tillage, due to enhanced soil aggregation and reduced erosion, enhances sequestration of carbon and contributes to mitigation of greenhouse gas and climate change issues.

Soil carbon sinks are increased by increased biomass due to increased yields, as well as by reducing organic carbon losses from oxidation and soil erosion. Fuel use and tractor hours are reduced up to 75%, with further reductions in greenhouse gas emissions (Dumanski et al., 2006). Zero tillage is applied on more than 95 million ha worldwide, primarily in North and South America. Approximately 47% of the zero tillage technology is practiced in South America, 39% is practiced in the United States and Canada, 9% in Australia and about 3.9% in the rest of the world, including Europe, Africa and Asia (Dumanski et al., 2006).

To evaluate, modify and promote conservation cropping, ICARDA has conducted zero and reduced tillage related research in various cropping systems around the West Asia and North Africa (WANA) region covering diverse agro ecological conditions in the mild lowlands in Syria, cold continental conditions of Central Asia and cold highlands in Turkey. The results from some of this work in the mild lowlands of West Asia are discussed below.

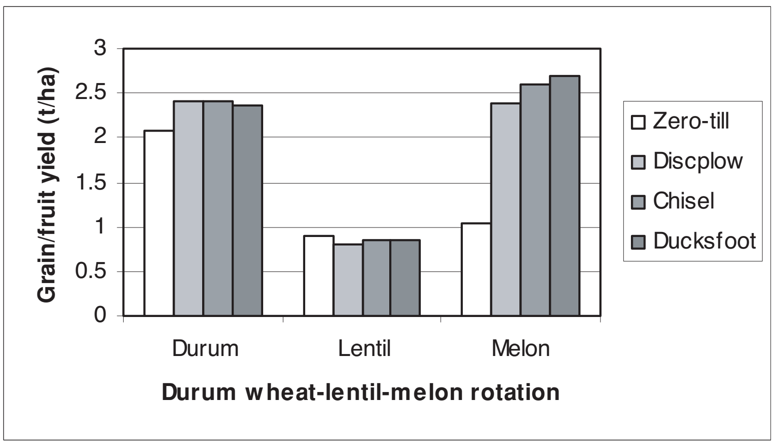
Comparison of Tillage Systems:

Pala et al. (2000), in comparisons of crop performance following establishment after conventional deep discplow and chisel cultivation (20 cm deep), shallow tillage by ducks-foot cultivator (20 cm blade opening at 10-12 cm deep) and zero-till direct drilling conducted over 12 years during 1986-97 where seasonal rainfall ranged from 234 to 504 mm at the ICARDA Tel Hadya research farm in northern Syria of ICARDA reported yields were similar in both rotations of durum wheat-lentil-melon and bread wheat-chickpea-melon. On average yields of durum and bread wheat showed very little difference between two deep tillage (disk plow and chisel) and shallow tillage (ducks-foot) systems, but zero-till yields tended to fall behind the other tillage systems (Figure 1). The expected trend is not visible within 5 years because of different weather pattern each year. But the zero-till give more advantageous in dry years in particular, so its major effect is coming from its economic use and soil quality improvements.

The yield decline under the zero-till system was apparently due to a gradual increase in grassy weed infestation in zero-till plots, where pre-planting herbicides did not provide adequate weed control because of the dry period at planting, and also due to a larger row spacing (30 cm) in the direct drilling, resulting from some technical limitations in the construction of the implement. For chickpea and lentils in rotation with cereals (Pala et al., 2000), yields showed small but significant differences across all four tillage systems, but deep disking was poorest. Minimum (ducks-foot) tillage or zero-till systems were the best because the row spacing (30 cm) used for direct drilling suited the legumes. Legumes use less water than wheat in general, and larger row spacing allows the legumes, particularly chickpea to have better stature with its expanded stems/branches under 30 cm row spacing.

This suggests legume crops do not need conventional deep tillage after cereal harvest, but shallow tillage by a ducks-foot implement at 10-12 cm depth after effective rainfall, allowing late November to Mid-December sowing, was promising. Deep disking or mouldboard plowing needed two and three times more fuel per hectare than chisel plowing and ducks-foot cultivation respectively. The zero-till system needed less fuel than the other systems but requires pre-planting herbicide, a major cost which brings its resource requirement per unit area close to that of minimum tillage. Soil organic matter was increased under conservation tillage, particularly by no-till direct drilling from 0.8 to 0.95% in the three-course wheat-lentil-summer crops rotation (Ryan et al., 2003). This change happened in 12 year of the experimentation period.

These results support a preference for the minimum tillage system over deep tillage on the grounds of both energy-use efficiency and increased net revenue for cereals and legumes. Implements for the minimum tillage system, unlike those for zero-till direct drilling, are readily available to farmers in the WANA region. If and when available and tested and adopted by farmers, results showed that zero-till direct drilling could increase soil organic carbon and sustain system productivity (Ryan et al., 2003; Pala, 2006). Melon does not fit to zero-till direct sowing but performs well under conservation tillage practices compared with conventional deep tillage systems because weed management is not properly done under direct drilling of melon as the summer weeds are controlled well by the shallow cultivation of conservation tillage by ducks-foot cultivator.



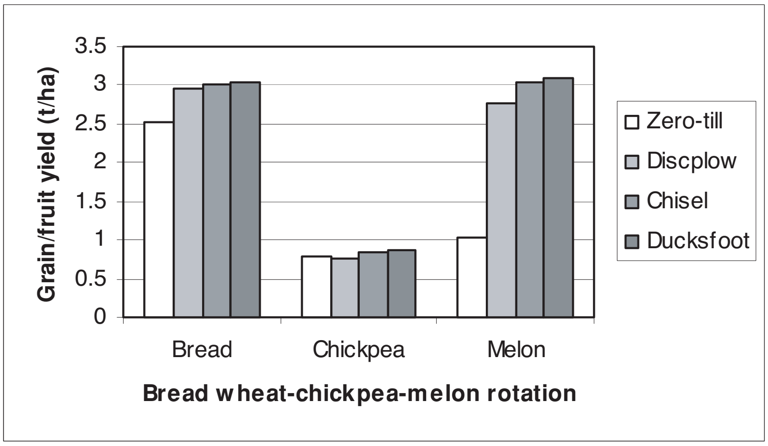


Figure 1: Mean crop yields over 12 year in 3-yr rotations with respect to tillage treatments, including zero-till direct drilling, Tel hadya, 1986-1997 (Modified from Pala et al., 2000).

WUE of each crop within both rotations followed the crop yield trends as given in Table 1, with means and ranges of water use efficiency levels with respect to different tillage systems not significantly different. Thus, conservation tillage for all crops and zero tillage for legumes in particular performed well. Zero-tillage system for wheat remained slightly lower for WUE, because of the wider row spacing, which reduces plant density to ≈ 60% under zero-till and increases water losses by evaporation compared to other tillage systems. Studies with a newer zero-till drill with 15-20 cm row spacings have shown that WUE and crop yields of zero tillage and conventional tillage systems are comparable, as shown below.

The effect of zero-till direct sowing compared to conventional and conservation tillage on crop productivity in common durum wheat/lentil legume rotation:

The research reported below was conducted during the 2001/02 and 2005/06 period for 5 years with the following objectives to compare current farmer tillage practices with zero-till practices with respect to a) the biological productivity of a 2-yr durum wheat-lentil crop rotation, b) soil physical parameters: aggregate stability, infiltration rate, porosity, bulk density, c) soil chemical properties: changes in OM%, microbial biomass, total N%, mineral-N, d) efficiency of water use, e) weed infestation and management level, and f) costs in relation to energy use efficiency. Because tillage effects on soil parameters are slow to emerge, only crop productivity and economics of tillage systems have been reported here. Tillage treatment combinations for wheat and lentil in the rotation were:

1) Shallow tillage by ducks-foot cultivator (10-12 cm) for wheat and conventional deep tillage by mouldboard plough (25 cm) for lentil phase of the rotation (shallow-deep tillage system),

2) Conventional deep tillage by mouldboard plough (25 cm) for both phases of the rotation (deep-deep tillage system),

3) Shallow tillage by ducks-foot cultivator (10-12 cm) for both phases of the rotation (shallow - shallow tillage system),

4) Zero-till direct drilling with 100% residue remaining on soil surface through chopping with the combine harvester, and

5) Zero-till direct drilling with 70% residue removed for livestock feed leaving 30% of residue as standing stubble.

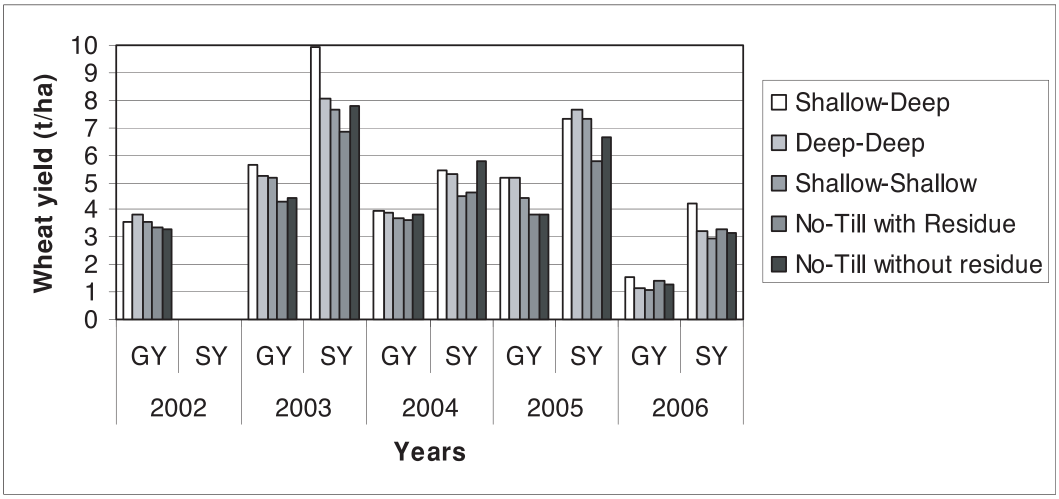
Soil physical and chemical parameters have been measured at the onset of the trial as a base for the changes after 2-4 cycles. Soil moisture measurements for water balance (15 cm interval with a hand auger until the depth of 150 cm was done at planting and harvest. However, because of the variability in the data at one profile only in such large plots (10 x 20m) we have used Seasonal rainfall (Oct-May) for estimation of rain- water productivity. Crop measurements were made for phenology (dates of emergence, stem elongation, heading, flowering, podding, physiological maturity and harvestable time), yield parameters (plant number, heads/pods per plant, seeds per head/pod, grain and straw yield) and N% in grain and straw. Weed infestation levels were monitored before herbicide applications. Cost of operations was also recorded for economic analysis.

Seasonal rainfall (October-May) was very favourable for 2001/02, 2002/03, and 2003/04 seasons with 404, 483, and 398, respectively and lower than the long-term average at 302 and 290 mm for 2004/05 and 2005/06 cropping seasons, respectively. Crop grain yields were poorly explained by seasonal rainfall with 42% in wheat ($y = 0.0114rain - 0.665$) and 31% in lentil ($y = 0.0031rain - 0.068$), because yield depended more on rainfall distribution throughout the cropping season as in the case of 2004/05 season where there was better distribution throughout the cropping season further to that when considering rainfall amounts to calculate WUE we will lose the impact of zero-till and stubble residues. Wheat and lentil grain and straw yields are given in Figure 2 for different years with respect to tillage systems.

Table 1: Crop water use efficiency (kg/ha/mm)) under four tillage systems for a three-course rotation with durum and bread wheat at Tel Hadya, Syria (1986-1997) (Modified from Pala et al., 2000).

3-course crop rotations	Tillage systems			
	No-till	Disc plow	Chisel	Ducks-foot
Durum wheat-Lentil-Melon rotation				
Durum wheat	6.4 (3.6-9.2)*	7.3 (4.2-9.9)	7.2 (4.1-10.6)	7.1 (3.8-9.4)
Lentil	3.8 (1.9-5.2)	3.2 (1.6-4.7)	3.5 (0.9-4.8)	3.5 (1.4-4.7)
Melon	3.7 (0.0-12.5)	8.6 (3.5-19.5)	9.2 (2.6-20.2	9.9 (2.4-19.5)
Bread wheat-Chickpea-Melon rotation				
Bread wheat	7.7 (4.3-10.2)	8.9 (4.5-12.8)	8.9 (5.5-12.9)	9.1 (5.2-12.9)
Chickpea	3.0 (1.2-4.5)	2.8 (1.1-4.3)	3.1 (0.9-4.4)	3.3 (1.2-4.5)
Melon	3.7 (0.0-13.9)	9.9 (2.0-22.3)	10.9 (2.4-20.1)	11.3 (2.8-25.0)

* Values in parenthesis show the range of crop water use efficiencies across the years.



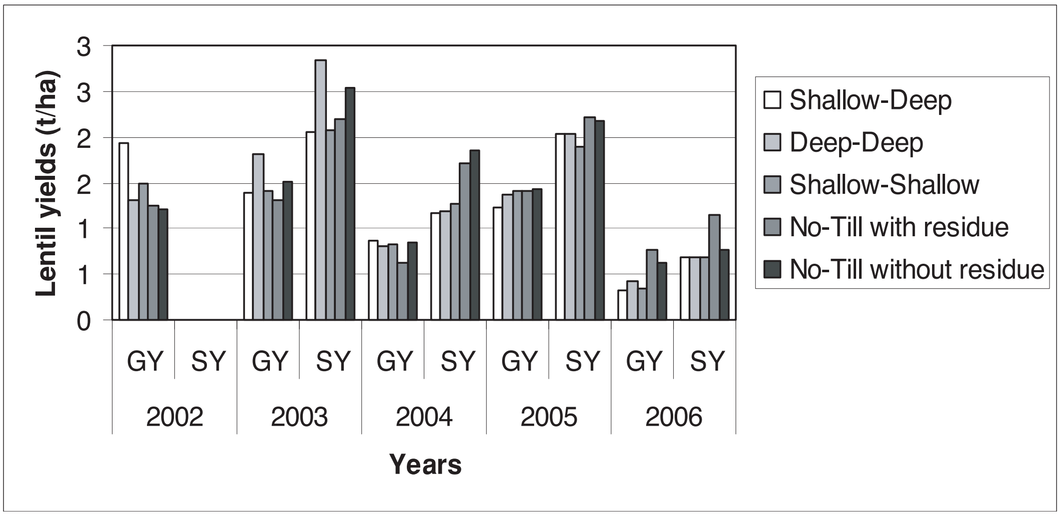


Figure 2: Grain (GY) and straw (SY) yields of wheat and lentil under different tillage systems and zero-till direct drilling at each growing season, Tel Hadya Research farm.

The recommended shallow-deep tillage system for wheat-lentil rotation provided the highest wheat yields in most of the years compared to other tillage systems (Table 2). Zero-till direct drilling provided quite good results especially in the driest season of 2005/06 under residue cover because of the prevention of moisture loss by mulch, but in good years residue left on the surface created physical problems in planting due to poor stubble flow between tynes with the seeder used; machinery needs to be appropriate for sowing under heavy residue cover. However, lentil yields were better under zero-till direct drilling particularly in the last two seasons, most probably due to more soil moisture provided for the use of lentil crop and other improved soil characteristics. This was very visible under zero-till direct sowing with residue cover in the driest season of 2005/06. There was no difference amongst tillage systems for lentil grain yield, but mean lentil straw yield was significantly higher under zero-till direct sowing (Table 2).

Table 2: Mean grain yields of wheat and lentil from the different types of tillage and zero-till direct sowing, (Mean for 2002-2006)

Tillage practices	Mean Crop Yields (t/ha)			
	Wheat grain	Wheat Straw	Lentil Grain	Lentil Straw
1. Conservation (Shallow-Deep) tillage	3.96	6.73	1.15	1.48
2. Conventional (Deep-Deep) tillage	3.85	6.05	1.14	1.69
3. Conservation (Shallow-Shallow) tillage	3.58	5.61	1.10	1.48
4. Zero-Till direct sowing (Residue left)	3.29	5.13	1.07	1.81
5. Zero-Till direct sowing (Residue removed)	3.33	5.83	1.12	1.83
SE (+/-) (significant for WGY, WSY and LSYat p<0.01; NS for LGY)	0.09	0.21	0.05	0.06

The first 5 years of the trial confirms the advantage of a shift from conventional deep-deep tillage by mouldboard at about 25 cm depth to shallow-deep tillage systems for cereal-legume rotations; in fact, most farmers in Western Asian lowlands have already adopted such conservation systems. Zero-till direct drilling may be more economic, particularly when residues are removed for better planting as seen in Table 3 and 4, which needs to be evaluated with farmers' participation in wide testing of this technology across dry areas. The lentil crop is more economic under zero-till direct sowing with or without residues. However, lentil was harvested by hand with some disturbance on the soil surface, which may interrupt the cumulative impact of zero-till on soil characteristics although zero-till equipment also has some disturbance on the soil surface. Wheat is more economic under zero-till direct sowing without residue compared to conventional deep-deep tillage system most probably due to seeding problems with the seeder when planting on residues(due to planting machine) as mentioned earlier.

The cereal-legume system zero-till direct sowing without residue gave a higher net return to farmers. It should be noted that in the very dry season of 2005/06 season, zero-till direct drilling was particularly out yielding the conventional tillage systems. However, during the experimental period, zero-till plots were sown at the same time as the other tillage treatment plots so as not to introduce sowing date as another factor into the evaluation. Therefore, zero-till plots did not show the acknowledged benefit of early crop emergence, higher plant vigour and earlier ground cover to reduce evaporation losses compared with the other tillage treatments except in the dry season of 2005/06 when zero-tillage used more effectively the lowest rainfall total of 76.1 mm for Oct-Dec period compared with the rainfall totals of 201.5, 131.5, 175, 5 and 139.5 mm for 2001/02 to 2004/05 seasons, respectively. If both systems are planted as soon as ready after rain, it is likely that zero-till can be planted earlier, with losses in attainable yield (increase in the yield gap) of 200-250 kg/ha for each week of delay in the cultivated systems (Keatinge at al., 1986; Acevedo et al., 1991).

Table 3: Input costs and incomes under different types of tillage and zero-till direct sowing, (Mean for 2002-2006)

Tillage Practices	Economics (SL/ha)			
	Wheat		Lentil	
	Input cost	Income	Input cost	Income
1. Conservation (Shallow-Deep) tillage	12205	44573	15569	22308
2. Conventional (Deep-Deep) tillage	13378	43324	15566	23273
3. Conservation (Shallow-Shallow) tillage	13065	40253	14240	21676
4. Zero-Till direct sowing (Residue left)	11430	36968	14226	23004
5. Zero-Till direct sowing (Residue removed)	11479	41826	14255	23764

US$ = 50.5 SL

Table 4: Net benefit of the different types of tillage and zero-till direct sowing, Tel Hadya Research farm (Mean for 2002-2006 periods for 5 years)

Tillage practices	Net return (SL/ha)		
	Wheat	Lentil	W-L rotation System
1. Conservation (Shallow-Deep) tillage	32368	6739	19554
2. Conventional (Deep-Deep) tillage	29946	7707	18827
3. Conservation (Shallow-Shallow) tillage	27188	7436	17312
4. Zero-Till direct sowing (Residue left)	25538	8778	17158
5. Zero-Till direct sowing (Residue removed)	30347	9509	19928

US$ = 50.5 SL

Parallel to the trials given above, zero-till direct sowing was applied in large plots at Tel Hadya Farm in 2005/06 and the yield advantage for chickpea was 78%, and wheat 44%, compared to a conventional tillage system because of higher moisture availability for the early growth stages of both crop, from increased infiltration and reduced evaporation, which allowed development of deeper root systems to utilize soil moisture in the deeper profile during the dry period later in the cropping season (Table 5).

Table 5: Wheat and chickpea grain yield under zero-till direct sowing compared with conventional tillage system at large plots (5 ha) at Tel Hadya research farm (2005/06; 289.7 mm seasonal rainfall)

Treatments	Wheat grain (t/ha)	Chickpea grain (t/ha)
Conventional tillage (CT)	1.12	0.76
Zero-till direct sowing (NT)	1.78	1.35
Yield increase over CT (%)	44	78

It can be summarized that when there is no machine available for zero-till direct sowing conventional deep tillage should be replaced by shallow tillage for cereals after legumes and deep tillage for legumes after cereals for incorporation of the residue into soil to allow better sowing for legumes. However, zero-till direct sowing equipment are available, seem to be effective, and could be manufactured by local workshops to promote uptake and provide long-term benefits in terms of savings in terms of time, fuel and machinery wear, better soil structure with more available water, higher OM for better soil quality and higher yield potential in dry years if timely planted.

Conservation tillage and zero-till direct drilling systems have also been tested in Jordan, Iran, Morocco, Sudan, Turkey and in Central Asia (Suleiman, 1994; Khalaf, 1996; Eskandari et al., 2003; Namr & Mrabet, 2004; Rasheed & Hamid, 2003; Avci, 2005; Ryan et al, 2004; Suleimenov et al,. 2004) with similar promising results to our research outputs given above.

Conclusions

Much rainwater is lost or not used efficiently in most rainfed areas because of traditional cultivation-intensive soil and crop management practices and low adoption of improved technologies by farmers. The choice of crop rotations, improved cultivars, optimum sowing date, efficient fertilizer use, and conservation tillage including zero-till direct drilling as components of conservation cropping need to be developed for local environmental conditions through applied and adaptive research with a participatory approach.

Among all the conservation cropping systems, conservation tillage and zero-till direct drilling are the most important components in dry area cereals-based production systems for resource use efficiency, integrated with the other components given above. Increasing soil organic matter in the topsoil compared with conventional deep tillage systems for long-term fertility build up and improvement of soil aggregate stability are strong advantages of zero-till systems. Keys to adoption will be local verification and modification of the technology and the development of a local industry for manufacturing suitable zero-till direct drilling equipment adapted to farmers' conditions.

Other constraints to adoption including technical and sociological factors, policies and environmental impacts need to be considered for the success of the system. However, still more research is necessary for widespread adoption of conservation tillage, particularly zero-till direct drilling systems in different agro-ecosystems of the region with farmers' participatory evaluation of the system to benefit directly and to improve livelihood of rural population. Linkage of biophysical and bio-economic models should be a further step to match identified strategies with the socio-economic conditions of the resource-poor farmers in the dry areas to optimise uptake and sustainability of conservation cropping systems.

References

Acevedo E., Harris, H.C. and Cooper, P.J.M.. 1991. Crop architecture and water use efficiency in Mediterranean environments. Pages 106-118 in Soil and Crop Management for Improved Water Use Efficiency in Rainfed Areas. (Harris, H.C., Cooper, P.J.M., and Pala, M., eds.). Proceedings of an International Workshop, Ankara, Turkey, May 1989. Aleppo, Syria: ICARDA.

Avci, M. 2005. Zero and minimum tillage as alternatives to conventional cultivation in dryland fallow/wheat and annual cropping systems in central Anatolia. pp. 89-100. In: Proceedings of a workshop organized by the Optimizing Soil Water Use (OSWU) Consortium (Management of improved water use efficiency in the dry areas of Africa and West Asia: M. Pala, DJ Beukes, JP Dimes and RJK Myers, eds.), 22-26 April 2002, Ankara, Turkey. Aleppo, Syria: ICARDA; and Patancheru, India:ICRISAT, vii+288 pp.

Bolton, F.E. 1991. Tillage and stubble management. Pages 39-47 in: Soil and Crop Management for Improved Water Use Efficiency in Rainfed Areas. (Harris, H.C., Cooper, P.J.M., and Pala, M., eds.). Proceedings of an International Workshop, Ankara, Turkey, May 1989. Aleppo, Syria: ICARDA.

CIMMYT and ICARDA, 2000. Conservation Tillage: a viable option for sustainable agriculture in Eurasia (Karabayev, M. A. Satybaldin, J. Benites, T. Friedrich, M. Pala and T. Payne, eds.). Proceedings of an International Workshop sponsored by NACAR/FAO/CIMMYT/ICARDA, 19-24 September, 1999. Shortandy, Astana, Kazakhstan, Almaty, Kazakhstan: CIMMYT; Aleppo, Syria: ICARDA, xi+194 pp.

Cooper, P.J.M. 1991. Fertilizer use, crop growth, water use and WUE in Mediterranean rainfed farming systems. Pages 135-152 in: Soil and Crop Management for Improved Water Use Efficiency in Rainfed Areas. (Harris, H.C., Cooper, P.J.M., and Pala, M., eds.). Proceedings of an International Workshop, Ankara, Turkey, May 1989. Aleppo, Syria: ICARDA.

Cooper, P.J.M., & Gregory, P.J. 1987. Soil water management in the rainfed farming systems of the Mediterranean region. Soil Use and Management 3: 57-62.

Cooper, P.J.M., Gregory, P.J., Keatinge, J.D.H., and Brown, S.C. 1987b. Effects of fertilizer, variety and location on barley production under rainfed conditions in northern Syria. 2. Soil water dynamics and crop water use. Field Crops Research 16: 67-84.

Cooper, P.J.M., Gregory, P.J., Tully, D., and Harris, H.C. 1987a. Improving water use efficiency of annual crops in the rainfed farming systems of West Asia and North Africa. Experimental Agriculture, 23: 113-158.

Dumanski, J., Peiretti, R., Benites, J.R., McGarry, D., and Pieri, C. 2006. The paradigm of conservation tillage. Proc. World Assoc. Soil and Water Conserv., P1: 58-64.

Erskine, W., and Malhotra, R.S. 1997. Integration of winter-sown chickpea and lentil into cropping systems in the Middle East. Grain Legumes 16: 20-21.

Eskandari, I., Asghari, C., Rahimzadeh, R., Ghaffari, A., Siadat, H., Pala, M., and Ketata, H. 2003. Sustainable soil management for cereal-based cropping systems in the dry highlands of western Iran. Sustainable development and management of dry lands in the 21st century: abstracts Seventh International Conference on Development of Dry Lands. 14-17 Sept 2003, Tehran, Iran. p. 15-16. (En). ICARDA, Aleppo, Syria. ICARDA Abstract (Proceedings in print).

FAO (Food and Agriculture Organization). 2002. Conservation Agriculture: matching production with sustainability. Land and Water Digital Media Series No. 18, FAO, Rome, Italy.

Gregory, P.J. 1991. Concepts of water use efficiency. Pages 9-20 in Soil and Crop Management for Improved Water Use Efficiency in Rainfed Areas. (Harris, H.C., Cooper, P.J.M., and Pala, M., eds.). Proceedings of an International Workshop, Ankara, Turkey, May 1989. Aleppo, Syria: ICARDA.

Gupta, U.S. 1995. Role of humidity in dryland crop production. Pages 271-295 in Production and improvement of crops for drylands (Gupta, U.S., ed.), New Delhi, India: Science Publishers, Inc.

Harris, H.C. 1994. Water use efficiency of crop rotations in a Mediterranean environment. Aspects of Applied Biology 38: 165-172.

Harris, H.C. 1995. Long-term trials on soil and crop management at ICARDA. Advances in Soil Science 19: 447-469.

Harris, H.C., Cooper, P.J.M., and Pala, M. (eds.). 1991a. Soil and Crop Management for Improved Water Use Efficiency in Rainfed Areas proceedings of an international workshop sponsored by MAFRA/ICARDA/CIMMYT, 15-19 May, 1989. Ankara, Turkey: ICARDA, Aleppo, Syria.

Harris, H.C., Osman, A.E., Cooper, P.J.M., and Jones, M.J. 1991b. The management of crop rotations for greater water use efficiency under rainfed conditions. Pages 237-250 in Soil and Crop Management for Improved Water Use Efficiency in Rainfed Areas. (Harris, H.C., Cooper, P.J.M., and Pala, M., eds.). Proceedings of an International Workshop, Ankara, Turkey, May 1989. Aleppo, Syria: ICARDA.

Ilbeyi, A., Ustun, H., Oweis, T., Pala, M., and Benli, B. 2006. Wheat water productivity and yield in a cool highland environment: Effect of early sowing with supplemental irrigation. Agricultural Water Management, 82: 399-410.

Jones, M.J., and Wahbi, A. 1992. Site-factor influence on barley response to fertilizer in on-farm trials in northern Syria: descriptive and predictive models. Experimental Agriculture 28: 63-87.

Jones, M.J., Pala, M., van Duivenbooden, N., and Doumbia, M. 1998. Optimizing Soil Water Use in dry-area Farming Systems of Sub-Saharan Africa and the West Asia/North Africa Region. Paper to be presented at The Soil, Water and Nutrient Management Programme Workshop in 16th World Congress of Soil Science, 20-26 August, Montpellier, France.

Joseph, K.D.S.M., Alley, M.M., Braun, D.E., and Gravelle, W.D. 1985. Row spacing and seeding rate effects on yield and yield components of soft red winter wheat. Agronomy Journal 77: 211-214.

Karaca, M., Guler, M., Durutan, N., Meyveci, K., Avci, M., Eyubogluand, H., and Avcin, A. 1991. Effect of rotation systems on wheat yield and water use efficiency in dryland areas of central Anatolia. Pages 251-259 in Soil and Crop Management for Improved Water Use Efficiency in Rainfed Areas. (Harris, H.C., Cooper, P.J.M., and Pala, M., eds.). Proceedings of an International Workshop, Ankara, Turkey, May 1989. Aleppo, Syria: ICARDA.

Keatinge, J.D.H., Dennett, M.D., and Rodgers, J. 1986. The influence of precipitation regime on the crop management of dry areas in northern Syria. Field Crops Research 13: 239-249.

Khalaf, M.M. 1996. Effect of nitrogen fertilizer on wheat production under different crop rotations, tillage practices, and crop residue management. Master of Science degree submission, University of Jordan.

Matar, A., Torrent, J., and Ryan, J. 1992. Soil and fertilizer phosphorus and crop responses in the dryland Mediterranean zone. Advances in Soil Science 18: 81-146.

Namr, K.I., and Mrabet, R. 2004. Influence of agricultural management on chemical availability of a clay soil of semi-arid Morocco. Journal of African Earth Sciences 39: 485-489.

Pala, M. 1991. The effect of crop management on increased production through improved water use efficiency at sowing. Pages 87-105 in Soil and Crop Management for Improved Water Use Efficiency in Rainfed Areas. (Harris, H.C., Cooper, P.J.M., and Pala, M., eds.). Proceedings of an International Workshop, Ankara, Turkey, May 1989. Aleppo, Syria: ICARDA.

Pala, M., and Mazid, A. 1992a. On-farm assessment of improved crop production practices in Northwest Syria. I. Chickpea. Experimental Agriculture 28: 175-184.

Pala, M., and Mazid, A. 1992b. On-farm assessment of improved crop production practices in Northwest Syria. II. Lentil. Experimental Agriculture 28: 185-193.

Pala, M., Matar, A., and Mazid, A. 1996. Assessment of the effects of environmental factors on the response of wheat to fertilizer in on-farm trials in a Mediterranean type environment. Experimental Agriculture 32: 339-349.

Pala, M., Harris, HC., Ryan, J., Makboul, R., and Dozom, S. 2000. Tillage systems and stubble management in a Mediterranean-type environment in relation to crop yield and soil moisture. Experimental Agriculture 36: 223-242.

Pala, M., Beukes, DJ., Dimes, JP., and Myers, RJK. (eds.). 2005. Management for improved water use efficiency in the dray areas of Africa and West Asia: proceedings of a workshop organized by Optimizing Soil Water Use (OSWU) Consortium, 22-26 April 2002, Ankara, Turkey. Aleppo, Syria: ICARDA; and Patancheru, India: ICRISAT. 288 pp.

Papendick, R.I., Parr, J.F., and Meyer, R.E. 1991. Tillage and stubble management: ongoing research in USA. Pages 66-78 in Soil and Crop Management for Improved Water Use Efficiency in Rainfed Areas. (Harris, H.C., Cooper, P.J.M., and Pala, M., eds.). Proceedings of an International Workshop, Ankara, Turkey, May 1989. Aleppo, Syria: ICARDA.

Rasheed, N.H., and Hamid, B. 2003. AAAID development program for transfer of zero tillage technology to the traditional farmers in the rain-fed areas of the Sudan. In http://www.Aaaid.org/pdf/magazine/2003/.

Ryan, J. (ed.). 1997. Accomplishments and future challenges in dryland soil fertility research in the Mediterranean area, proceedings of a Soil Fertility Workshop, 19-23 November1995. Aleppo, Syria: IMPHOS/ICARDA. 369 pp.

Ryan, J. 1998. Changes in organic carbon in long-term rotation and tillage trials in northern Syria. Pages 285-296 in Management of Carbon Sequestration in Soil (Lal, R., Kimble, J.M., Follett, R.F., and Stewart, B.A., eds.). Boca Raton, USA: CRS.

Ryan, J.; Masri, Z.; Diekman, J.; Pala, M. ICARDA, Aleppo (Syria). 2003. Organic matter and nutrient distribution following conservation tillage, straw management and compost application under dryland Middle Eastern conditions. American Society of Agronomy Annual Meeting. Nov. 2-6, 2003, Denver, Colorado. npn. (En). American Society of Agronomy, Denver, Colorado.

Ryan, J., Vlek, P., and Paroda, R. (eds.). 2004. Agriculture in Central Asia: Research for Development. Proceedings of a Symposium held at the American Society of Agronomy Annual Meetings at Indianapolis. Indiana, USA, Nov. 10-14, 2002. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria. xviii + 361 pp.

Ryan, J., Pala, M., Singh, M., Makboul, R., Masri, S., and Harris, H. (2008). Rainfed wheat-based rotations under Mediterranean-type climatic conditions: Crop sequences, nitrogen fertilizer, and grazing intensity in relation to cereal yield parameters. J. Agric. Sci. Camb. (in review).

Silim, S.N., and Saxena, M.C. 1991. Winter sowing of chickpea - a case study. Pages 119-129 in Soil and Crop Management for Improved Water Use Efficiency in Rainfed Areas. (Harris, H.C., Cooper, P.J.M., and Pala, M., eds.). Proceedings of an International Workshop, Ankara, Turkey, May 1989. Aleppo, Syria: ICARDA.

Silim, S.N.; Saxena, M.C., and Erskine, W. 1991. Effect of sowing date on the growth and yield of lentil in a rainfed Mediterranean environment. Experimental Agriculture 27: 145-154.

Suleiman, Ayman A.A. 1994. Moisture content and some physical properties of vertisols under different tillage and crop residue management practices. Master of Science degree submission, University of Jordan.

Suleimenov, M., Kaskarbayev, Z., Pala, M., and Karajeh, F. 2001a. Minimum tillage as integrated part of conservation agriculture in northern Kazakhstan. Paper submitted to FAO/Pakistan International Workshop on Conservation Tillage Workshop, 5-9 February, 2001, Lahore, Pakistan.

Suleimenov, M.; Pala, M.; Karajeh, F. 2001b. ICARDA's network on conservation agriculture in Central Asia. 1st World Congress on Conservation Agriculture, Vol. 2: Offered Contributions 1st World Congress on Conservation Agriculture. 1-5 Oct 2001, Madrid, Spain. p. 7-10. (En). Garcia-Torres, L. Benites, J. Martinez-Vilela, A. (ed.).

Suleimenov, M., Akhmetov, KA., Kaskarbayev, JA., Khasanova, F., Kireyev, A., Martynova, LI., and Pala, M. 2004. Developments in tillage and cropping systems in Central Asia. Pp. 188-211 in ‘Agriculture in Central Asia: Research for Development (J. Ryan, P. Vlek, R. Paroda, eds.). The Proceedings of a Symposium held at the American Society of Agronomy Annual Meetings at Indianapolis, Indiana, USA, Nov. 10-14, 2002. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria.

Tavakkoli, A.R., and Oweis, T. 2004. The role of supplemental irrigation and nitrogen in producing bread wheat in the highlands of Iran. Agricultural water Management 65: 225-236.

Whitman, CE.,Parr, JF., Papendick, RI., and Meyer, RE.(eds).1989. Soil, water and crop/livestock management systems for rainfed agriculture in the near east region. Proceedings of the Workshop, January 18-23, 1986, Amman, Jordan. USDA/USAID/ICARDA, Washington, DC, USA.

Conservation Agriculture in Morocco: A Research Review

Rachid Mrabet
National Institute of Agricultural Research (INRA)
Regional Agricultural Research Center of Meknes
P.O. Box 578 Meknes 50000 Morocco
rachidmrabet@yahoo.co.uk; Phone: +21235300243; Fax: +21235300244

Abstract

Entering the third millennium, the overriding challenge facing Moroccan agriculture is the need to increase food production enough to feed the ever-growing population. Achieving food security is of great importance. The question arises as to whether agriculture can in fact reasonably be expected to fulfill this required role. Several studies identified several soil degradation processes due to agricultural development as being major threats to the environment and to sustainable agriculture and hence to food security. The most disturbing aspect was not only the extent of soil degradation that exists in the country, but the inability to identify and apply effective responses. Fortunately, Morocco has great agricultural potential and agricultural development should continue with strong relief to farmers affected by land degradation. Moroccan agriculture is characterized by the co-existence of both modern agriculture and the traditional version. From the research conducted over the last three decades, the vast majority of beneficial tillage effects are very transient. Conversely, the harmful effects of conventional tillage systems are long-lasting, if not permanent. Technological change in agriculture is a necessary condition for achieving sustained increases in food production. The present work is intended to describe major achievements in no-tillage research conducted in semiarid Morocco and to present important ways to implement these achievements within the Moroccan rural society. No-tillage systems are found and recognized to revert several degradation processes and enhance productivity of most cropping systems. These systems have revolutionized cropping worldwide and in semiarid localities of Morocco, resulting in reduced soil erosion, greater soil water conservation, improved soil quality, environment protection and higher crop yields. Changes in crop production practices due to shifting to no-tillage systems and retention of crop residue at or near the surface produce progressive qualitative and quantitative variations in soil quality attributes. These changes resulted in physical and chemical differentiation, mainly at the seed-zone. Even though the introduction of no-tillage systems in the 1980s caused an important change in agricultural research and production, it is opportune to ascribe the slow adoption of no-tillage systems to a lack of knowledge available to most researchers, developers and their advisers and other reasons, such as imperfect information, uncertainty, inadequate human capital and institutional constraints.

Keywords: Conservation agriculture, no-tillage, residue management, cropping systems, carbon sequestration, soil quality

1. Introduction: Moroccan agriculture

Agriculture accounts for 13 to 20% of gross domestic product (GDP) depending on harvest, 20% of exports and 44% of employment in Morocco. Morocco's total area is of 71.08 million hectares (M ha), including 9.2 M ha of cultivated lands (13%), 5.8 M ha of forest (8%) and 24 M ha of rangelands (30%). The area of cultivated land increased from 7 M ha in 1970 to 9.2 M ha in 2000. In fact, agriculture is reaching the limits of available land and water resources.

The continuous increase in population has contributed significantly to agriculture expansion to fragile lands. The continuous population growth is associated with depleted natural resources and then with growing food insecurity. Morocco's population was 17.3 million in 1975, currently stands at 30.4 million, and is projected to increase to 39 million by 2025 (Chebbi & El Mourid, 2005). While rural inhabitants represent 44% of the population, agriculture accounts for 75% of the manpower in rural areas and 36% of national workforce.

According to agricultural statistics, more than 70% of farmers have less than 5 ha and exploit less than 30% of the agricultural area. Cereals and fallow represent 80% of the agricultural cropping systems, which explain the importance of searching for improved water conservation and stabilization of yields in cereal cropping systems. Hence, wheat-fallow is the dominant cropping system in the low-precipitation (<300 mm) region of the country. Continuous wheat is also an important land use in an important area of the country, mainly on slopes and small farms. Crop diversification is essentially an orientation for farmers of more humid areas such as Saïs, Gharb and Zaer.

In a period of 30 years, cereal area varied from 4.5 to 5.3 M ha contributing to a 2-fold increase in cereal production (from 25 M quintals in 1961-65 to 53 M quintals in 1996-2000). However, production performances are weak due to stagnation in crop yields (cereals and food legumes) over years. In fact, water conservation and ultimately crop production were limited by reduced water capture potential in dryland cropping systems, which were affected by inappropriate soil and crop management. In response to this yield decline of major crops, the Moroccan government focused its policy on drought mitigation.

2. No-tillage systems: Why the shift?

2.1. Climate change, drought and scarcity in rainfall

In Morocco, the climate's characteristics are endemic and unpredictable drought, intensive storms in early season, variable and erratic rainfall, and dry summers (Barakat & Handoufe, 1998; Le Houérou, 1993).

The challenge for sustainable productivity is accentuated by extremely variable rainfall such that some years may allow the crops to express their attainable yield, while in others to fail completely. Another remark is that water use efficiency is sometimes low even in years of good rainfall (Balaghi, 2006). This low use of water by crops can be due to inappropriate soil management systems (basically tillage systems).

It is now generally agreed that the planet has warmed over the last century, although causes remain controversial. In fact, the global average surface temperature fluctuates over time, but recently it has increased dramatically. The sharpest rise occurred between 1975 and 2005, when temperature rose steadily by about 0.5°C.

Worldwide, the agriculture sector accounts for about one-fifth of the annual anthropogenic increase in greenhouse forcing, producing about 50 to 75% of the anthropogenic methane and nitrous oxide emissions and about 5% of the anthropogenic CO2 emissions. Plowing or soil inversion is the principal cause of carbon dioxide (CO_2) emission from croplands (Reicosky, 2001). There is scientific evidence that soil tillage has been a significant component of the increase in atmospheric CO_2 which has occurred in the last few decades.

In Morocco, during the last 40 years, there was an overall reduction of 50 to 200 mm in rainfall. Future climate change could critically undermine efforts for sustainable development in the Mediterranean region. In particular, climate change may add to existing problems of desertification, water scarcity and food production, while also introducing new threats to human health, ecosystems and national economies.

2.2. Mechanical Tillage: A serious cause of desertification

Soil degradation, with its various facets, is a serious problem threatening agricultural and rural development in Morocco. Actual land uses based upon unnecessary abusive tillage, overgrazing, over-intensification and inappropriate crop management are major contributors to soil destabilization through erosion processes and to crop failure through extreme soil dryness. In fact, more than 90% of the country's land is affected by desertification (Le Houérou, 1995). With drought, the misuse of mechanization has aggravated land degradation processes and created desert. Government's approaches to agricultural development have not been sufficiently successful (agricultural productivity is low, and economic stagnation and environmental damage are increasing) to halt these phenomena.

According to AMMA (1999), the 20th century marked the development of the mechanization and tillage and all farming technologies were improved. Intensive tillage with the moldboard plough as a primary tillage is still used for tilling depths down to 30-35 cm, followed by different hoe and disk harrow implements for seedbed preparation. On these traditional systems and previous to tillage operations, crop residues are removed, grazed or even burned. An off-set disk for both primary and secondary tillage operations is also becoming common in some areas. Chiseling and surface tillage with small hoe cultivators are now more common than 40 years ago. Sub-soiling to destroy sub-compacted layer is also practiced (Oussible et al., 1992).

Tillage translocation, the movement of soil downhill during tillage operations, and erosion are believed to be responsible for a significant reduction in topsoil depth and sedimentation of reservoirs in Morocco (Arnoldus, 1977; Karmouni, 1988; Merzouk, 1985). Downhill plowing with disk implements is a tradition in Morocco, even though it is harming the quality of our soils and reducing yields. The negative effects of soil tillage on farm productivity and sustainability, as well as on environmental processes, have been increasingly recognized and documented both in the developed and developing worlds. In contrast, no-till management reduces the energy of rainfall striking the soil by providing year-around protection via a combination of canopy and crop residue (Mrabet et al., 1993; 2003a).

Soil compaction is one of the major problems facing modern agriculture. Overuse of machinery, intensive cropping, short crop rotations, intensive grazing, and inappropriate soil management lead to compaction. Soil compaction occurs on a wide range of soils and climates. It is exacerbated by low soil organic matter content and tillage or grazing at high soil moisture content. Soil compaction increases soil strength and decreases soil physical properties and fertility through decreasing storage and supply of water and nutrients, which leads to additional fertiliser requirement and increasing production cost.

Lal (1986) reported that friable, coarse-textured, self-mulching, and structurally active soils are likely to respond better to no-tillage than soils with massive structure or which are easily compacted. McGarry et al. (2000) showed that no-tillage is particularly attractive on clay soils to minimize compaction and induce natural formation of soil structure through shrink-swell cycles. These effects were also achieved by Bouzza (1990) and Mrabet (1997) on vertisols. Lal (1986) also added that the ecological limits of no-tillage systems can be extended by developing appropriate equipment for seeding.

2.3. No-tillage systems: A need for an evolution of crop-livestock integration

Most dryland farming systems integrate crop and livestock production. In fact, livestock represents an important activity for Moroccan farmers (the 5th sector). Livestock accounts for 26 to 32% of the Agricultural Gross Domestic Product. Livestock is dominated by sheep, with 16 M head, 5.1 M goats, and roughly 2.7 M head of cattle.

Crop residue destinations typically include extraction, grazing, burning in situ, incorporation, weathering and retention as mulch. Conventional farming involving continuous tillage, crop residue removal (for fodder/fuel, by in situ grazing and/or by burning) is practised by most small and medium scale farmers where crop/livestock production systems predominate. These management measures imply a scarcity of residue at or near the soil surface. In addition, these farming practices are mining the soil resource base, intensifying erosion, and provoking a decline in soil organic matter causing chronic degradation of soil properties essential for sustainable cropping.

Crop residues are a vital source of livestock feed. Hence, a principal challenge facing no-tillage agriculture is how to achieve sustainable increases in crop and livestock production with limited amounts of crop residues. With respect of not further mining soil fertility, it is important to partially retain crop residues on the land.

Inclusion of a forage crop in the rotation helped in an ad hoc integration of livestock and grain production and the reduction of dependence on crop residues for feed. Therefore, in order to satisfy a better integration of livestock in no-tillage cropping systems and avoid excessive grazing of stubble and flat residues, a forage crop (barley, oat, and vetch) was incorporated as a second crop in wheat-fallow rotation. In terms of yields, wheat performed equally or better in the 3-year rotation (forage-wheat-fallow) than in wheat-fallow at Sidi El Aydi (Mrabet & Bouzza, 1994). Thus, an important option for implementing no-tillage in a farmer's system is to combine partial straw exportation and forage based triennial rotation in order to satisfy simultaneously water storage for stabilizing wheat yield and enhancement of soil organic matter for fertility build-up.

2.4. No-tillage systems: promoting industrial seeder sector

Conducted research on no-tillage systems was basically carried out using imported no-till drills (Bouzza, 1990; Mrabet, 1997). Direct dry seeding and deep placement of nitrogen and phosphorus fertilizer were the major drivers for developing appropriate no-till drills for crops in Morocco. Dry early seeding is important for guaranteeing crops maximum use of rainfall and early cover for better protection against intense rainfall and cold. Apart from the environmental benefits offered by no-tillage systems, the reduced time requirements for plowing and seedbed preparation are crucially important. This applies in particular to semiarid zones where seeding is possible only during very short periods. In fact, early seeding is a prerequisite for high and stable yields due to the avoidance of late drought and hot winds. In addition, deep fertilization promotes plant vigor the while crop is being established and promotes root growth.

For these reasons, in the early 1990s, there was intensive research on developing no-till drills for cereals and certain food legumes (Bahri, 1992; Dahane, 1992; Nousfi, 1993). Intensive research was conducted in this aspect and requirements of a versatile direct seeding machine were developed

(Mrabet & Bourarach, 2001). For fine textured soils, Bourarach et al. (1998) recommended hoe type no-till drills for seeding winter cereals and several food legumes. Consequently, an industry was developed for no-till drills in Morocco. However, no-till drills for row crops are not available and further research is needed for their development.

3. No-tillage systems: Impact on crops and cropping systems

3.1. Clean vs. chemical fallow: Storing scarce water

Water conservation research, starting in the early 1970s, has focused on the effects of tillage systems, row spacing, seeding rate, rotation (including fallow type) and varieties on yields of wheat. All of the early studies either removed residue by grazing and/or incorporated residue with tillage. Burning residues in place is rare because of low residue production.

In the dissertation work by Bouzza (1990), water conservation impact on wheat yield was evaluated during four years of study in semi-arid areas of Morocco. The absence of any data on water availability to the crop in a continuous cropping system compared to wheat after fallow led to this research. The ability of the soils to store water during fallow and stored water effectiveness on yield was studied. No-tillage management, when compared to conventional tillage management, yielded more for continuous wheat and wheat after fallow. In a very dry year, grain yield in a no-tillage system was 100% and 72% higher than the conventional management and fall chisel plowing, respectively, in continuous and wheat after fallow. In areas averaging 240 to 300 mm annual rainfall, wheat after fallow used water as efficiently as continuous wheat. No-till management and no soil disturbance in the dry period after harvest were requirements for successful fallow.

In other studies regarding soil management during fallow in semiarid dryland zones, conventional tillage management, with moldboard plowing as the primary tillage followed by repeated shallow cultivation, was found inefficient for soil water conservation. Fallow conservation tillage systems were evaluated as an alternative to traditional fallow management. Kacemi (1992) and Kacemi et al. (1995) did not observe differences in soil water storage between no-tillage and minimum tillage following fallow in a vertisol.

However, Bouzza (1990) found that fallow water storage efficiency increased from 10% (weedy fallow) to 28% (no-tillage fallow) (Figure 1). This increased water availability was reflected in wheat yields under no-tillage systems.

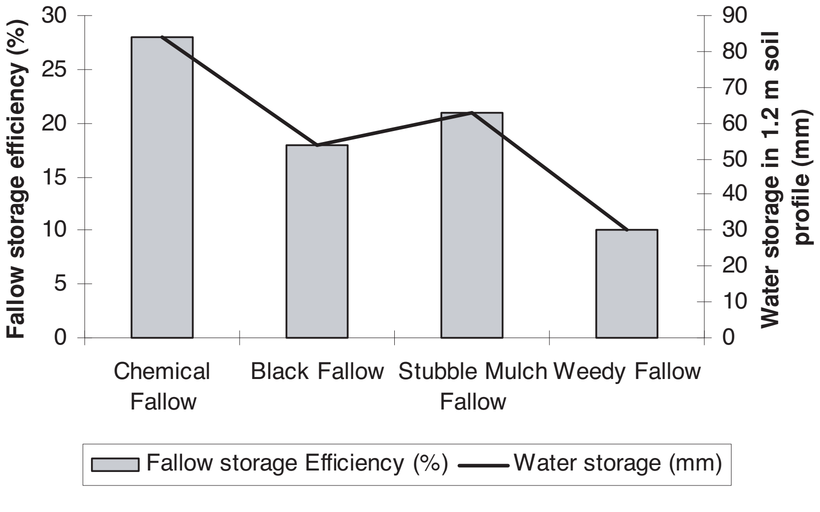


Figure 1: Water storage by fallow management at Sidi El Aydi station (Bouzza, 1990).

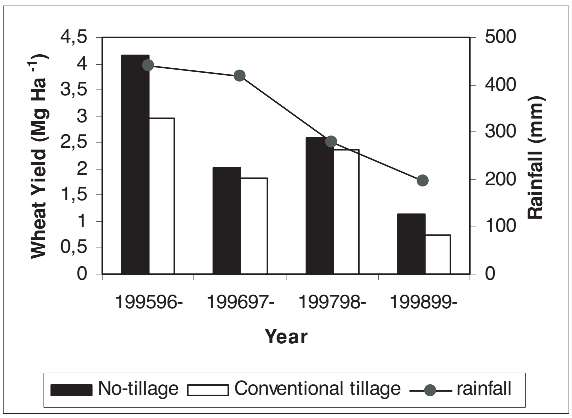
3.2. Wheat yield and water use efficiency

In the last 3 decades, a significant number of studies dealt with the effects of tillage systems on crop yields for different wheat rotations under rainfed conditions with special emphasis on no-tillage. In most of these studies, authors reported that generally wheat yields were higher under no-tillage systems than conventional tillage systems, especially in years where accumulated rainfall was lower than normal. Under continuous wheat or wheat fallow, mean yields with no-tillage, over a 10-year period at Sidi El-Aydi station (clay soil, 358 mm) and a 19-year period at Jemma Shaim station (clay soil, 270mm), were higher or equal to minimum tillage (sweep), with both being significantly better than conventional tillage (Table 1) (Bouzza, 1990; Mrabet et al., 1993; Mrabet, 2000a).

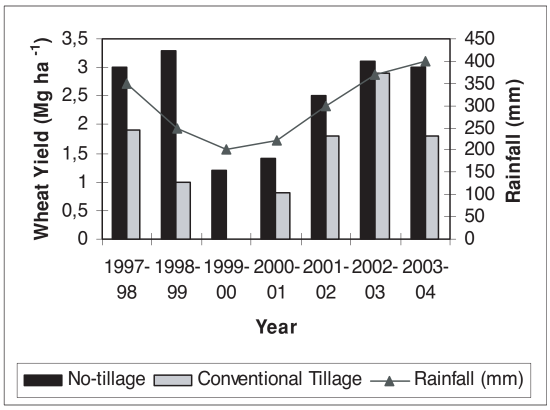
Table 1: Wheat grain yield (Mg ha-1) as affected by tillage (Bouzza, 1990; Mrabet et al., 1993; Mrabet, 2000a).

Tillage system	Continuous Wheat	Wheat-Fallow
	Sidi El Aydi	
No-tillage	1.9	3.7
Reduced Tillage (sweep)	1.6	3.7
Conventional Tillage	1.4	2.6
	Jemaa Shaim	
No-tillage	1.6	3.1
Reduced Tillage (sweep)	1.6	3.1
Conventional Tillage	1.4	2.4

These results are confirmed for 4-year continuous wheat by Mrabet (2000b), as shown in Figure 2a as well as in farmer's fields (Figure 2b).



a



b

Figure 2: Tillage effect on wheat grain yield at Sidi El Aydi experiment station with a deep clay-rich soil (Mrabet, 2000b) (a) and at a semi-arid Moroccan farm with medium depth clay soil on sloping land (b) (Mrabet & El-Brahli, 2005).

In farmer's field, wheat yield increased with no-tillage compared to conventional tillage (Figure 2b). In other terms, no-tillage system was applied for 7 years without any depression of wheat production. In this figure, wheat production under no-tillage in a drought year like 1999 expresses the stabilizing effects of favorable conditions of soil properties and microclimate when applying no-tillage and residue cover. However, crop failure in case of farmer's situation under conventional tillage means that conditions for degradation are prevalent.

Mrabet et al. (2003b) found no significant difference in terms of grain wheat yield, number of grains per spike, 1000 kernel weight and grain protein between no-tillage, minimum tillage, conventional disking, chiselling and rotavator after 7 years of continuous wheat at Sidi El Aydi Station (Table 2). Exceptionally, chiselling permitted the highest biomass production.

Table 2: Tillage effect on wheat yields, yield component and grain protein after 7 years of experimentation (Mrabet et al., 2003b).

Tillage systems	Grain yield (Mg ha^{-1})	Total Biomass (Mg ha^{-1})	Number of grain/spike	1000 kernel weight (g)	Grain nitrogen (%)
No-tillage	2.16	6.06	36.25	33.20	2.56
Off-set disk	1.64	4.95	28.25	35.26	2.53
Disk plow	1.65	6.34	37.50	36.05	2.37
Rotavator	1.99	5.15	28.50	33.82	2.53
Chisel	2.17	8.22	42.50	35.74	2.31
Sweep plow	2.09	5.66	33.25	33.61	2.47
Average	1.98	6.29	34.14	34.57	2.46
LSD (5%)	0.855	2.002	12.93	2.661	0.33

Increasing the efficiency of water use by crops is an escalating thematic of research because of the increasing demand for water use by agriculture and other sectors. In rainfed agriculture, water use efficiency (which is the ratio of grain yield in kg/ha to total water used by wheat crop from seeding to harvest in mm) (WUE) is correlated to the effectiveness of the use of precipitation because there is no other source of water. (Define and show how you calculate WUE) Hence, increasing soil water storage impacts positively the WUE. Soil management affects water and nutrient status within the soil and offers opportunities to improve WUE. These improvements are related with the manipulations of the soil surface by tillage and surface residue management or mulching. That's why these manipulations should favor transpiration and seasonal storage of water in the soil in place of drainage, evaporation and runoff.

According to Mrabet (2000b), WUE ranged from as low as 2.5 kg/ha/mm in off-set disking (1998-99) to 10.7 kg/ha/mm for chisel plowing (1995-96), with tillage systems significantly affecting WUE in all years. Reduced evaporation in the NT is reflected in WUE. At the same site and after 7 years of experimentation, Mrabet et al. (2003b) found that NT has higher or equal grain (Table 2) and WUE as the other tillage systems.

3.3. Crop residue management for no-tillage crop yield improvement

Almost all the benefits of the no-tillage system come from the permanent cover of the soil and only very few from not tilling the soil. In other words, it is not the absence of tillage but the presence of crop residues on the soil surface that results in a better performance of no-tillage in comparison to conventional tillage system (Derpsch, 2005). No-tillage without plant residues on the soil surface will result in poorer crop development and yields below those obtained in conventional tillage (Mrabet, 1997; 2000b; 2002a). In other terms, this latter author showed that wheat grain yields in all years have been directly related to the amount of ground cover applied after the previous harvest. Consistently, the lowest yields were obtained in no-tillage with no residues.

Seedling growth is retarded most severely in the field spots where residues are concentrated and it approaches normal or becomes greater where residues are partially removed (Mrabet, 1997; 2002a) (Figure 3). As shown in Figure 4, the issue of the need to use post-harvest crop residues for animal feeding or fuel has been investigated, and it was found that up to 30% of the produced residues could be removed from the field without affecting final yield (Mrabet, 2002a).

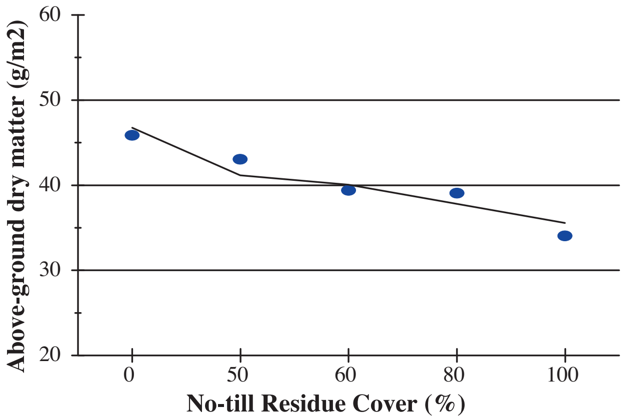


Figure 3: Effect of no-tillage residue cover on early growth (3-leaf stage) of soft wheat (Mrabet, 1997).

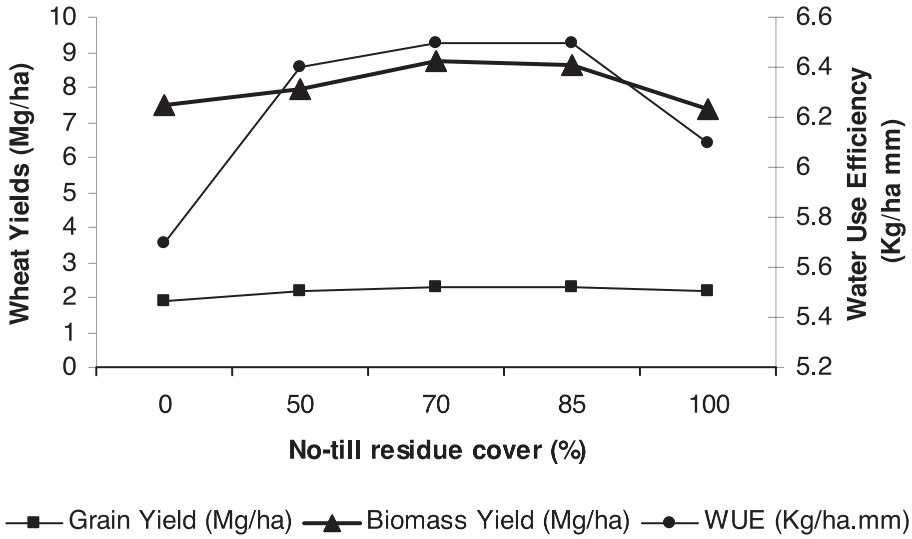


Figure 4: Residue cover effect on bread wheat water use efficiency and yields under no-tillage systems (Mrabet, 2002a).

3.4. Crop diversification in semiarid Morocco under no-tillage systems

Generally, a range of crops (Figure 5) responded favorably to no-tillage systems and residue cover, such as corn, lentil, chickpea and faba bean (Kacemi, 1992), sunflower (Aboudrare et al., 2006), vetch-oat (El-Brahli et al., 1997) and barley (Mrabet & Bouzza, 1994), either by increasing or not negatively affecting yield in comparison with conventional tillage systems. In Meknes region receiving an average rainfall of 560 mm, Aboudrare et al. (2006) did not find much impact of tillage systems (no-tillage; moldboard plow; chisel plow) on sunflower yield for the first two years of experimentation. However, conventional tillage systems based upon off-set disk and paraplowing reduced sunflower yield in the second year.

In rainfed areas, less-than-desirable or inconsistent corn yield performance under NT management has been related to several factors such as insufficient water in late corn development stages, delayed crop growth and development, and increased difficulties with pest control and soil management. However, using a line-source irrigation system to define varying water regimes, Mrabet (1997) found that the no-tillage system ameliorated seedling establishment and growth of corn. The yield under no-till increased compared to tilled systems and ranged from 8 to 22% greater for corn depending on moisture regimes.

Kacemi et al. (1995) reported that no-tillage system effect on wheat grain yield was superior or equal to minimum tillage (V-blade Sweeps) for wheat-corn, wheat-lentil and wheat-chickpea cropping systems in two climatically contrasting sites.

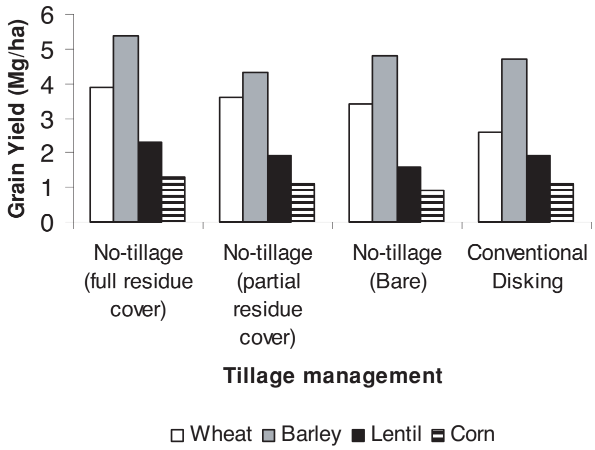


Figure 5: Tillage and residue cover effects on grain yield of selected crops

4. No-tillage systems: Impact on soil physical quality

4.1. Soil structure and aggregation

Rapid water entry into soils requires both adequate pore space and large pore openings; thus, soil aggregation is critical. Soil aggregation plays an important role in an array of processes such as soil erodibility, organic matter protection and soil fertility.

Soil structure research showed that the lack of annual tillage, as provided under continuous no-tillage management, encouraged the development and persistence of a soil surface horizon rich of stable aggregates in semiarid Morocco (Gregorich & Carter, 1997; Mrabet, 2002b; Mrabet & Beqqali, 2005). Table 3 shows increased wet aggregation index with increased residue cover under no-tillage system, mainly at the soil surface (0-25 mm and 25-70 mm). In addition, Mrabet et al. (2004) found that even without residues the untilled plots had higher levels of aggregation than tilled plots near the soil surface. Dry aggregation is not, however, a good soil quality indicator.

Table 3: Influence of crop residue on aggregation (Lahlou, 1999; Mrabet et al., 2004).

Tillage treatment	Horizon depth (mm)					
	WAS			MWD		
	0-25	25-70	70-200	0-25	25-70	70-200
No-tillage without residues	52B	40B	42A	3.03B	6.40A	4.16A
No-tillage half cover	56B	47AB	46A	2.85B	6.60A	3.62A
No-tillage full cover	65A	51A	45A	3.03B	6.03A	4.40A
Conventional Tillage	48B	45AB	44A	4.06A	4.30B	4.01A
Average	56	46	44	3.42	5.82	4.05

Measurements were done 4 years after initiation of the experiment. WAS = percent of water stable aggregate (stability of 1-2 mm aggregates); MWD = mean weight diameter (mm). In each column, values followed by same letter are not significantly different at p =0.05 (LSD).

4.2. Soil bulk density and pore size distribution

Soil bulk density is probably the most frequently measured soil quality parameter in tillage experiments. Current soil quality indexing methods (Andrews et al., 2002) consider that crop growth could be reduced if bulk density is higher than a critical level that varies with soil texture. In other words, crop yield will be reduced only if compaction limits root development and function such that crops cannot obtain air, water, and nutrients at adequate rates.

Measurements of pore characteristics are also being used more and more to characterize soil structure since they influence numerous functions in soils (Lahlou et al., 2004). Significant changes take place over time when tillage is eliminated. With no-tillage, soils are loosened only locally and superficially; yet they have to bear the normal load of traffic in the field. In general, the differences are greatest in the soil layer which is loosened by ploughing. In no-tillage, natural consolidation and mechanical compaction cause denser packing of topsoil as found by Lahlou (1999) after 4 years. However, Ait Cherki (2000) did not find a significant increase in dry bulk density under no-tillage systems compared to conventional tillage after 6 years of experiment in semiarid Morocco (Table 4). It is also important to note that, after 6 years, the no-tillage system had lower soil bulk density at the plowpan zone.

After 4 years, Kacemi (1992) reported a difference in bulk density in the rainy season in the 5-10 cm depth between NT and minimum tillage with V-Sweep at Sidi El Aydi. Nevertheless, this difference disappeared in spring of the same year. It is, however, important to indicate that the V-blade sweep cuts the soil at around the 12 cm depth. According to the same author, differences in soil bulk densities were negligible among rotations for both tillage systems. These findings reflect that root growth was not affected by tillage systems. Shaver et al. (2003) found a negative correlation between soil bulk density and crop residue retention. This implies that NT progressively ameliorated the soil tilth.

Table 4: Tillage effect on bulk density (Mg/m^3) after 4 and 6 years of experimentation (Lahlou, 1999; Ait Cherki, 2000; Mrabet, 2006).

	After 4 year		After 6 years	
	0-8 cm	8-16 cm	0-8 cm	8-16 cm
Direct seeding	1.56A	1.54A	1.26A	1.29B
Conventional tillage	1.45B	1.54A	1.23A	1.32A
Average	1.51	1.54	1.25	1.31

In each column, values followed by same letter are not significantly different at p =0.05 (LSD).

The change in bulk density in no-tillage systems was accompanied by a concomitant change in pore size fractions (Figure 6). This figure also demonstrates that the soil was able to recover to some extent from compaction due to biological and physical processes. These improvements in pore size distribution at the seedzone may explain better infiltration process and high level of stored water when soil is kept untilled.

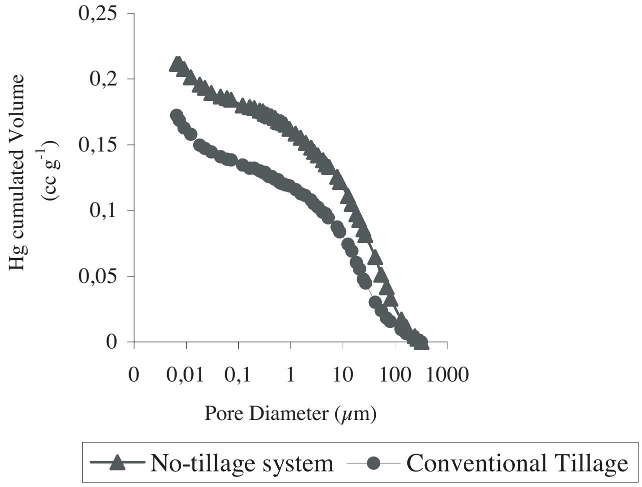


Figure 6: Tillage effect on pore fractions under continuous wheat (Lahlou et al., 2005).

4.3. Water infiltration

Rainfall infiltration is improved under no-tillage systems, and for heavy textured soils, the amounts of soil water available for plants increase (Bouzza, 1990; Kacemi, 1992; Debaeke & Aboudrare, 2004; Aboudrare et al., 2006), and for structurally weak soils, formation of crusts is eliminated with residue mulch (Chekli, 1991; Lal, 1997). Therefore, for most soils, the infiltration properties are improved under no-tillage systems. This is the case of a clay soil in semiarid Morocco (Figure 7). The high infiltration rate under NT can be attributed to high hydraulic conductivity, and this later increases the development of macroporosity. It was also found that NT does not significantly impact bulk density in the soil profile, which normally affects positively hydraulic and permeability properties.

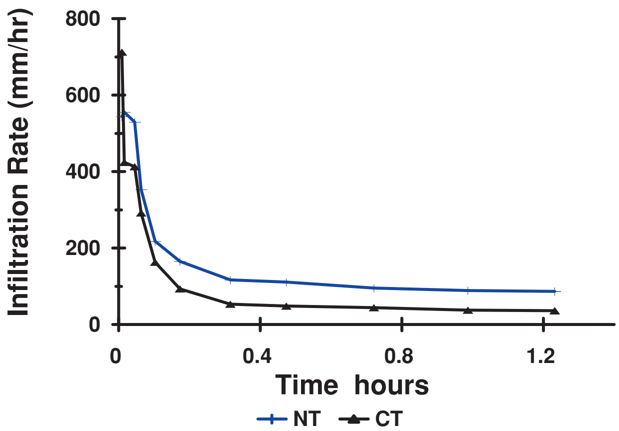


Figure 7: Impact of tillage system on infiltration process in Sidi El Aydi clay soil (unpublished data). NT = no-till & CT = off-set disking.

4.4. Soil moisture evaporation and retention

Crop residue influences the hydrologic cycle in many ways. Evaporation research showed that residue suppressed evaporation primarily in the first stage of evaporation and if drying persisted long enough (several months); evaporation from soils with high mulch rate matched or exceeded evaporation from bare or tilled soils (Steiner, 1989). Jalota & Prihar (1989) and Mrabet (1997) described a negative exponential relationship between mulch rate and the initial evaporation from a mulch covered soil.

Information about the energy associated with soil water is essential for understanding its movement in soil and its availability for crop growth. Differences between tilled and untilled soil are shown in Figure 8 in terms of retention of water by the soil. Most remarkable is the observation that soil water tensions were affected by tillage system in all range. In the untilled soil, the soil water retention remained at a higher level. This behavior indicates a lower resistance of the zero-tilled soil to infiltration. Therefore, no-tillage may prevent or retard slaking and sealing of the soil surface and reduce runoff.

The study by Mrabet (1997) was undertaken to analyze, in field conditions, the effects of tillage and traffic on soil structure and evaporation. Time to reach moisture content of the soil at wilting point was proportional to residue cover under NT as expressed in Figure 9. In other words, the wilting point was reached faster under tilled surfaces (especially disk plow) than under untilled covered surfaces.

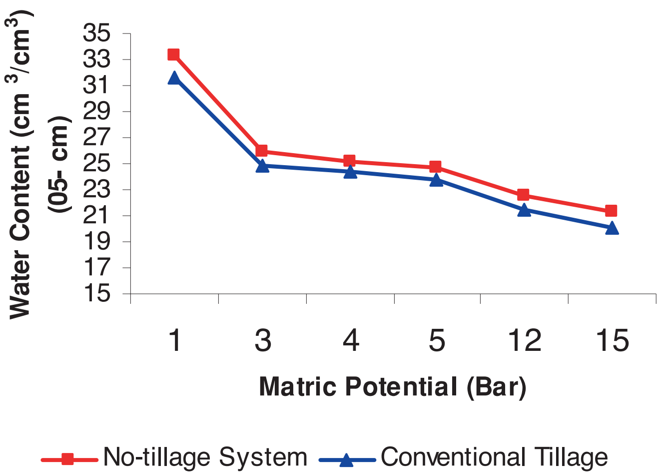


Figure 8: Water retention curve as affected by tillage system (Ait Cherki, 2000; Mrabet, 2006).

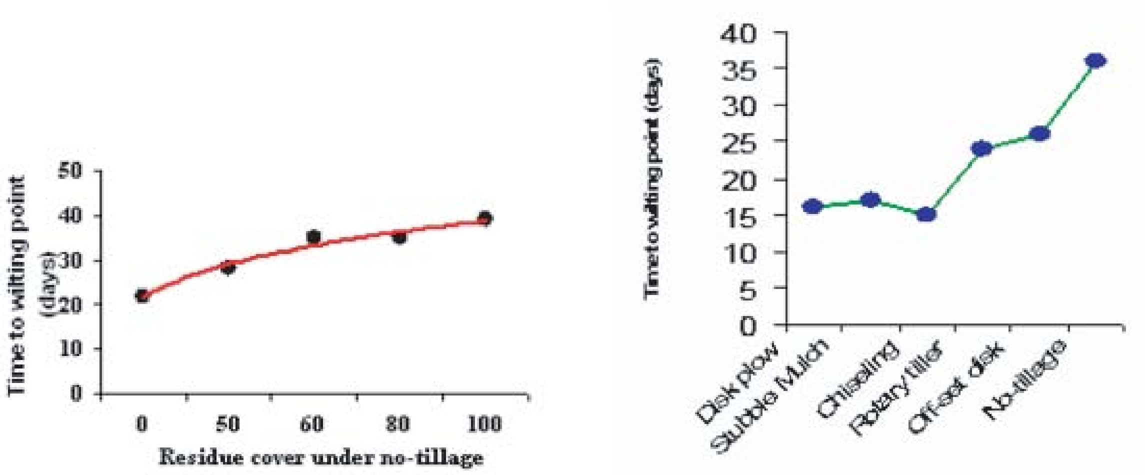


Figure 9: Soil water evaporation as affected by level of crop residue under no-tillage systems (left) and soil management by tillage (right) (Mrabet, 1997).

Water evaporation is reduced by no-tillage because of the mulch formed by crop residues at the soil surface. A cover of 80% on NT is the management treatment permitting the least evaporation of water from the soil (Figure 10). Figure 11 shows the soil surface water content is greater on no-tilled plots than on conventional tilled plots. Uncovered no-till surfaces lose the greatest amount of water by evaporation. All tillage systems increased evaporation as compared to no-tillage with residue cover. As shown in Figures 10 & 11, soil cover management is a key agent in managing water capture and hence reducing water evaporation in dryland cropping systems.

Figure 9 illustrates that no-tillage soils are not as compacted and will hold soil moisture as long as 2 weeks after a conventionally tilled field has been lost due to drought. This increased water-holding capacity can also be important in getting a uniformly emerged stand at planting time. Such fields may retain planting moisture longer where CT fields may have lost their planting-moisture following tillage operations for controlling weeds resulting in delayed planting.

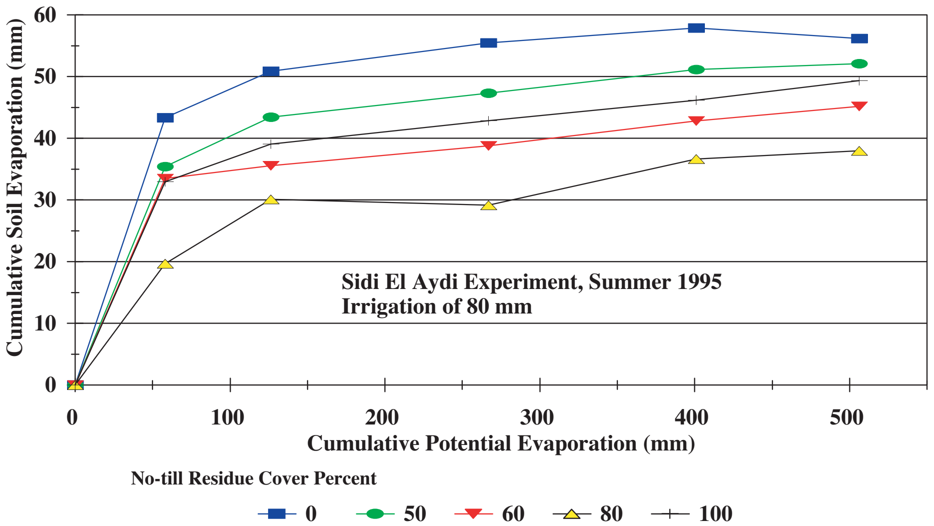


Figure 10: Cumulative soil surface evaporation under various levels of residue cover under zero-tillage (Mrabet, 1997)

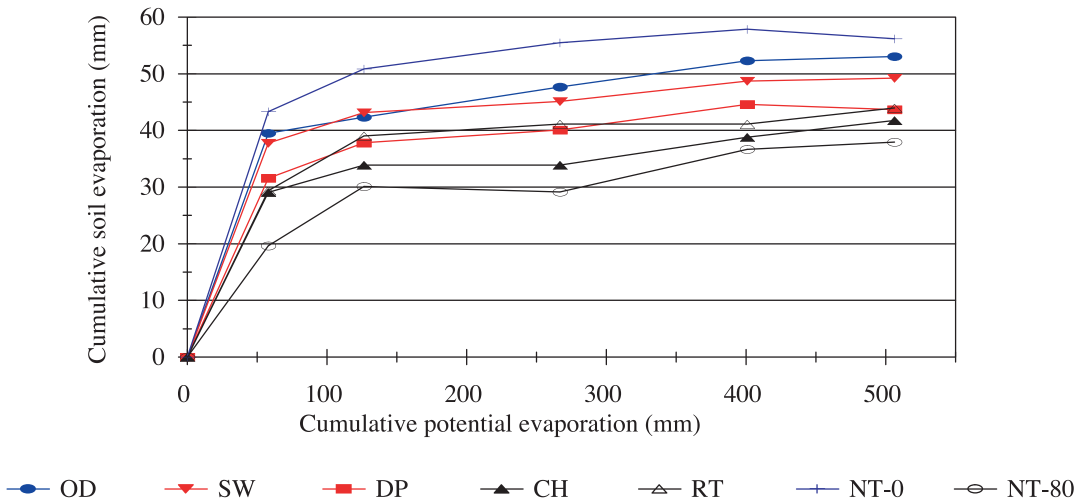


Figure 11: Cumulative soil surface evaporation under various tillage systems (OD= off-set disking, SW = Sweep plow, DP = Disk plow, CH = Chisel plow, RT = Rotary tiller, NT-0 = No-tillage without residue cover, NT-80 = No-tillage with 80% residue cover) (Mrabet, 1997).

5. No-tillage systems: Impact on soil chemical quality and carbon sequestration

5.1. Total and particulate nitrogen

Differential accumulations of organic matter imply changes in concentration and distribution of nitrogen (N), either total or particulate. After 11 years of experimentation at Sidi El Aydi, NT soils recorded significantly higher nitrogen contents than conventional off-set disking (CT), particularly at the surface (0–2.5 cm in Table 5). Mrabet et al. (2001a) reported that the nitrogen content of the intermediate soil depth (2.5-7 cm) was higher in NT than CT for all three rotations (Table 5).

After 7 years, Tab (2003) found in the same site and under a continuous wheat rotation that NT sequesters more N than conventional and reduced tillage systems (Table 6). The disk plow is the system which performed the worst by reducing N content of the soil in all depths.

Soil organic matter accumulation under no-tillage produces total N and nitrate accumulations in the upper 5 cm of soil. Total N increase may be due to delayed nitrification in response to reduced aeration of the soil. Fallow promotes organic matter loss compared to continuous wheat or other wheat-barley-fallow (Mrabet et al., 2001a). At the same time, N enrichment to the soil was higher in continuous wheat than for wheat-fallow rotation.

Table 5: Total nitrogen (g/kg) in the calcareous soil after 11 years of no- and conventional tillage systems (Mrabet et al., 2001a).

Depths (cm)	No-tillage	Conventional tillage	Average
0 – 2.5	1.84A	1.33B	1.59
2.5 – 7	1.49A	1.34B	1.41
7 – 20	1.20A	1.20A	1.20

In the same raw, values followed by same letter are not different (LSD, 5%)

Table 6: Tillage systems effect on total nitrogen under continuous wheat (7 years after experimentation at Sidi El Aydi station) (Tab, 2003).

Tillage Systems	0-5 cm	5-10 cm	10-15 cm	0-15 cm
		%		Mg Ha^{-1}
No-tillage	0.18 A	0.15 AB	0.14 C	2.90 A
Off-set disking (OD)	0.14 CD	0.14 C	0.14 C	2.61 C
Disk plow + OD	0.13 D	0.12 D	0.13 D	2.34 D
Chisel plow + OD	0.15 C	0.15 BC	0.15 B	2.73 B
Rotary Tillage	0.17 B	0.16 A	0.15 B	2.91 A
Stubble Mulch Tillage (Sweep)	0.16 C	0.16 AB	0.14 C	2.79 B
Average	0.15	0.15	0.14	2.71

In the same column, values followed by same letter are not different (LSD, 5%)

Particulate organic matter (POM) or light fraction (LF) is generally considered one of the primary indicators of soil quality, both for agriculture and for environmental functions (Leifeld & Kogel-Knabner, 2005). Soil organic matter fractions with turnover times of years to decades, such as POM or LF, often respond more rapidly to NT-induced changes in the SOC pool than more stabilized, mineral-associated fractions with longer turnover times (Cambardella & Elliott, 1992; Gregorich & Janzen, 1996; Six et al., 1998; Bessam & Mrabet, 2003).

Particulate nitrogen (Npom) presented an identical general trend to N. Cpom and Npom tend to be higher under full residue cover at the surface. C/N was not influenced while C/Npom was affected by no-tillage residue maintenance at all depths (Table 7). At 0–2.5cm, N particulate organic matter was significantly affected by rotation in the following order Wheat > Fallow Wheat > Fallow Wheat Barley (Ibno-Namr & Mrabet, 2004).

Bessam & Mrabet (2001; 2003) reported that particulate nitrogen (Npom) was higher under NT than conventional tillage in the seedzone following 4 to 13 years of experimentation (Figure 12). However, the effect of these tillage systems was not significant at lower depths (5-10 & 10-20 cm). These finding are also reported in Table 7. From this same table, CT resulted, at the surface, in lower Cpom, Npom and C/Npom compared to NT without residues at the surface.

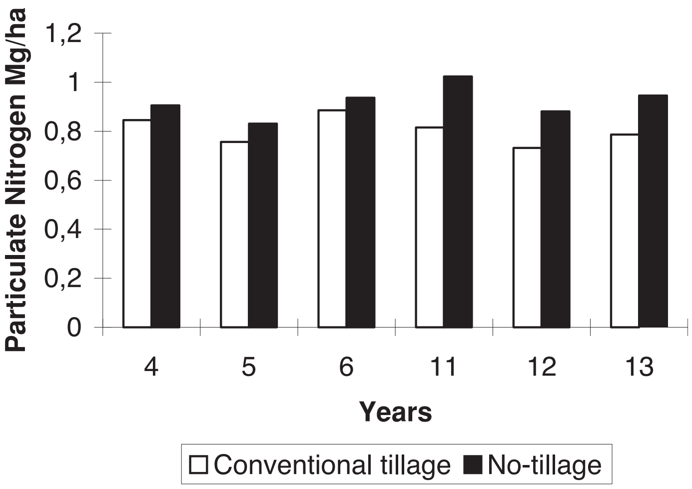


Figure 12: Time Effect on surface particulate nitrogen content (Mg/ha) of tillage systems at Sidi El Aydi experiment station (Bessam & Mrabet, 2003).

A differential increase in nitrogen content, along with a greater C/N ratio and a relative increase in particulate organic nitrogen fraction near the surface suggest changes in the rates of N mineralization and hence in the amounts of available N. However, the higher water content in the surface of no-tilled soil (Mrabet, 1997) may influence the downward displacement of soluble N.

Table 7: Tillage systems and residue rate under NT as affecting particulate carbon (C_{pom}) and nitrogen (N_{pom}) and C_{pom}/N_{pom} after 5 years of experimentation (Ibno-Namr, 2005).

Horizon	0-2.5 cm			2.5-7 cm			7-20 cm		
Index	Cpom	Npom	C/N-pom	Cpom	Npom	C/N-pom	Cpom	Npom	C/N-pom
Cropping System									
WW	21.4 A	1.7 A	12.56 A	15.1 A	1.3 A	11.33 A	12.7 B	1.3 A	10.35 A
FW	19.2 A	1.5 B	12.61 A	14.1 A	1.3 A	11.22 A	12.7 B	1.2 B	11.03 A
FWB	20.0 A	1.5 B	13.16 A	13.6 A	1.2 A	11.06 A	13.6 A	1.1 C	10.69 A
Tillage and residue management									
NT_{100}	26.9 A	1.8 A	15.33 A	14.5 A	1.3 A	11.23 B	12.9 A	1.1 A	11.37 A
NT_{50}	17.9 C	1.6 A	10.92 B	14.1 A	1.3 A	10.96 B	11.5 B	1.2 A	9.75 B
NT_{0}	21.5 B	1.5 A	14.25 A	14.9 A	1.2 A	12.04 A	13.5 A	1.1 A	11.95 A
CT	14.4 D	1.4 B	10.61 B	13.7 A	1.3 A	10.58 B	11.2 B	1.2 A	9.69 B
Average	20.2	1.6	12.78	14.3	1.3	11.20	12.2	1.2	10.69

WW = continuous wheat, FW = Fallow wheat, FWB = Fallow-Wheat-Barley, NT0 = NT with residue cover, NT50 = NT with half residue cover, NT100 = NT with full residue cover, CT = Offset disk. In the same column, values followed by the same letter are not significantly different at 5% level (LSD).

5.2. Phosphorus (P) and potassium (K) concentration and distribution

The contents of available P and K near the soil surface were higher on no-tilled than on tilled soil, whereas in deeper layers the reverse has been observed (Mrabet et al., 2001b). Table 8 shows that P and K accumulated in the seed-zone of the untilled soil. P and K were probably higher in the surface of NT soil due to higher soil organic carbon and to the fact that these systems maintained surface-applied P. Progressive mineralization of organic matter was the most important source of these nutrients in this soil under NT. Consequently, no-tillage systems affect the vertical distribution of plant nutrients within the topsoil.

From Table 8, it is shown that P is depleting in lower horizons while it is accumulating at the surface (stratification). These findings challenged researchers to design no-till drills where P is banded in the crop row at 7-8 cm depth (Bourarach et al., 1999). However, in the conventional tillage, the P content did not vary significantly with time and was evenly distributed in the profile.

In terms of acidity, NT permitted a surface slight acidification of surface horizon, mainly due to organic matter accumulation in this depth (Table 8). This decrease in pH by 0.2 unit may be important for nutrient release for use by wheat or other crops.

Table 8: Soil extractable P, exchangeable K and pH under no- and conventional tillage after eleven years of experimentation (Mrabet et al., 2001b).

Depth (mm)	No-tillage	Conventional tillage	Average
		Extractable P (mg kg^{-1})	
0 – 25	29.9A	18.0B	23.9
25 – 70	19.3A	16.5B	17.9
70 – 200	8.7B	10.9A	9.8
		Exchangeable K (mg kg^{-1})	
0 – 25	476.4A	284.1B	380.3
25 – 70	291.7A	256.9B	274.3
70 – 200	148.6B	177.9A	163.3
		pH water	
0 – 25	7.8B	8.0A	7.9
25 – 70	8.1A	8.0A	8.1
70 – 200	8.2A	8.2A	8.2

In the same raw, values followed by same letter are not different (LSD, 5%)

5.3. Total soil organic carbon

Results from tillage experiments showed increased soil organic matter from using NT. There is a trend towards a stratification of soil organic matter at the surface under NT. This build-up of organic matter in surface horizon (generally the seed-zone) improves seedling establishment, sometimes an important factor in crop growth under no-tillage (Figure 13).

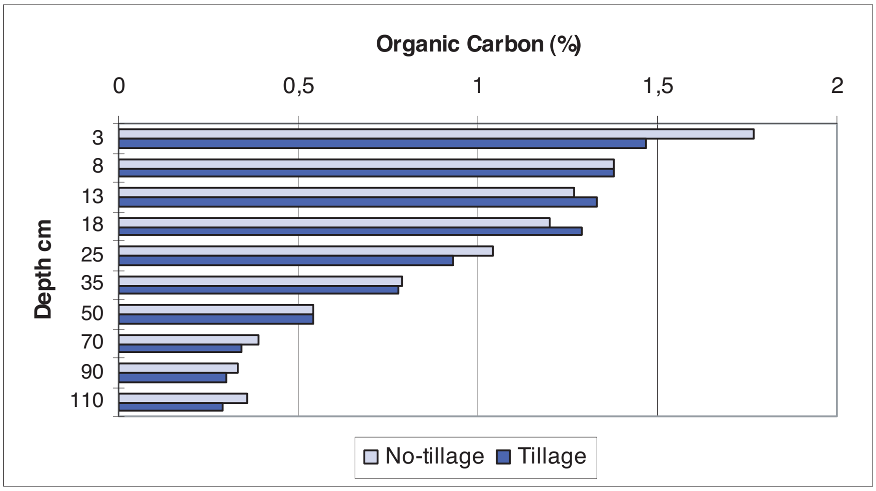


Figure 13: Organic carbon profile under No-tillage and conventional tillage systems after several years of experimentation at Sidi El Aydi Station (Mrabet, 2006).

From Figure 14, it is clear that residue cover improves considerably the soil organic content of the soil surface over time. Hence, as residue cover increases; the build process of organic carbon is important.

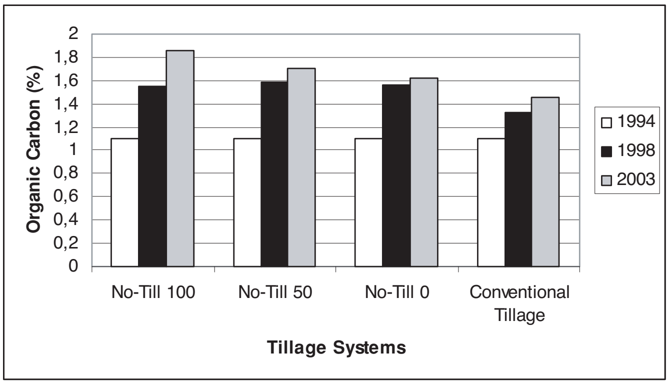


Figure 14: Time-Tillage and residue cover effects on organic carbon of a surface horizon (0-5 cm) of a Calcixeroll soil in semiarid Morocco (experiment started in 1994, Average annual rainfall: 358 mm, No-Till 100, No-Till 50 & No-Till 0 correspond to no-tillage plots with full cover, 50% partial cover and bare) (Compiled from Mrabet et al., 2001b; Ibno-Namr and Mrabet, 2004).

Aggregation and organic build-up are co-processes (Golchin et al., 1994; Angers & Chenu, 1998; Carter, 2002; Mrabet, 2006). This is shown in Figure 15. Changes in total soil organic carbon with change in tillage or cropping system can be partially explained by the way carbon is allocated in different aggregate classes. These trends in organic carbon accumulation were also reported by Lal (2002).

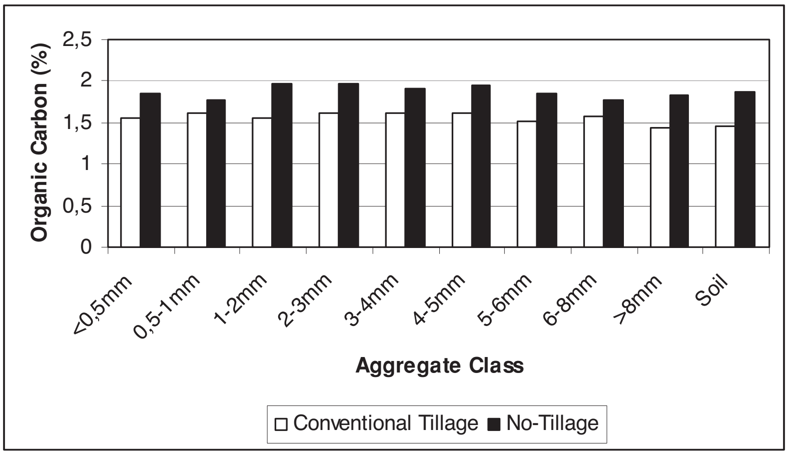


Figure 15: Effect of tillage system on organic carbon of soil and its aggregates (Tab, 2003).

5.4. Particulate organic carbon

NT improves the quality of organic matter by increasing the level of the active fraction (also termed particulate organic matter (Cpom) or light fraction), which consists primarily of living plant roots, rapidly decomposing material and micro- and macro-organisms (Bessam & Mrabet, 2003; Beare et al., 1994). Results for a semiarid soil of Morocco are shown in Table 9 clearly indicates that NT improved Cpom in the surface zone compared to conventional tillage. The benefits of improving soil quality and hence reducing degradation are cumulative. This cumulative effect of NT is a reflection of short or long-term gain in production. Cpom is a good soil quality indicator of tillage system comparison since it responds to residue management as well (Table 7). Continuous wheat had the overall highest level of total and particulate organic carbon and nitrogen followed by fallow-wheat-barley rotation (Table 7). Wheat-fallow rotation had a reducing effect on the contents of organic carbon and nitrogen.

Table 9: Carbon content in particulate organic matter (Mg/ha) as affected by contrasting tillage histories in semiarid Morocco (Bessam & Mrabet, 2003).

Time Years	Horizon (mm)					
	0-50		50-100		100-200	
	NT	CT	NT	CT	NT	CT
5	10.62 A	9.75 B	9.45 A	9.32 A	17.23 A	16.81 A
13	11.88 A	8.94 B	8.53 A	9.07 A	14.80 B	16.28 A

In each raw and for each horizon, values followed by same letter are not significantly different at p=0.05 using LSD test; NT = No-tillage and CT = Conventional tillage with disk harrows.

6. No-tillage systems: Further Research

In semiarid Morocco, the introduction of no-tillage systems in the 1980s caused an important change in agricultural research and production. However, in spite of higher yields, the process of adoption of these systems is taking a longtime and even traditional tillage systems are still widely used. Various reasons, such as imperfect information, uncertainty, inadequate human capital, and institutional constraints have been related to this slow adoption. The scarcity of water puts a brake on development of no-tillage.

Further research is needed to provide farmers a scientifically sound framework and reference base for the determination, dissemination and implementation of regionally-defined no-tillage seeding strategies. Evidently, the research and development of adaptable no-tillage tillage strategies in Moroccan dryland farming systems with small-scale mechanization is still a big challenge.

Even though the ability of conservation tillage, and especially no-tillage, to increase grain yields was well documented, its ability to provide better economic performance, reduce production risks, and improve energy use efficiency is not yet sufficiently documented.

As stated by Lal et al. (2007) and applied to research in Morocco: “Soil-specific research is needed to enhance applicability of no-till farming by alleviating biophysical, economic, social and cultural constraints. There is a strong need to enhance sustainability of production systems while improving the environmental quality”. In other words, supplementary studies should be undertaken in other soil types in order to generalize the effect of no-tillage systems on the improvement of crop yields and on the restoration of soil and environment quality.

The focus of soil quality research was mainly on the effect of different tillage systems on chemical and physical properties. The future focus should be on biochemical properties and soil ecology. Other biochemical and chemical studies of soil organic matter are needed to comprehend better the carbon dynamics and microbial activity. Soil erosion and carbon emission under tillage systems should also be prioritized in agricultural research centers. In fact, agronomic and environmental benefits from no-tillage systems could be ameliorated and better recognized in prevision of future scenarios of climate change (rise of temperature and evapotranspiration) that may occur in Morocco. Hence, studies on microbiological and faunal activity and biodiversity, C mineralization, organic matter humification and C sink functions should be carried for short and long terms under no-tillage cropping conditions.

A NT system, a non-thesis to plow-based tillage, prevents and eventually reverses erosion processes, due largely to alteration of soil functions and processes. It is at the same time the ultimate technology to simultaneously boost the soil resistance to soil degradation and reduce the magnitude of desertification. However, soil erosion research is not yet a high priority in the country. This dilemma should be resorted.

Even though most uncertainties in achieving flexible sustainable movement of no-tillage in semiarid arise from the factors related to sociology and politics. These issues should be searched with great detail.

Increased effort in modelling is a priority if agronomists are to contribute efficiently and effectively to the design of optimal cropping systems for the future. Diversification and intensification permitted by no-tillage systems should be perceived correctly and this is possible only through long-term experimentation and cropping system modelling. Drought mitigation by NT system requires an in-depth understanding of crop behaviour, physiology and adaptation to drought stress and other limiting abiotic factors.

Crop management under no-tillage has been studied conveniently. Weed development is the main challenge, causing reduced yields of crops. The appropriate herbicide use and application for weed control is critical for the success of NT. The adequate control of weed infestation is mainly important in early adoption of NT. Yet, weed and disease research is lacking under conditions of conservation agriculture. Major efforts should be made to get profound understanding of weed, disease and insect responses to NT soil and microclimate conditions. Development of integrated weed, disease or pest control strategies is of paramount importance.

Growing cover crops, a basic component for NT successful adoption in Latin America, is an important strategy to reduce soil erosion and fertility depletion and hence restoring degraded soils. These species should be experimented in research stations to seek possible advantages and uses.

Interactions between variety and no-tillage lack of soil perturbation may exist. Consequently, these interactions should be investigated. Crop variety development should be carried out for NT systems in order to account for best advantages from genetic and agronomic performances of the crop.

Management of risk is a critical aspect of economic survival and farmers are understandably risk averse in their adoption of new technology, mainly if they are complex such as no-tillage systems. Comprehensive studies and simulation models should be carried out in order to ascertain these risks and appropriately convey the technology to the society and community.

The selection of an appropriate drill is a challenge connected with dry soils, fertilizer banding and straw management. However, farmers have several choices among manufactured drills but need relevant information and skills for their proper use. Therefore, the challenge to design no-tillage cropping systems that are economically and environmentally sound is still enormous. For this reason, there is a great need to develop a research agenda on various effects of conservation agriculture vs. conventional tillage on environmental processes with economical analysis of the impacts at all scales (farmer, community, watershed and region).

The transition to no-tillage has technical implications for farmers, among them no-till drill use. In various no-tillage leader countries, no-till implements are specifically designed for the management of crop residue left on the soil surface and for all types of crops. However, in Morocco, there is still a gap in knowledge in using no-till drills and availability of row-crop drills is nil. Effort should be directed to enforce the on-going industrialization of national no-till drills for cereals and to open new research direction for experimenting or designing no-till drills for crops such as corn, sunflower, faba bean and many others.

Consequently, substantial efforts and appropriate policies are needed to increase adoption and growth of NT at large scale during the next coming years. Conditions for assuring prolonged adoption of NT and hence implementing conservation agriculture should be satisfied through partnership building, subsidies to and participation of farmers. Finally, no-tillage as a system of documented benefits in preventing desertification should be included in the United Nation Convention to Combat Desertification text, mechanisms and agenda.

7. Conclusions: Needed developments

Factors contributing to no-tillage financial viability are: (1) low cost of labor and tractor, (2) low dependence on equipment and maintenance costs, (3) high opportunity for crop diversification, (4) time saving and independence of rain event for planting and (5) high and stable yields. Therefore, if crop yields are increased, equal to, or decreased only slightly, then crop production is more economical with no-tillage than with any other tillage system.

The Moroccan Government is engaging important efforts to ameliorate food security, modernize agriculture, combat desertification, and promote safe environment and sustainable use of soil and water resources. It is believed that adopting no-tillage systems would facilitate these objective efforts. Nevertheless, there is yet no sizeable scale of no-tillage adoption by farmers. Moroccan agriculture must seek new directions to be able to defy the changes and challenges in climate, ecology, technology, economy, rural development and society. At the same time, the world's agriculture is undergoing a paradigm shift from the conventional age to conservation age. Countries around the world are putting their resources and efforts into agricultural transformations to ensure economical growth and prosperity as well as to enrich the agricultural society. Hence, it has been obvious that Morocco also needs a new strategy and action plan befitting the new environment as the conservation agriculture become pervasive and no-tillage technologies are deployed to accelerate changes.

For a possible increased adoption of no-tillage systems, there is a need for establishment of alliances among stakeholders (farmers, community decision makers, public sector, private enterprises ...). These alliances will allow growing firm roots of no-tillage systems in the country. In fact, for small farmers, the introduction of no-tillage systems may reduce drudgery and labor requirement for crop production and help create time for off-farm work.

Through adoption of no-tillage, the economic and social system of rural society can be revolutionized to boost productivity of the country. Having suffered from natural resources degradation and declining productivity, Morocco's agriculture should experience a transition based upon conservation and intensification. It has been shown that no-tillage is a win-win technology that brings together production and protection. Conservation agriculture based upon widespread use of no-tillage will satisfy at the same time farmers and decision makers. Policy makers will have their short-term requirements of cutting cost and increasing production as well as their long-run expectations of stable ecosystems guarantied. On the other hand, farmers with their day-to-day decisions and the imperative need of producing sufficient food for their families can be greatly satisfied. For the nation as a whole, resource conservation will generate additional benefits in terms of poverty alleviation through food security, environment protection and citizen's well being (Steiner, 1998).

For semiarid Morocco, no-tillage systems contribute to the overall agro-ecosystem sustainability through its positive influence on environmental quality (soil, water and air), agronomic sustainability (high and stable yields, drought mitigation) and socio-economic viability (high return, low risk, low input). No-tillage systems also contribute to improvements of performances at both individual and societal level. In the light of available technology, no-tillage agriculture can make an effective and sustainable contribution to the solution of agri-environmental problems.

In mixed farming systems, NT does not provide miracle solutions if constraints are not overcome. Constraints include the relatively high investment costs especially in training of extension people and farmers. Institutional and land tenure problems, for example customary laws that allow livestock to graze-off crop residues, may limit its application. In mixed crop-livestock systems, stall-feeding or controlled grazing may need to replace free grazing on harvested fields. Other agro-ecological limitations, such as the rainfall requirements of particular crops, may complicate the introduction of NT in pluvial Morocco.

Farmers are required to have good knowledge on planter, herbicide and fertilizer use and application and improve their skill permanently. The farmer's perceptions concerning effectiveness of NT systems are of critical importance of technology transfer. Hence, technologies associated to NT can be modified or improved according to conditions of specific localities.

In order to establish a reform of the agriculture sector, no-tillage agriculture should be focused and prioritized through satisfying the following:

- Acquiring a national agreement upon conservation agriculture and direct seeding techniques.
- Arraying strong enforcers for no-tillage dissipation.
- Fostering linkages among agriculture's sectors.
- Providing skills for agriculturalists and farmers in developing no-tillage and accepting conservation agriculture principles.
- Encouraging mass-communication of no-tillage benefits and principles.

References

Aboudrare, A., Debaeke, P., Bouaziz, A. & Chekli, H. (2006). Effects of soil tillage and fallow management on soil water storage and sunflower production in a semi-arid Mediterranean climate. Agricultural Water Management 83:183-196

Ait Cherki, R. (2000). Comportement physique du sol sous différents systèmes de labour et de rotations céréalières en milieu semi-aride marocain. Diplôme des Etudes Supérieures Approfondies (DESA), UFR Sciences de l'Environnement. Faculté des Sciences et Techniques Settat, Maroc. 66p.

AMMA (1999). La mécanisation agricole au Maroc. Association Marocaine de Machinisme Agricole. 50p.

Andrews, S.S., Karlen, D.L., & Mitchell, J.P. (2002). A comparison of soil quality indexing methods for vegetable production systems in Northern California. Agric. Ecosyst. Environ. 90:20-45.

Angers, D.A. & Chenu, C. (1998). Dynamics of soil aggregation and C sequestration. In: Soil processes and the carbon cycle. Lal et al. (eds). CRC Press, Boca Raton, FL. Chapter 14, pp:199-206

Arnoldus H.M.J. (1977). Methodology used to determine the maximum potential average annual soil loss due to sheet and rill erosion in Morocco. Assessing soil degradation. FAO Soils Bulletin No 34.

Bahri, A. 1992. Evaluation of opener and press wheel combinations on a no-till grain drill when seeding wheat. M.Sc Thesis. University of Nebraska, LN. USA.

Balaghi, R. (2006). Wheat grain yield forecasting models for food security in Morocco. PhD Thesis. University of Liege, Belgium. 103 pp.

Barakat, F. & Handoufe, A. (1998). Approche agroclimatique de la sécheresse agricole au Maroc. Sécheresse 9: 201-208.

Beare M.H., Hendrix P.F. & Coleman D.C., (1994). Water-stable aggregates and organic matter fractions in conventional- and no-tillage soils, Soil Sci. Soc. Am. J. 58:777–786.

Bessam, F. & R. Mrabet. (2001). Time influence of no tillage on organic matter and its quality of a vertic Calcixeroll in a semiarid area of Morocco. In Proceedings of First World Congress on Conservation Agriculture. Garcia-Torres et al. (eds). Madrid, Spain. October 1-5, 2001. pp: 281-286.

Bessam, F. & R. Mrabet. (2003). Long-term changes in soil organic matter under conventional and no-tillage systems in semiarid Morocco. Soil Use & Management 19(2):139-143.

Bourarach, E.H, Bouzza, A., & Nousfi, A. (1998). Développement d'un système d'enterrage de semoir direct pour le travail en sol sec. Hommes Terres et Eaux. 28(109): 5-10.

Bouzza, A. (1990). Water Conservation in wheat rotations under several management and tillage systems in semiarid areas. PhD thesis, University Of Nebraska.

Cambardella C.A., & Elliott E.T., (1992). Particulate soil organic matter changes across a grassland cultivation sequence, Soil Sci. Soc. Am. J. 56:777–783.

Carter, M.R. (2002). Soil quality for sustainable land management: organic matter and aggregation interactions that maintain soil functions. Agron. J. 94:38-47.

Chebbi, H.E. & El Mourid, M. (2005). L'agriculture au Maghreb: une lecture du contexte économique. ICARDA Publication. 58p.

Chekli, H (1991). Eléments du choix des séquences d'installation de la culture du blé dans la région de Meknès. Modification des états structuraux et aspects énergétiques. Thèse de Doctorat Es-Sciences Agronomiques, Institut Agronomique et Vétérinaire Hassan II, Rabat, Maroc. 229p.

Dahane D. (1992). Comparaison de trois semoirs commerciaux et un semoir expérimental. Mémoire de 3ème cycle Agronomie. Institut Agronomique et Vétérinaire Hassan II, Rabat, Maroc.

Debaeke, P. & Aboudrare, A. (2004). Adaptation of crop management to water-limited environments. Eur. J. Agron. 21:433–446.

Derpsch, R. (2005). The extent of Conservation Agriculture adoption worldwide: Implications and impact. III World Congress on Conservation Agriculture: "Linking Production, Livelihoods and Conservation", 3rd to 7th October 2005, Nairobi, Kenya. 15p.

El-Brahli A, Bouzza A & Mrabet R (1997). Stratégies de lutte contre les mauvaises herbes dans plusieurs rotations céréalières en conditions de labour et de non-labour. INRA Rapports Annuels. Centre Aridoculture, Settat, Maroc. pp: 171-174.

Gregorich E.G. & Janzen H.H. (1996). Storage of soil carbon in the light fraction and macroorganic matter, in: Carter, M.R. & Stewart B.A. (Eds.), Structure and organic matter storage in agricultural soils, CRC: Lewis Publishers, Boca Raton, pp: 167–192.

Gregorich E.G. & Carter, M.R. (1997). Soil quality for crop production and ecosystem health. Developments in Soil Science 25. Elsevier. 448p.

Golchin, A., Oades, J.M., Skjemstad, J.O. & Clarke, P. (1994). Soil structure and carbon cycling. Aust. J. Sci. Res. 32: 1043-68.

Ibno Namr, K. & Mrabet, R. (2004). Influence of agricultural management on chemical quality of a clay soil of semi-arid Morocco. Journal of African Earth Sciences 39(3-5): 485-489.

Ibno-Namr, K. (2005). Effet à moyen terme du travail du sol, de la gestion des résidus de récolte et de la rotation céréalière sur la qualité chimique d'un sol calcimagnésique à caractère vertique dans le semi-aride Marocain. PhD Thesis, Faculty of Sciences, El Jadida, Morocco. 143p.

Jalota, S.K. & Prihar, S.S. (1998). Reducing soil water evaporation with tillage and straw mulching. Ames, IA; Iowa State Univ. Press.

Kacemi, M. (1992). Water conservation, crop rotations, and tillage systems in semiarid Morocco. Ph.D. Dissertation. Colorado State University. Fort Collins, CO. USA. 203p.

Kacemi, M., Peterson, G.A. & Mrabet, R. (1995). Water conservation, wheat-crop rotations and conservation tillage systems in a turbulent Moroccan semiarid agriculture. p. 83-91. In El Gharrous et al. (ed.). Conference on Challenges in Moroccan Dryland Agriculture. INRA, Rabat, Morocco.

Karmouni, A. (1988). Problèmes de l'érosion hydrique au Maroc: Importance des phénomènes et Causes. In. Séminaire National sur l'aménagement des bassins versants. 18-23 Janvier 1988. PNUD/FAO pp : 1-13.

Lahlou, S. (1999). La qualité physique du sol sous différents systèmes de travail du sol et de management des cultures en zones semi-arides Marocaines. Diplôme des Etudes Supérieures Approfondies. Faculté des Sciences El-Jadida, Maroc. 60p.

Lahlou, S., Mrabet, R. & Ouadia, M. (2004). Soil physics: a Moroccan perspective. Journal of African Earth Sciences. 39(3-5): 441-445.

Lahlou, S., Ouadia, M., Malam Issa, O., Le Bissonnais, Y. & Mrabet, R. 2005. Modification de la porosité du sol sous les techniques culturales de conservation en zone semi-aride Marocaine. Etude et Gestion des Sols. 12(1):69-76.

Lal, R. (1986). No-tillage and surface tillage systems to alleviate soil related constraints in the tropics. In. No-tillage and surface tillage agriculture: The tillage revolution. Sprague, M.A. & Triplett, G.B. (eds). NY. John Wiley. Pp: 261-317.

Lal, R. (2002). Carbon sequestration in dryland ecosystems of West Asia and North Africa. Land Degradation & Development 13:45-59.

Lal, R. (1997). Residue management, conservation tillage and soil restoration for mitigating greenhouse effect by CO2-environment. Soil & Till. Res. 43:81-107.

Lal, R., Reicosky, D.C. & Hanson, J.D. (2007). Evolution of the plow over 10,000 years and the racional of no-till farming. Soil & Till. Res. 93:1-12.

Le Houérou, H.N. (1993). Changements climatiques et désertisation. Sécheresse. 4 :95-111.

Le Houérou, H.N. (1995). Dégradation, régénération et mise en valeur des terres sèches d'Afrique. In. Pontanier et al. (eds). L'homme peut-il refaire ce qu'il a défait? John Libbey Eurotex, Paris.

Leifeld, J. & Kogel-Knabner, I. (2005). Soil organic matter fractions as early indicators for carbon stock changes under different land-use? Geoderma. 124: 143–155.

McGarry, D., Bridge, B.J., & Radford, B.J. (2000). Contrasting soil physical properties after zero and traditional tillage of an alluvial soil in the semi-arid subtropics. Soil & Till. Res. 53:105–115.

Merzouk, A. (1985). Relative erodibility of nine selected Moroccan soils as related to their physical, chemical and mineralogical properties. PhD Thesis, University of Minnesota.

Mrabet, R., A. Bouzza, & G.A. Peterson. (1993). Potential reduction of soil erosion in Morocco using no-till systems. Agron. abstract p. 323, ASA. Madison, WI.

Mrabet, R. & Bouzza, A. (1994). Conservation de l'eau sous différentes rotations céréalières et systèmes de gestion des résidus de récolte en semi-aride. Ann. Report. Aridoculture Center.

Mrabet, R., (1997). Crop residue management and tillage systems for water conservation in a semiarid area of Morocco. PhD Diss. Colorado State Univ. Fort Collins, CO. USA. 220p.

Mrabet, R. (2000a). Long-term No-tillage influence on soil quality and wheat production in semi-arid Morocco. In proceedings of the 15th ISTRO Conference Tillage at the Threshold of the 21st Century: Looking Ahead, July 2-7, 2000, Fort Worth, Texas, USA.

Mrabet, R. (2000b). Differential response of wheat to tillage management systems under continuous cropping in a semiarid area of Morocco. Field Crops Res. 66:165-174.

Mrabet, R. & Bourarach, E. (2001). Le Semis Direct: Une technologie avancée pour une Agriculture durable au Maroc. Bulletin de Transfert de Technologie en Agriculture MADR-DERD. N° 76, 4p.

Mrabet, R., N. Saber, A. El-Brahli, S. Lahlou & F. Bessam. (2001a). Total, Particulate Organic Matter and Structural Stability of a Calcixeroll soil under different wheat rotations and tillage systems in a semiarid area of Morocco. Soil & Tillage Research 57:225-235.

Mrabet, R., K. Ibno-Namr, F. Bessam & N. Saber. (2001b). Soil Chemical Quality Changes and implications For Fertilizer Management after 11 Years of No-Tillage Wheat Production Systems in Semiarid Morocco. Land Degradation & Development 12:505-517.

Mrabet, R. (2002a). Wheat yield and water use efficiency under contrasting residue and tillage management systems in a semiarid area of Morocco. Experimental Agriculture 38:237-248.

Mrabet R. (2002b). Stratification of soil aggregation and organic matter under conservation tillage systems in Africa. Soil Tillage & Research 66:119-128.

Mrabet, R., El-Brahli, A., F. Bessam, F. & Anibat, I. (2003a). No-Tillage Technology: Research review of impacts on soil quality and wheat production in semiarid Morocco. Options Méditerranéennes 60:133-138.

Mrabet, R., Tab, N. & Bessam, F. (2003b). Influence des systèmes de labour et de la fertilisation azotée sur la productivité du blé et la qualité du sol en milieu semi-aride Marocain. Rapport d'activité, INRA Settat.

Mrabet, R., Lahlou, S., Le Bissonnais, Y. & Duval, O. (2004). Estimation de la stabilité structurale des sols semi-arides marocains : Influence des techniques culturales simplifiées. Bulletin du Réseau Erosion 23(2) :405-415.

Mrabet, R. & Beqqali, M. (2005). Semis direct: une technique conservatrice de la qualité du sol. Proceedings Séminaire International Gestion environnementale de l'agriculture : Maîtrise des flux de matières et rationalisation des pratiques agricoles. Soudi et al. (edts), 9-10 Juin 2005, Institut Agronomique et Vétérinaire Hassan II, Rabat, Maroc. pp: 121-140.

Mrabet, R. & El-Brahli, A. (2005). Soil and crop productivity under contrasting tillage management systems in semiarid Morocco. III World Congress on Conservation Agriculture: "Linking Production, Livelihoods and Conservation", 3rd to 7th October 2005, Nairobi, Kenya. 6p.

Mrabet, R. (2006). Soil quality and carbon sequestration: Impacts of no-tillage systems. Options Méditerranéennes 69:43-55.

Nousfi, A. (1993). Contribution à l'amélioration de système d'enterrage d'un semoir direct. Mémoire de 3ème cycle. IAV Hassan II, Rabat, Maroc. 79p.

Oussible, M., Crookston, R.K., & Larson, W.E. (1992). Subsurface compaction reduces the root and shoots growth and grain yield of wheat. Agron. J. 84:34-38.

Reicosky, D.C. (2001). Conservation agriculture: Global environmental benefits of soil carbon management. Garcia-Torres et al. (edts). In: Proceedings of I World Congress on Conservation Agriculture, Madrid 1-5, October. Vol 1:3-12.

Shaver, T.M., Peterson, G.A., Ahuja, L.R., Westfall, D.G., Sherrod, L.A. & Dunn, G. (2003).

Surface soil physical properties after twelve years of dryland no-till management. Soil Sci. Soc. Am. J. 66 :1296-1303.

Six, J., Elliott, E.T., Paustian, K., & Doran, J.W. (1998). Aggregation and soil organic matter accumulation in cultivated and native grassland soils. Soil Sci. Soc. of Am. J. 62:1367– 1377.

Steiner, J.L. (1989). Tillage and surface residue effects on evaporation from soils. Soil Sci. Soc. Am. J. 42:486-491.

Steiner, K. (1998). Conserving natural resources and enhancing food security by adopting no-tillage. An assessment of the potential for soil-conserving production systems in various agro-ecological zones of Africa. GTZ Eschborn, Tropical Ecology Support Program, TÖB publication number: TÖB F-5/e, 53pp.

Tab, N. (2003). Contribution à l'étude de l'influence des systèmes de travaux du sol et de la fertilisation azotée sur le comportement du blé et la qualité chimique d'un sol argileux du semi-aride Marocain. DESA UFR Amélioration de la production agricole. FST-Settat, 95p.

Application of Sustainable Agriculture Principles in Weed Management

Hani Z. Ghosheh
Department of Plant Production, Faculty of Agriculture
Jordan University of Science & Technology, *P O Box 3030, Irbid 22110., Jordan*
E-mail: Ghosheh@just.edu.jo

Abstract

A sustainable agriculture is one that, over the long term, enhances environmental quality and the resource base on which agriculture depends; provides for basic human food and fiber needs; is economically viable; and enhances the quality of life for farmers and society as a whole. An increasing interest in the sustainability of agricultural systems has led to significant developments in cropping practices over the past years. This was associated with an enthusiastic search for alternative agricultural production systems that require fewer production inputs. To some extent, weeds are a result of crop production, but to a larger extent they are a consequence of management decisions. While herbicides have proved to be very effective in the past five decades, the current emphasis on reducing pesticide use has led to increased interest in alternative weed management methods. Managing croplands according to nature's principles will reduce weed problems. The opportunities to address the root causes of weeds are not always readily apparent, and often require some imagination to recognize. Creativity is a key to taking advantage of these opportunities and devising sustainable cropping systems that prevent weed problems, rather than using quick-fix approaches. Annual monoculture crop production generally involves tillage that creates conditions hospitable to many weeds. This paper discusses, through reviewing a few recently published articles, several alternatives to conventional weed management systems, including reduced tillage systems, allelopathy, intercropping, crop rotations, cover crops, and integrated weed management that retain to the principles of sustainable agriculture within arid-regions.

Key words: alternative weed management arid-regions, cultural practices, integrated weed management, non chemical methods

What is sustainable agriculture?

Many definitions of sustainable agriculture have been proposed, but one of the first to be adopted in the US was "A sustainable agriculture is one that, over the long term, enhances environmental quality and the resource base on which agriculture depends; provides for basic human food and fiber needs; is economically viable; and enhances the quality of life for farmers and society as a whole" (American Society of Agronomy, 1989). Later, the term sustainable agriculture evolved to legally describe an integrated system of plant and animal production practices having a site-specific application that over the long term will satisfy human food and fiber needs; enhance environmental quality and the natural resource base upon which the agricultural economy depends; make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls; sustain the economic viability of farm operations; and enhance the quality of life for farmers and society as a whole (US Congress, 1990).

As the concept of sustainable agriculture developed throughout recent years, five areas of emphasize could be outlined. These are productivity, environmental quality, and efficient use of nonrenewable resources, economic viability, and quality of life. Thus, a farm that emphasizes short-term profit, but sacrifices environmental quality, would not be sustainable in the long term. From the other end, pursuing environmental quality without ensuring viability of short-run returns also would be unsustainable. A farm that is very productive but uses large quantities of a nonrenewable resource, such as fossil fuel or a non-rechargeable aquifer, to achieve and maintain that productivity would not be considered sustainable in the long run (Norman et al., 1997).

Farming sustainably means growing crops and livestock in ways that meet three measures. The first is economic sustainability and is achieved as the family's net worth is consistently going up, while the farming family debt is consistently going down. This will definitely reflect on that farm enterprises are consistently profitable from year to year. Certainly purchase of off-farm feed and fertilizer is decreasing. Additionally, reliance on government payments is decreasing simultaneously. The second measure is social sustainability that is achieved through the fact that the farm will support other businesses and families in the community. Immediate economical benefits will circulate within the local economy. As a result of these benefits, the number of rural families is going up or holding steady. Young people take over their parents' farms and continue farming. The third measure is environmental sustainability that can be created and maintained in agricultural land by having no bare ground. Clean water flows in the farm's ditches and streams. This will be reflected on abundant wildlife. Overall farm landscape is diverse in vegetation (Sullivan, 2003).

Sustainability of farming system in arid and semi-arid -regions

Arid and semi-arid regions dominate many Mediterranean countries. These regions are characterized by extended droughts. Droughts, defined as periods of prolonged below-normal precipitation, create conditions that are insufficient for crop or forage growth. Regular precipitation in many arid regions is insufficient to recharge aquifers, lakes, and reservoirs, or to provide irrigation water. This reduces water availability for irrigation and livestock needs. Producers in arid regions should have an adequate understanding of the needs of grown plants for nutrients and water. Farmers should use conservation practices that increase water infiltration and minimize water loss. They should protect the soil surface with plants, cover crops, mulches, and residues, and additionally, farmers should use buffers to reduce runoff, and prevent erosion.

While dryland production limits management options, good farm management practices are nevertheless vital for sustaining production in these areas. Producers should establish farming systems that tolerate drought. In arid regions, farmers should select and manage livestock and forages based on the nature and condition of their lands. They should choose species and breeds adapted to prevailing environments. Including a combination of crop and livestock enterprises for greater management flexibility is a wise approach. This might also include introducing drought-tolerant species to ensure harvesting economical yields, even in dry years. Using a combination of species in the field or within rotations enhances pest control and water and nutrient use (Bellows, 2004).

Balanced crop-livestock productions should always be maintained in arid and semi-arid farms and enterprises. Producers should cycle nutrients between crops and livestock. Soil quality is greatly improved once manure is recycled to fertilize crop fields. In the same context, soil tilth improves when crops are rotated with forage production. All these practices provide options for production under dry conditions. Great attempts should be expended to reduce the use of water-demanding crops, and simultaneously produce livestock and drought-tolerant plants (Bellows, 2004).

Arid- and semi-arid agriculture

In the WANA (West Asia and North Africa) region, wheat and barley production dominates dry-land agriculture that takes place under limited, variable, and chronically deficient precipitation. These crops are grown in rotation with food legume crops, mainly chickpea and lentil (Pala et al., 1999). Jordanian semi-arid lands are located within the 200 to 350 mm rainfall zone of the eastern Mediterranean region. This cropping area occupies an important part of the country and needs to be well understood to achieve optimum management. Vegetation dynamics and seasonal growth patterns need special attention as many plant communities are exposed to long term overgrazing (El-Shatnawi et al., 1999). Cereal crops, such as wheat and barely are widely grown in the rainfed areas of the semi-arid and arid Mediterranean regions. In the semi-arid regions of the Eastern Mediterranean basin, barley is the most widely grown cereal crop. The barley-based farming system exists in the dry (200-300 mm annual rainfall) areas in Syria, Jordan and Iraq. The barley-fallow cropping sequence is the dominant system in areas devoted to barley cropping. Yield is considered to be very low for cereals grown in developing countries compared with harvests in developed countries. Low barley yield is attributed to limited and uneven distribution of precipitation, poor soil moisture conservation, improper cultural practices, poor crop stands and weed competition (Jaradat & Haddad, 1994).

Weed control paradigm

Weeds are not in the field because of a deficiency of herbicides or cultivation, rather, they are the natural result of defying nature's preference for high species diversity and covered ground. Nature is trying to move the system in one direction, the farmer in another. We create weed problems through conventional crop production methods. After we create these problems, we spend huge sums of money and labor trying to "control" them. Thus the "weed control" paradigm is reactive—it addresses weed problems by using various tools and technologies. "How am I going to get rid or control this weed?" is a reactive statement. The conventional tools to "get rid of" or "control" weeds—cultivation and herbicides—are reactive measures for solving the problem. The opposite of reactive thinking is proactive thinking, by which we seek what we want through effective design and planning. A proactive approach to weed management asks, "Why do I have weeds?"

Why weeds are successful?

Weeds can be divided into two broad categories—annuals and perennials. Annual weeds are plants that produce a seed crop in one year, then die. They are well adapted to succeed in highly unstable and unpredictable environments brought about by frequent tillage, drought, or other disturbance. They put much of their life cycle into making seed for the next generation. This survival strategy serves plants in disturbed environments well, since their environment is likely to be disturbed again. When we establish annual crop plants using tillage (i.e., disturbance) we also create an environment favourable for annual weeds.

Perennial weeds prosper in less-disturbed and more stable environments. They are more common under no-till cropping systems. Their objective is to put some energy into preserving the parent plant while producing a modest amount of seed for future generations. After a field is converted from conventional tillage to no-till, the weed population generally shifts from annual to perennial weeds. Perennial weeds possess many of the characteristics of annual weeds: competitiveness, seed dormancy, and long-lived seed. In addition to these characteristics, many perennial weeds possess perennating parts such as stolons, bulbs, tubers, and rhizomes. These parts allow the parent plant to regenerate if damaged and to produce new plants from the parent plant without seed. Additionally, the perennating parts serve as food storage units that also enhance survival. These stored-food reserves allow for the rapid regrowth perennial weeds are known for (Radosevich, Holt, & Ghersa., 1997).

Role of weeds in ecological succession

When a piece of land is left fallow, it is soon covered by annual weeds. If the field is left undisturbed for a second year, briars and brush start to grow. As the fallow period continues, the weed community shifts increasingly toward perennial vegetation. By the fifth year, the field will host large numbers of young trees in a forest region, or perennial grasses in a prairie region. This natural progression of different plant and animal species over time is a cycle known as succession. This weed invasion, in all its stages, can be viewed as nature's means of restoring stability by protecting bare soils and increasing biodiversity. Weeds are evidence of nature struggling to bring about ecological succession. When we clear native vegetation and establish annual crops, we are holding back natural plant succession, at great cost in weed control (Savory, 1988). Generally speaking, biodiversity leads to more stability of the ecosystem as a whole. Modern crop agriculture is typified by large acreages of a single plant type, accompanied by a high percentage of bare ground—the ideal environment for annual weeds to prosper in agricultural lands.

Weed seed distribution and density in agricultural soils are influenced by cropping history and the management of adjacent landscapes, and may be highly variable. A study of western Nebraska cropland found 140 seeds per pound of surface soil, equivalent to 200 million seeds per acre (Wilson, 1988). Equipment moved from one field to the next—especially harvesting equipment—spreads weed seeds, as does hay brought from one farm to another. Crop seed is often contaminated with weed seed. Livestock transport weed seeds from one farm to another in their digestive tracts and in their hair. Practical actions that can be taken to prevent the introduction and spread of weeds include the use of clean seed, cleaning equipment before moving from one field to the next, and composting manures that contain weed seeds before applying them to the field.

Survival and germination of weed seeds in the soil depend on the weed species, depth of seed burial, soil type, and tillage. Seeds at or near the soil surface can easily be eaten by insects, rodents, or birds. Also, they may rot or germinate. Buried seeds are more protected from seed eating animals and buffered from extremes of temperature and moisture. Here they remain dormant for several years, depending on the species. On average, about 4% of broadleaf and 9% of grass weed seeds present in the soil germinate in a given year (Lehnert, 1996). Seeds near the surface face lots of hazards to their survival, while those buried deeply by tillage are more protected. When those deep-buried seed are plowed up to the surface again they have a good chance of germinating and growing. Thus seed germination rate were higher with increasing depth of burial (Wilson, 1988).

Human activities help weeds to become weeds. Viable weed seeds are widely distributed in moldboard systems. A percentage of seed remains near the soil surface under chisel plow and no-till. The moldboard plow is stirring the soil more, burying lots of weed seeds, and keeping weed seeds more evenly distributed down to a six-inch depth, where they remain dormant (Zimdahl, 1993)..

Proactive Weed Management Strategies

The question is "how do we begin to manage an unnatural system to our best benefit without compromising the soil and water?" The answer starts by activating the principles of ecology, while minimizing actions that only address symptoms.

Allelopathy and Allelopathic compounds

Some crops are especially useful because they have the ability to suppress growth of other plants in their vicinity... Allelopathy refers to a plant's ability to chemically inhibit the growth of other plants. Rye is one of the most useful allelopathic cover crops because it is winter- hardy and can be grown almost anywhere. Rye residue contains generous amounts of allelopathic chemicals. When left undisturbed on the soil surface, these chemicals leach and prevent germination of small-seeded weeds. Similarly, use of natural amendments could be used sustainably to control certain weeds. The use of olive jift, a solid by-product of olive (Olea europea L.) oil processing, was evaluated in greenhouse experiments. Soil-jift mixtures were utilized as potting medium in ratios of 1:0, 1:1, and 3:1 soil to jift. Broomrape seed were evenly incorporated in the potting media. Jift in soil reduced broomrape germination and infection on host crops of tomato, faba bean, and peas (Ghosheh et al. 1999). Other related results indicated that mixing jift with soil did not affect the numbers of leaves, branches, pods, flowers and nodules of faba beans. Jift treatments did not adversely affect the growth or yield of a subsequent faba beans crop planted approximately 6 or 12 months from the initial jift-incorporating date. (Ghosheh, Al-Tamimi & Hameed., 2006).

Intercropping

Intercropping (growing two or more crops together) can be used as an effective weed control strategy. Growing different plant types together enhances weed control by increasing shade and increasing crop competition with weeds through tighter crop spacing. Where one crop is relay-intercropped into another standing crop prior to harvest, the planted crop gets off to a weed-free start, having benefited from the standing crop's shading and competition against weeds. Planting method, planting date, and variety must be well-planned in advance.

Cover crops

Cover crops are crops that are planted prior to planting the main crop. There main purpose is to reduce weed competitiveness in main crops and to prevent soil erosions common on bare lands. Worsham (1991) conducted studies in North Carolina and concluded that leaving a small grain mulch on the soil surface and not tilling gives a 75 to 80% early-season reduction of broadleaf weeds Just the absence of tillage alone gave 68% grass control and 71% broadleaf control.

Smother crops

Certain crops can be used to smother weeds. This proved to be effective in northern Jordan. Field experiments were conducted at two semi-arid locations in Jordan to investigate the effects of alfalfa grown as a smother crop on corn and weeds. Treatments were mixtures of alfalfa-corn that varied in clipping frequency, compared to pure corn and pure alfalfa. Results indicated that alfalfa reduced corn grain yield more than total above ground dry biomass. Grain yield reductions ranged from 23 to 53% of amounts harvested in weed-free corn plots. Yields were comparable or greater than amounts harvested from weedy check plots, indicating that alfalfa imposed equivalent or less competition on corn than the prevailing weeds of the two sites. Alfalfa harvested from frequently clipped plots was 48 to 57% of quantities harvested from weed-free alfalfa plots. Results of these experiments encourage corn producers to replace polyethylene mulches with alfalfa as a smother crop to maximize utilization of the scarce water resources available for Mediterranean agriculture. Possible economic advantages, besides reducing environmental hazards from scattered polyethylene residues, arise from lowering the initial costs of polyethylene mulches and additional returns from producing a high-quality forage crop, thus compensating for any reductions in corn grain yields (Ghosheh et al., 2004).

Crop Rotations

Crop rotation is defined as the alternation of different crop species on the same land. Crop rotation is an effective tool for weed management by changing the pattern of disturbance, which diversifies selection pressure (Radosevich et al. 1997). This diversification prevents the proliferation of weed species well suited to the practices associated with a single crop (Buhleret al., 1992). Crop rotations limit the buildup of weed populations and prevent major weed species shifts. Weeds tend to prosper in crops that have requirements similar to the weeds. Fields of annual crops favor short-lived annual weeds, whereas maintaining land in perennial crops favors perennial weed species. The crop-fallow rotations are common in areas receiving rainfall below 300 mm per year because of the variability of rainfall, where the annual soil moisture supplies are insufficient to sustain adequate growth without a stored soil moisture supply from a previous season. Although moisture conservation is the main objective for most crop-fallow rotations, weed species vary in their response to fallow-rotation. Some crop-fallow sequences decreased weed numbers compared with continuous cropping, particularly weeds with short dormancy periods and certain perennial weeds were reduced (Hume, 1982). This conclusion was also observed in northern Jordan, where weed species densities varied between tillage systems and rotations. The results also indicate the complexity of weed communities in their response towards different tillage-rotation combinations, which require further evaluation (Ghosheh & Al-Hajaj, 2004).

Current weed control tools and their effects

Herbicides

Herbicides can be effective in maintaining ground cover in no-till systems by replacing tillage operations that would otherwise create bare ground and stimulate more weed growth. Until better weed management approaches can be found, herbicides will continue to remain in the toolbox of annual crop production. However, some farmers are realizing that with continued herbicide use, the weed problems just get worse or at best stay about the same. Nature never gives up trying to fill the vacuum created by a simplified bare-ground monoculture, and long-term use of the same herbicide leads to resistant weeds, as they adapt to the selection pressure applied to them. But compared to tillage systems where bare ground is maintained, herbicide use may be considered the lesser of two evils. At least where ground cover is maintained, the soil is protected from erosion for future generations to farm. There are many approaches to reducing costly herbicide use, such as banding combined with between-row cultivation, reduced rates, and using some of the other methods discussed earlier (Zimdahl, 1993).

Weeder animals

Weeder geese, goats, sheep, and even cattle could be utilized to reduce weed impacts. While geese are known to work well at removing weeds between plants in rows that cannot be reached by cultivators or hoes, other grazing animals can be utilized effectively in integrated plant-animal production operations.

Tillage

Tillage and cultivation are the most traditional means of weed management in agriculture. An often stated objective of tillage is to prepare a clean seedbed, in view of reducing competition between crops and weeds during the initial growing stages. But the bare ground is an invitation for weeds to grow. Bare ground also encourages soil erosion, speeds organic matter decomposition, disturbs soil biology, increases water runoff, decreases water infiltration, damages soil structure, and costs money to maintain (for fuel and machinery or for hand labor). However, tillage stimulates weed seed germination thus magnifying weed problems. Buhler et al. (1992) indicated that tillage, as a major soil disturbance, affected population dynamics, depending on the location of seed in the soil profile. In general, cultivation practices affect plant species composition through distributing seed at various soil depths and altering their numbers, and hence, the composition of the soil seed bank.

Research on weed seed banks is rather limited in these semi-arid environments where barley cropping prevails. Seed banks of five weed species were monitored in response to tillage and crop rotations in a semi-arid location in northern Jordan. Tillage practices of mouldboard- or chisel-plowing and cropping patterns of barley planting or fallow were evaluated on permanently established subplots. Soil samples were collected from the upper 10 cm for three consecutive years, immediately after performing tillage and prior to planting. Generally, mouldboard plowing increased weed seed banks when combined with frequent fallowing. Conversely, chisel plowing combined with barley cropping generally reduced weed seed bank sizes. Results emphasized the importance of managing weeds during fallow to avoid the build up of H. marinum, a serious grass weed in semi-arid environments (Ghosheh & Al-Hajaj 2005.)

Integrated weed management

Weed scientists are very much aware of public concerns regarding the use of herbicides. Many programs were implemented to reduce herbicide use. Among these systems, the Integrated Weed Management system (IWM) has been widely promoted. An integrated approach means assembling a weed management plan that incorporates a number of tools consistent with farm goals. Included are sanitation procedures, crop rotations, specialized tillage schemes, cover crops, and herbicides. The best examples of integrated approaches have been developed on farm, by farmers themselves.

Weed scientists develop IWM systems for crops and specific weeds or weeds complexes in crops. (Suwan, 1998). Integrated weed management was described as “the application of many kinds of technology in a mutually supportive manner (Elmore, 1996). This researcher proposed that IWM become a component of Integrated Crop Management (ICM). In this system, it is assumed that the best weed management system will not select a single technology or method but it will rather integrate several methods. Integration will consider cultural methods such as grazing management, fertilizer application, and irrigation practices, seeding rate, and the use of competitive cultivars. It will consider options such as tillage before and cultivation during the crop growth, mowing, burning, flooding or mulching. Biological methods such as biological enemies, as well as chemical methods including herbicides (Zimdahl, 1993) should be used. Developing such an integrated system requires collecting field data. As with sustainable agriculture, this is a knowledge based approach. Knowledge about the history of the field; past cropping sequence; and weed control methods reveal the kind of weed problems to be expected. The way in which the soil and seedbed were prepared is also important. The method and timing of irrigation is also an important aspect that influence weed species diversity and density. Past and present insect and disease management must be integrated with weed management and may influence it.

References

1. American Society of Agronomy. 1989. Decision reached on sustainable agriculture. Agronomy News. January, pg 15, Madison, Wisconsin.

2. Bellows B. 2004. Drought introduction. National Sustainable Agriculture Information Service. www.attra.ncat.org

3. Buhler D D, Gunsolus J L, Ralston D F. 1992. Integrated weed management techniques to reduce herbicide inputs in Soybeans. Agronomy Journal 84: 973-978.

4. Elmore C L 1996. A Reintroduction to Integrated Weed Management. Weed Science 44:409-412.

5. Hume L. 1982: The long-term effects of fertilizer application and three rotations on weed communities in wheat (after 21–22 years at Indian Head in Saskatchewan). Canadian Journal of Plant Science 62: 741—750.

6. El-Shatnawi M K J, Ghosheh H Z, Sihnnaq H K, Ereifej K I. 1999. Defoliation time and intensity of wall barley in the Mediterranean rangeland. Journal of Range Management 52:258-262.

7. Ghosheh H Z, Al-Hajaj N. 2004. Impact of Soil Tillage and Crop Rotation on Barley (Hordeum vulgare) and weeds in a Semi-arid environment. Journal of Agronomy & Crop Science, 190: 374-380.

8. Ghosheh H Z, Al-Hajaj N. 2005. Weed seedbank response to tillage and crop rotation in a semi-arid environment. Soil & Tillage Research 84:184-191.

9. Ghosheh H Z, Bsoul E, Yousef A. 2004. Utilization of Alfalfa (Medicago sativa L.) as a Smother Crop in Field Corn (Zea mays L.)". Journal of Sustainable Agriculture, 25(1):5-19.

10. Ghosheh H Z, Al-Tamimi E, Hameed K M. 2006. Effect of olive-jift and sub-lethal glyphosate applications on faba beans (Vicia faba). Acta Agronomica, 54 (1): 61-68.

11. Ghosheh H Z, Hameed K M, Turk M, Al-Jamali A F. 1999. Olive (Olea europea) Jift Suppresses Broomrape (Orobanche spp.) Infections in Faba bean (Vicia faba), Pea (Pisum sativum) and Tomato (Lycopersicon esculentum). Weed Technology, 13:457-460.

12. Jaradat A A, Haddad N I. 1994. Analysis and interpretation of Mashreq project. (1990-1992). Report of ICARDA West Asia Regional Program, Amman, Jordan.

13. Lehnert D. 1996. Breaking the weed seed bank. Soybean Digest. Mid-March. p. 52.

14. Norman, D., L. Bloomquist, R. Janke, S. Freyenberger, J. Jost, B. Schurle, and H. Kok, 1997. Sustainable Agriculture: Reflections of Some Kansas Practitioners. Manhattan Kansas: Kansas State University.

15. Pala M, van Duivenbooden N, Studer C, Bielders C L. 1999. Cropping systems and crop complementarity in dryland agriculture. Proceedings of efficient soil water use workshops: 299-330. International Crops research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India.

16. Radosevich S, Holt J, Ghersa C. 1997: Weed Ecology: Implications for Management. John Wiley& Sons Inc., USA.

17. Savory A. 1988. Holistic Resource Management. Island Press. Washington, DC. 564 p.

18. Sullivan P 2003. Applying the Principles of Sustainable Farming. National Center for Appropriate Technology. http://www.attra.ncat.org/attra-pub/PDF/

19. Suwan M. 1998 (Editor). Vegetable crops in Jordan: Facts and solutions. Agricultural Engineers

Newsletter. Vol. 63-64. pp. 157-186.

20. United States Congress 1990. Food, Agriculture, Conservation, and Trade Act of 1990, Public Law 101-624. Title XVI, Subtitle A, Section 1603. Washington, DC: US Government.

21. Wilson R G. 1988. Biology of weed seeds in the soil. p. 25–40. In: Miguel Altieri and Matt Liebman (eds.). Weed Management in Agroecosystems: Ecological Approaches. CRC Press, Inc. Boca Raton, FL

22. Worsham A D. 1991. Allelopathic cover crops to reduce herbicide input. Proceedings of the Southern Weed Science Society. 44th Annual. Volume 44. p. 58–69.

23. Zimdahl R L. 1993. Weed Management Systems. Fundamentals of Weed Science. Academic Press Inc. California USA.p375-403.

The Use of Forage Plants for Landscape Management and Soil Conservation in Dry Areas

Ghufran Kattach
The Arab Center for the Studies of Arid Zones and Dry Lands
E-mail:g-kattach@acsad.org
gkattach@scs-net.org

Abstract

Most of the natural pastures in Syrian steppe are considered degraded. The improvement of degraded rangeland in arid zones was the main objective of this study. The rehabilitation process to increase forage quantity and quality in the Beshrri area by direct seeding of the valuable native shrub Salsola vermiculata without tillage was carried out in 2003. Following three years of rehabilitation and protection, plant diversity increased from 27 plant species of 23 genera and 13 families to 83 species of 55 genera and 17 families. Bare soil decreased from 91.3% to 32.2%, while density of palatable shrubs increased from 0.02 plants/m^2 to 4.1 shrubs/m^2. Fodder productivity increased from 90 kg/ha to 320 kg/ha. Using a light stocking rate of 0.6 sheep/ha for 180 days on improved rangeland will help keep the pasture in a good condition. These results confirm the great and positive role played by no tillage agriculture in achieving the sustainable development under such environment via increasing plant coverage which help in reducing soil erosion, increasing organic matter content in soil, storing the organic carbon, and improving the water storage capacity of soil. The remaining plant on the soil surface help in reducing evaporation and creating the environmental conditions which are suitable for the return of many plant species, especially legumes which were disappeared as a result of the change of the micro environmental condition and which play a major role in fixing the atmospheric nitrogen in the soil and improving the soil fertility. Conservation agriculture means many things to many people, but a key tenet is sustainability and conservation of the natural resources.

Key words: rehabilitation, Syrian steppe, palatable shrubs, diversity, sustainable use, water harvesting.

Introduction

Syria is located on the eastern coast of the Mediterranean region. The climate is characterized by a relatively short and cold winter period when most of the annual precipitation occurs. There is a long hot dry summer, especially in July and August. The spring and autumn seasons are relatively short and more traditional. More than half of the total area of Syria (55%) consists of arid and semi-arid steppe, receiving less than 200 mm of annual rainfall (WAAD, 2003). This region is often use as natural pasture, and is the major animal producing area in the country. Approximately 70% of the country's sheep graze this region for 4 to 7 months every year during the grass growing period (Habib, 2003).

Most of the natural pastures in the Syrian steppe regions are considered degraded. Rapid population growth coupled with a rise in consumption rates has increased the demand for agricultural goods and put pressure on the national food supply (SY and UNDP, 2002; Barrow 1991). Frequent droughts coupled with mismanagement of resources have contributed to rapid land degradation in these fragile ecosystems.

Geerken et al. (1998) compared satellite images taken in 1985 and 1993 for the Beshrri area and showed that the risk emanating from barley cultivation includes the destruction of soil structure and the loss of the soil stabilizing vegetation cover, especially after harvesting.

Sheep production is considered one of the major private sector activities where the pastures are owned by the public sector but used freely by individuals. This results in an increase of the number of sheep to numbers that exceed the pasture capacity. The number of sheep increased from 12,079,000 head in 1995 to 19,651,000 head in 2005 (SY, 2005).

As rangeland resources diminish, production of natural goods such as milk, meat and wool declines rapidly. The productive capacity of agricultural land in Syria is estimated to decrease by more than 25% during the next two decades if preventive measures are not taken (SY and UNDP, 2002). This will further increase the economic pressure on the supply of agricultural goods and livestock commodities.

The objective of the present study was to improve the natural pasture in the dry lands and increase the fodder supply for the livestock by sowing palatable shrubs of Salsola vermiculata without tillage and applying rain water harvesting techniques.

Materials and Methods

Study area

The Beshrri area was considered the best natural pasture ground in the Syrian steppe. The region is about one million hectares, located in the northeast part of the Syrian steppe (Figure 1). It is mountainous land with several plateaus with the highest one 840 m above see level. The area is suffering from severe land degradation due to ploughing and overgrazing. Soil degradation processes are very pronounced with wind and water erosion of particular concern. Dust storms occur frequently.

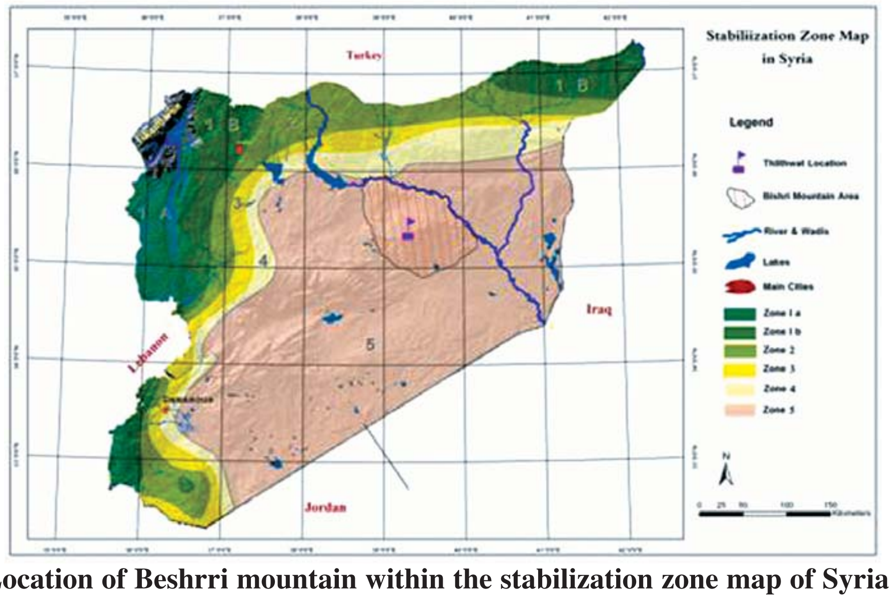


Figure 1: Location of Beshrri mountain within the stabilization zone map of Syria

Source: Waad 2003.(for coloured picture see annex #3, p.287).

Climate

The Beshrri area is mainly rangeland that receives between 140 and 190 mm annual total rainfall that occurs between November and April. The region receives its precipitation mostly as convective downpours of high intensity and short duration. The big, heavy drops trigger water erosion by dislocating soil particles with their high kinetic energy (Maginguet, 1999). The annual temperature average is 17-18 ºC. The summer months are absolutely dry with maximum temperatures in the upper 30s to lower 40s (ºC) (Sy, 1977).

Soil

Aridisols are dominant in the Beshrri Mountains. They form calcids and gypsids (SY and UNDP, 2002) that contain high concentrations of soluble salts, calcium carbonate or gypsum. Wind erosion, along with other causes such as repetitive ploughing, overgrazing, and firewood collection induced natural vegetation degradation and biodiversity loss in the investigated area. Habib (2003) estimated that over 573 million tons of fine soil particles were carried away by a single storm . Askar (1991) has calculated that 10 to 20 cm of surface soil, which is equivalent to 40-48 to 80-96 t/h/yr, were lost in 20 years by dust storms from lands in certain areas of the steppe.

Vegetation

The Beshrri region contained until 1930 several tree species such as Pestacia atlantica, Rhmnus palastinus and Amygdalus spp. (ACSAD and GTZ, 1995). The recent vegetation has been categorized as shrubby steppe in semi-arid to arid climate with woody plants, less than 3 m high, and a sparse herbaceous understory (Ilaiwi 2000).

Thorny plant species, unsuitable for grazing by sheep, can easily propagate because they do not have to compete with many fodder plant (SY and UNDP, 2002). Because of their thorns, they have a low transpiring surface and are well adapted to the climatic conditions of the steppe. Some plants like Noaea mucronata combine leaf and branch shedding to balance their water economy (Batanouny, 2001)

Rehabilitation measures of the degraded rangeland in the Beshrri mountain area

The introduction of appropriate grazing management systems, together with rehabilitation of rangelands by reseeding, and supported by the use of water harvesting techniques, would contribute significantly to halting and reversing the land degradation and to improving the carrying capacity.

During autumn of 2003, Salsola vermiculata was directly sown into the vegetation cover (of less than 20%) on an area of 100 ha. Twenty-five percent of the target area was ploughed with a tractor in contour fashion, and sown by hand (15 kg/ha of seeds). The germination of seeds depends on the precipitation in the winter after sowing. Roughening the soil inhibits seeds being taken away by erosive wind forces.

The whole study area was protected by two guards living there with their family. They ensured that no grazing took place within the protected area (ACSAD, 2006).

Investigation of vegetation cover

Vegetation cover is important to avoid wind and water erosion. Investigation of plant cover in the study area was conducted to reveal whether or not the rehabilitation measures were capable of achieving this target. The development of vegetation was monitored by field surveys in spring and autumn for the three years (2003-2006) on selected representative locations. Global Positioning System (GPS) was used to record the coordinates of these locations. The vegetation cover was determined using the step-point methods (Evan and Love, 1957). The shrub density was determined by the density array procedure proposed by Curtis and Mclnton (1950) and practiced by ACSAD. The fodder productivity of the palatable above-ground plant was determined according to Stoddart et al. (1975). The carrying capacity was estimated according to Legel (1990).

Results and discussion

Qualitative composition of the vegetation cover

Vegetation cover

The results showed the improvement of vegetative cover. Before the initiation of the rehabilitation measurement, the ground exposed was 91.3%, while the percentage of the bare soil decreased to 32.2% after rehabilitation (Figure 2). In spring 2003, the plants covered 40.7 % of the soil surface, while the vegetation cover increased to 67.8 % in 2006. The percentage of litter was increased through the rehabilitation process and protection from grazing by animals, which contributed to increase the organic matter accumulation, infiltration and soil moisture holding capacity.

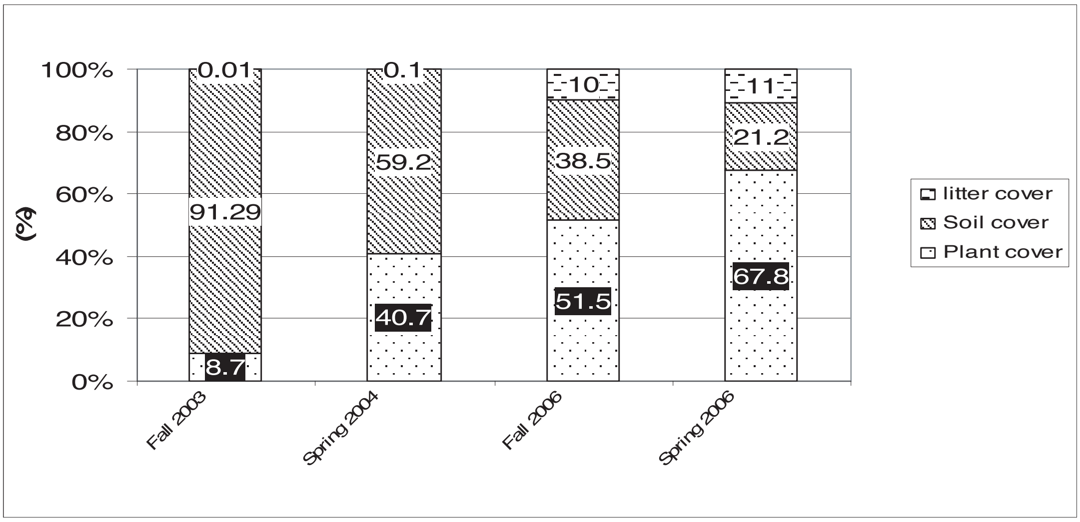


Figure 2: The Effect of vegetation rehabilitation processes on soil cover

The family Poaceae covered 0.9 % of soil surface and increased to 19.8 % after rehabilitation of the vegetation cover (Figure 3). This family has special importance because of the high fodder value and the fibrous root system which played an important role for soil conservation and prevention of soil erosion. The coverage of the family Fabaceae, known as valuable fodder plants with a high protein content and nitrogen fixing root system, increased from 0.2% to 6.6%. The cover of the family Chenopodiacea increased up to 14.8% after three years due to the young Salsola vermiculata plants. The successful rehabilitation reduced the soil exposed to erosion and increased soil fertility.

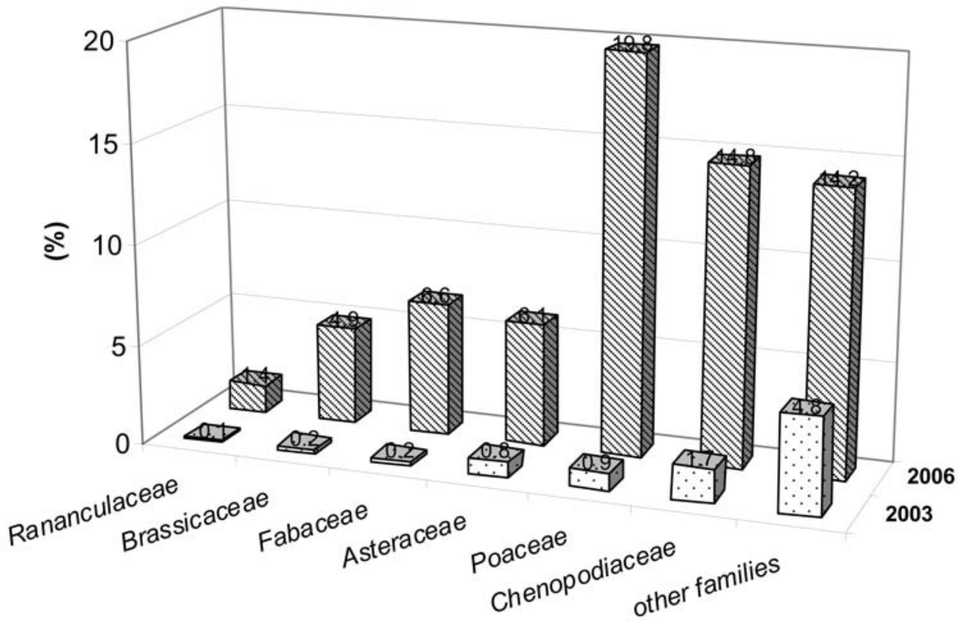


Figure 3: Development of vegetation cover in the studied area after 3 years of rehabilitation

Flora diversity in the studied area

The plant cover survey at the end of the project period showed positive changes in the composition of vegetation cover. Most of plant species that were almost extinct have nicely regenerated. In spring 2004 only 27 plant species of 23 genera and 13 families were identified, while in the year 2006 the plant diversity increased to 83 species of 55 genera and 17 families (Table 1). In 2003, the families Poaceae and Fabaceae were represented by only 3 species each, while in 2006 the abundance of these families increased to 13 species and 10 species respectively (Figure 4)

Table 1. Development of vegetation composition in the studied area

Type of vegetation	Initial No. (2003)	Final No. (2006)
Families	13	17
Genera	23	55
Shrubs	6	9
Herbages	21	74

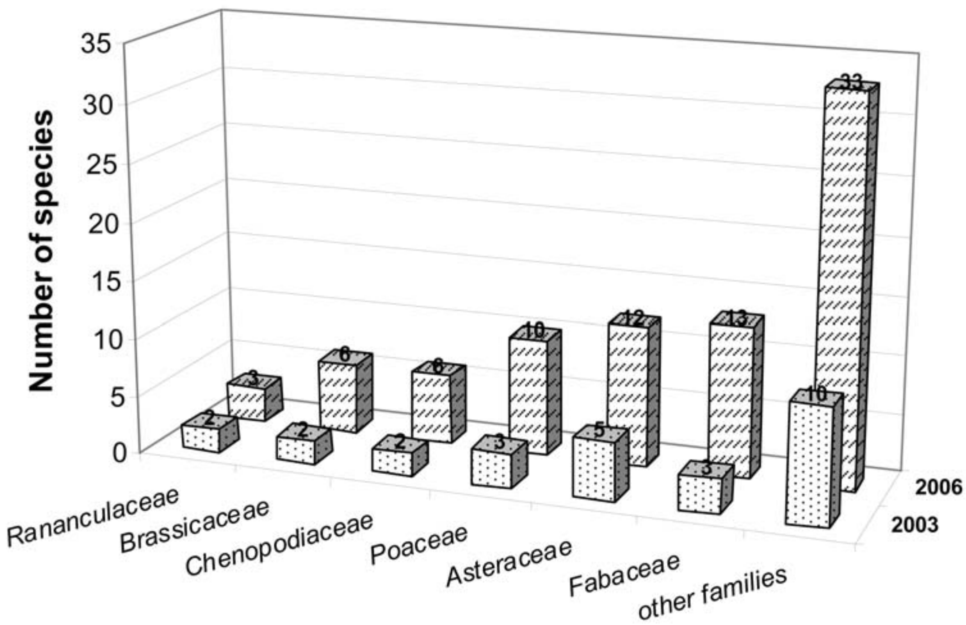


Figure 4: Development of plant diversity in the studied area after 3 years of rehabilitation

Shrub density

As a result of the rehabilitation measures the shrub density increased to a great extent. At the beginning of the rehabilitation process, the shrub density was 0.09 plant/m^2, and increased up to 5.8 plant/m^2 in 2006 (Figure 5). The density of palatable shrubs increased to 0.02 plant/m^2 in 2003, and up to 4.1 plant/m^2 in 2006. The high density of palatable shrubs is mainly based on propagation of Salsola vermiculata. The seedlings of this species have low fodder productivity and surface area. However, the unpalatable shrubs such as Noaea mucronata, Cornulaca setifera and Astragalus spinosus increased at a low ratio, only.

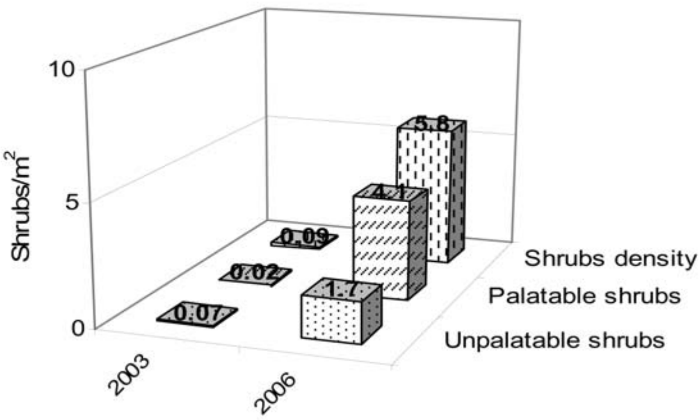


Figure 5: Development of shrubs density in the studied area after 3 years of rehabilitation

Plant productivity

The above-ground biomass can not be consumed entirely by sheep (Maingute, 1999). It contains thick woody parts that are unpalatable, and only the palatable above-ground plant material counts as fodder resources. Therefore protection from grazing by animals over a long period will increase the woody branches that are unpalatable. However, For sustainable use of the natural pasture, animals may graze only half of the available fodder (Stoddart, et al. 1975). Rehabilitation of the degraded vegetation cover increased fodder productivity from 90 kg/ha in year 2003 to 320 kg/ha in the year 2006 (Table 2). The results show that one hectare of improved rangeland could feed 0.6 sheep for 180 days, whilst fodder productivity before rehabilitation was just enough for 0.16 sheep for the same period.

Table 2: The Effect of vegetation rehabilitation processes on forage productivity (kg / ha) and carrying capacity (sheep head / ha / 180 days).

	Rehabilitation process starting	2006
Fodder productivity (kg / ha)	90	320
Available fodder productivity (kg / ha)	45	160
Carrying capacity (sheep head/ha/180 day)	0.16	0.6

Conclusion

The sustainable development and improved management of rangeland will assure sustainable growth of plant species and keep the range area in good condition. These results confirm the great and positive role of direct sowing in achieving sustainable rehabilitation via reducing soil disturbance and increasing plant coverage which would reduce soil erosion, increase soil organic matter , sequester more carbon, and improve soil water storage capacity. Besides, the reappearance of legumes among many other plant species would have improved soil fertility by their symbiotic nitrogen fixation. Finally it has to be emphasized that determining the suitable grazing capacity is one of the major factors to rationalize rangeland management.

References

Askar M. 1991. Fixation of sand duns and conservation of Syrian Al-Badiah from desertification . Arab Agriculture engineer. 30 pp 27-31.

Barrow C. J. 1991. Land Degradation Development and Breakdown of Terrestrial Environment. Cambridge University Press, Cambridge, United Kingdom.

Batanouny K. H. 2001, Plants in the Desert of Middle East Springer-Verlag, Berlin, Germany.

Evan R. A. and Love R. M. 1957. The step-point method of sampling – A practical tool in range research. J. Range Manage 10. pp. 208-212.

Geerken R., Ilaiwi M., Jaja M., Kaufmann H., Roeder H., Sankary M. N. and Segle K. 1998. Monitoring Dry land Degradation to Define and Implement Sutable Measures towards Sustainable Rangeland Management. In Sqires V. R., Sidahmed A. E. (Eds.), Dry lands: Sustainable Use of Rangelands into the Twenty-first Century, pp. 31-44.

Habib L. 2003. Land Degradation in Syria. In: Akca E., Steduto p. and Zdruli P. (Eds.), Medcoastland Project. Workshop Proceedings. Ecosystem-based assessment of soil degradation to facilitate land users' and land owners' prompt actions Adana, Turkey, 2-7 June 2003, pp. 278-289.

Ilaiwi M. 2000. Land Degradation in Syria (Case study-Jabal Al Beshrri). In: Arab Bank for Economic Development in Africa and Arab Center for studies Arid Zones and Dry lands (ACSAD) (Eds.), Proceeding of second Training Course on the Use of Remote Sensing Techniques and Geographic Information System in Monitoring and Combating Desertification 9-13 October 2000. pp. 157-179. Damascus, Syria

Legel S. 1990. Nutztier der Tropen und Subtropen. Bd. 2, Herzel Verl. Leipzig. Germany

Maginguet M. 1999 Aridity Droughts and Human Development. Springer-Verlage, Berlin Heidelberg, Germany.

Curtis J. T. and Mclnton R. P. 1950. The interrelations of certain analytic and synthetic phytosociological characters. Ecology 31. pp. 434-455.

Stoddart, L.A., Smith A. D. and Box T.W. 1975. Range Management. Third edition. McGraw-Hill Book Company, New York, 532 p.

Syrian Arab Republic (SY) Ministry of Defense, Meteorological Department, Climate Division. 1977. Climatic Atlas of Syrian. Damascus, Syria.

Syrian Arab Republic (SY) Ministry of State for Environmental Affairs, Land Directorate and United Nation Development Program (UNDP) 2002. National Action plan to Combat Desertification in the Syrian Arab Republic. Syria

Syrian Arab Republic (SY) 2005. The annual agricultural statistical abstract Damascus (Syria), Ministry of Agriculture and Agrarian Reform.

The Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) 1999. Animal wealth in Syrian Steppe (Bushri Mountain) Damascus, Syria.

The Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) 2006. Integrated National Resources Management for Combating Desertification in West Asia, Final Report of UNCCD/SRAP Pilot Project, in Syria and Yemen 2003-2006. ACSAD, Damascus, Syria.

The Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) and the German Agency for Technical Cooperation (GTZ) 1995. Participatory Rapid Appraisal: Characteristics of Inhabitants in the Beshrri Mountains Deir Ezzor- Syria. Development Service Office, Amman, Jordan.

Waad I. 2003. National Conditions and Dominant Factors of Land Degradation in Syria. In: Akca E. Steduto P. and Zdruli P. (Eds.), Medcoastland Project. Workshop Proceedings. Ecosystem-based assessment of soil degradation to facilitate land users' and land owners' prompt actions Adana, Turkey, 2-7 June 2003, pp. 291-301.

Farmer Participation in the Development of CA Technologies

Kurt Steiner

Goethestr.7, 69250 Schönau, Germany

e-mail: landconsult@kurtsteiner.de

Abstract

Agricultural research in many countries has been criticised in the last decades as having no impact on agricultural development. This was mainly the case in developing countries, where most farmers are smallholders, having no strong lobby and no political voice. Researchers were accused of following their own research interests while neglecting the real problems of farmers. It became also evident that the idea of technology transfer did not work. The environmental and socio-economic circumstances of farmers vary so much that technologies developed under different circumstances cannot be directly adopted by farmers.

As a means of making research more client-oriented, and gaining more impact on agricultural development, research and extension organisations realised the need for direct involvement of farmers in the research and development process. During the 1980s, the idea of on-farm experimentation and participatory technology development was born and specific methodologies were developed. The role of farmers, extension workers and researchers was redefined. Farmers were accepted as equal partners. The advantage of on-farm experimentation soon became evident as it proved to be time- and cost-efficient. Involvement of farmers in problem identification, testing of potential solutions, and evaluation of research results, provides a direct feed-back. Socio-economic factors are taken more in consideration and technical options can be regularly adapted to the requirements, thus increasing the probability of a later wide adoption by farmers. On-farm research and experimentation are specially required when new technologies necessitate investments, e.g., for farm implements like it is the case with conservation agriculture.

On-farm experimentation requires trial layouts and statistical analyses other than station research. While the underlying hypothesis of station trials is that conditions are homogenous, it is evident that factors like soil, local weather and management vary between farms.

It is often argued that it is too risky to expose farmers to unproven technologies. However, an ex-ante evaluation of technical options can reduce the risk of complete failure. Experience has shown that farmers' confidence is not lost when the nature of experimentation is explained and when they are accepted as equal partners and experts in their environment.

The paper gives an overview on the principles and main steps of on-farm research, and provides information on organisation and assessment of on-farm experiments.

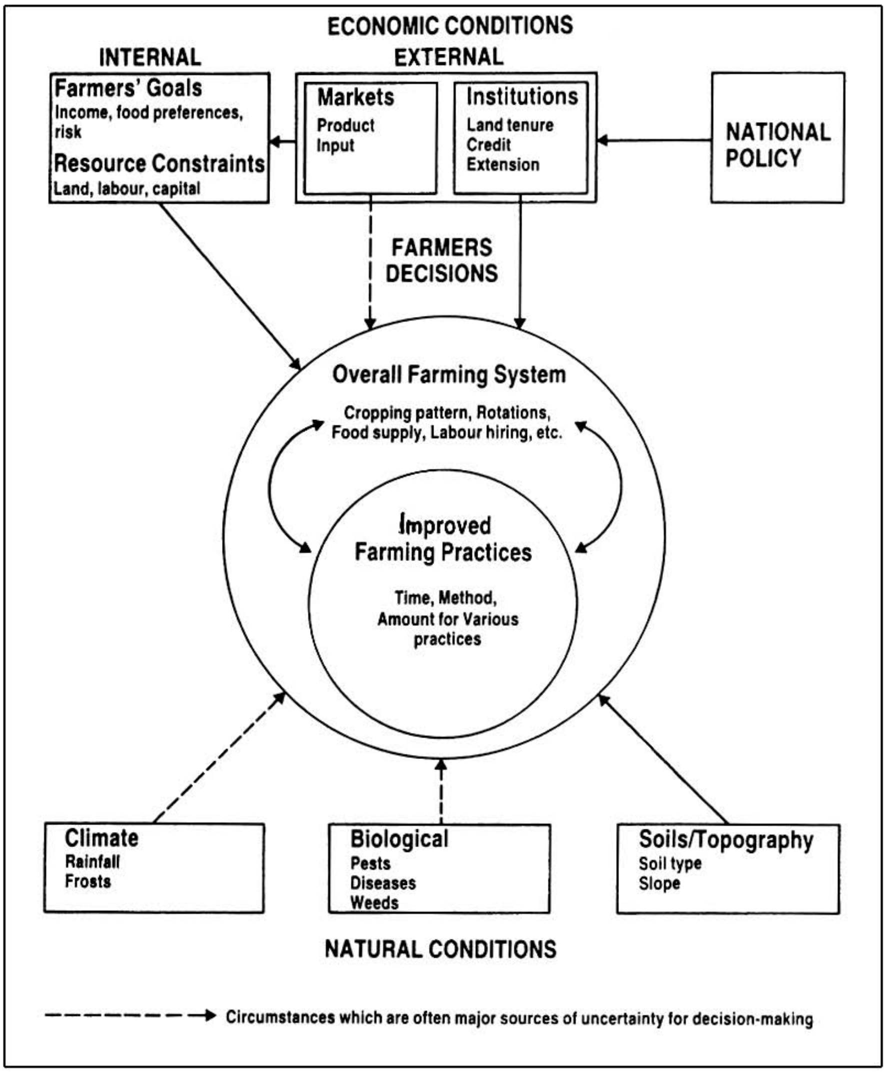
Key words: on-farm research, on-farm experimentation, farmer participation,

1. Introduction

Agricultural research in many countries has been criticised in recent decades as having no impact on agricultural development. This resulted often in reduced research budgets, and even less impact on agricultural development. This was mainly the case in developing countries, where most farmers are smallholders, having no strong lobby and no political voice. Researchers were accused of following their own research interests while neglecting farmers' real problems. It became also evident that the idea of technology transfer did not work. Farmers' environmental and socio-economic circumstances vary so much that technologies developed under different circumstances could not be directly adopted by farmers.

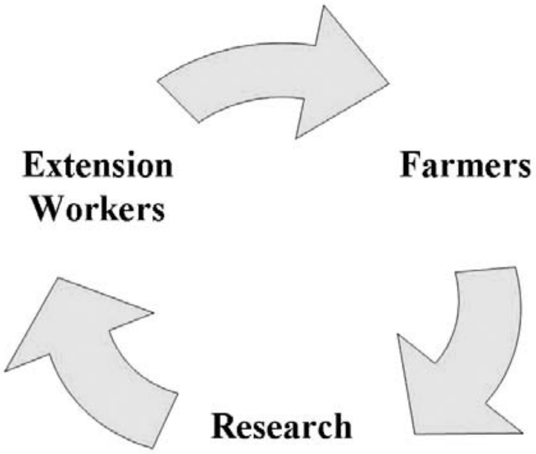
Figure 1: Circumstances affecting farmers' choice of a farming practice (cited from Steiner, 1986)

Cited from Steiner, 1986



In order to make research more user-oriented, approaches were developed already in the 1980s to involve farmers and extension workers in the research process. The roles of farmers, extension and development workers and researchers were redefined. The idea of "farmer-first" was born, which means that farmers have to articulate their needs and priorities. The hierarchical process of research and extension where research is on the top and the farmer on the bottom was replaced by a triangle of equal partners: farmers, extensions workers and researchers. Farmers became accepted as experts in farming and disposing specific local knowledge (Steiner 1986). This new paradigm was not easily accepted by many researchers and extension workers, who feared loosing their aura of authority.

Figure 2: Changed role of farmers in applied agricultural research – "Farmer-First"



Top-down approach of research Farmer-First approach

Adapted from Steiner 1986 and Hagmann 1999

The objective of this Conservation Agriculture Workshop was to exchange knowledge and information in view of accelerating the spread of conservation agriculture practices in the Arab countries. An objective of this paper is to stress the importance of on-farm research as an efficient means of achieving this goal.

2. Understanding On-Farm Research (OFR)

The objective of applied agricultural research is to identify new farming practices and materials that will improve farmers' production systems and increase their productivity and improve farmers' livelihood in a sustained way. On-farm research is considered an efficient tool in the development and transfer of appropriate technologies. On-farm research is expected to enhance the relevance of research by taking direct cognizance of farmers' conditions and needs and by choosing new technology in cooperation with farmers and testing it under local conditions (Mutsaers et al. 1997).

In essence, the OFR approach is conducting an important part of the applied research together with farmers, i.e., the clients of research or users of research results, in their own environment, with the aim of finding adoptable and sustainable solutions for their production constraints.

Table 1: The development of agricultural innovations: purposes, criteria and methods at different stages

Stage	Purpose	Criteria	Tools/Methods
Exploring demand	Explore: – Who demands innovation? – What is demanded? – Where is it demanded?	Farmers' perceived needs Present and expected problems Non-utilized opportunities	Secondary information Exploratory survey Dialogue on innovation Approp. analytic. tools
Identifying options	Identify: – Which available technologies can satisfy the demand?	Correspondence with farmers goals and preferences Ecological compatibility Economic viability Feasibility	Secondary information Dialogue on innovation Approp. analytic. tools
Testing alternatives	Collect information to examine how far alternatives comply with defined criteria	Correspondence with farmers goals and preferences Ecological compatibility Economic viability Feasibility	Experiment Observation Dialogue on innovation Farmer assessment
Assessing alternatives	Analyze, interpret and decide which of the tested alternatives comply with criteria	Correspondence with farmers goals and preferences Ecological compatibility Economic viability Feasibility Adoption	Organizing data Scaling and rating Statistical analysis Economical analysis Analysis of farmer assessment

Cited from Werner, 1993

2.1. Going in circles

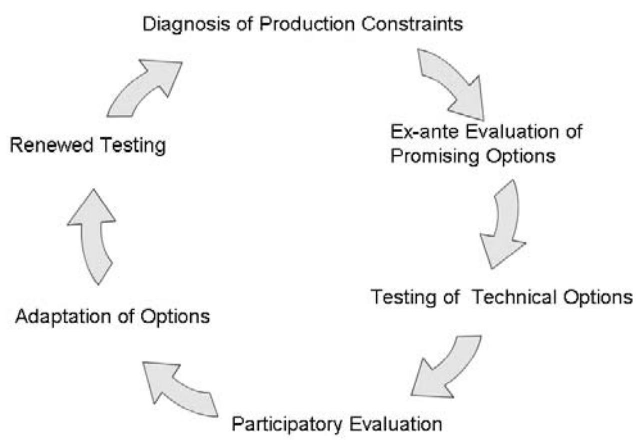
OFR consists of three main components:

‡ Developing a clear understanding of the farm and its environment as well as farmers' goals, constraints and opportunities (the diagnostic component)

‡ Choosing or designing appropriate innovations, in close cooperation with farmers, and testing them under real farm conditions (the experimentation component)

‡ Evaluating the performance of the innovations and monitoring their adoption, or analysing the causes of non-adoption (the evaluation component).

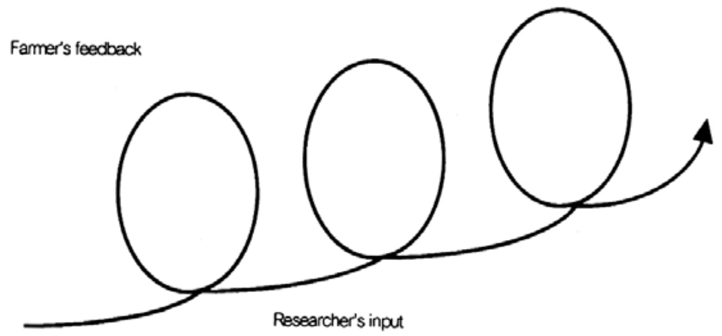
Figure 3: The circular model of on-farm research



In fact, OFR is not a linear but a circular process, as the evaluation results usually in a refinement of the original design of the innovation under test. This is in contrast to the traditional linear model of transfer of knowledge and technology (Fig. 2). Farmers, as the potential users of the research results, are involved in all components and steps of the research and development approach. The process begins with the identification of constraints and the search for potential solutions. Potential solutions undergo a strict ex-ante evaluation before being tested in field experiments.

The second round of the circle is not just a repetition but takes into consideration the outcome of the evaluation and the better understanding of the situation by working together with the target group. Hagmann (1999) talks of learning loops. This signifies the progress or step ahead made by participatory experimentation or technology development. Often OFR has to pass several circles or learning loops until an innovation or new technology fits farmers' requirement.

Figure 4: Learning loops



Cited from Steiner and Drechsel, 1998

2.2. Principles of OFR

OFR is based on a few principles (Werner 1993):

Understanding farmers and their circumstances

Each farm is different as to its history, the owner, and the preferences of the owner. Farmers decisions are determined by their production goals and preferences as well as by the natural (environmental) and socio-economic circumstances of the farm. These factors also determine farmers' attitude towards a new technology, and should therefore guide the researcher in the development of an innovation.

Farmers are in the centre of action

Nobody has a better understanding of the needs and opportunities the farm offers than the farmer. No one else is better able to judge which kind of technology would be required and how to get it to work on the farm. Therefore, the earlier the specific knowledge of the farmer is combined with the technical knowledge of researchers, the more likely new technologies are to succeed.

As farmers are the centre of attention, they should also play a key role in determining the subject of research and choice of appropriate technologies. The role of researchers is more:

- To help farmers articulate their demand for innovation, to offer a choice of options to satisfy this demand, and

- To provide the principles and methods for testing these rather than deciding what a farmer needs.

This theory does, however, not always comply with the practice (see also Section 2.3). Usually researchers have to offer not more than one or two technical options designed to overcome production constraints specific for a certain region, production system, and farm type. This is, e.g., the case with conservation agriculture. For testing and refining these options under real conditions, interested farmers are searched for in the potential target zones.

Technical options are tested in farmers fields, under farmers management and using farmers own practice as control

The purpose of on-farm experimentation is not so much to show the potential productivity of an innovation but rather to prove its feasibility under actual farming conditions. Experimentation in farmers' fields provides data regarding the feasibility of an innovation under the diverse ecological conditions farmers face. Farmers' own practice is used as the control which provides an appropriate basis for comparison.

The response of farmers is a primary evaluation criterion

As farmers are the potential users of an innovation, it is their judgement that determines whether an innovation will be adopted or not. Farmers' judgement, therefore, deserves to be a key criterion in the evaluation of different innovations tested in the OFR programme

The innovation must be technically sound, economically viable and warrant sustainability

To have a chance of adoption, an innovation must show clear advantages compared to farmers' practice. Yield is just one criterion. Profitability and ease of application may be even more important.

The success of an innovation is measured by its adoption

The research process and the responsibility of researchers do not end with publication of research results. What counts is the adoption by the target group and the impact on farmers' livelihood and the environment.

A systems perspective is applied

No activity on a farm exists in isolation. They are interrelated through competition for scarce resources or when products of one farm activity are used as the basis for another. The optimisation of one component or production technique of the farming systems may require that specific characteristics of other components or production techniques be taken into consideration.

This is, for example, the case with conservation agriculture in mixed farming systems where the need of crop residues for groundcover is competing with the need as forage for livestock.

On-farm and station research are complementary

On-farm research cannot replace station research; it is just complementary to station research. By providing feed-back from users, OFR helps to constantly readjust station research thus making it more time-and cost-efficient.

Extension workers are involved from the beginning forward

Researchers should avoid that extension workers regard OFR as an intrusion into their competences. Extension workers usually know “their” farmers and can help identify farms and farmers for conducting on-farm experiments. Involving extension workers into the development and testing of innovations will make it later-on easier to promote successful innovations.

Private sector companies

Whenever tested options require external inputs, or services, private sector companies should be involved in the research and development process. This is the case for a practice like conservation agriculture, which requires special seed drills and seeds of cover crops, not yet available on local markets.

Table 2: Characteristics of on-farm research (Werner 1993)

Objectives:
- To develop innovations consistent with farmers circumstances, compatible with actual farming systems and corresponding with farmers’ goals and preferences

Primary location:
- Farmers’ fields

Role of farmers:
- To discover needs for agricultural innovations
- To select from o choice of technologies
- To test and evaluate whether chosen technologies meets demand
- To transfer knowledge in farmer-to-farmer extension.

Roles of extension workers:
- To point out their own need for information about innovations
- To help farmers to articulate their demand for innovation
- To spread knowledge about innovation.

Role of researchers:
- To inform farmers of potential solutions of production constraints
- To demonstrate choice of possible technology to satisfy need
- To explore and use farmers’ local knowledge
- To provide principles and methods to test chosen technologies
- To evaluate productivity and sustainability.

Primary criteria for assessment of technology:
- Correspondence with farmers’ circumstances, goals and preferences and sustainability are as important as productivity

Primary criterion for successful innovation:
- Its adoption

2.3. OFR in relation to an institute's mandate

OFR is a necessary research tool for any agricultural research institute in a developing country, and the research methods do not differ essentially in different countries or ecologies. An institute's research mandate will, however, affect the way OFR is conducted, in particular the way in which target zones or test technologies are chosen. This can rise to the following situations (Mutsaers et al. 1999).

Commodity-driven OFR

Many research institutes are specialised on certain crops such as cereals, grain legumes or sugar beets. Research is covering all aspects of a crop such as breeding, plant pathology, and production techniques. Most international research institutes have mandates for specific crops, such as maize and wheat in the case of CIMMYT. The commodity-driven approach has the advantage of providing a clear focus on which researchers from the different disciplines involved in OFR can readily agree. But it runs the risk of overemphasising one crop when other crops or resource-management constraints may be more important.

Constraint-driven OFR

OFR can address specific constraints such as certain plant diseases or noxious weeds like Imperata or Striga. Targets zones are defined in relation to the occurrence and severity of these disorders. This approach has the advantage of giving a high priority to a few major constraints for all disciplines within an institute and of establishing multidisciplinary approaches to these problems.

Technology-driven OFR

The objective is the assessment of the performance of specific technologies under farming conditions. One example is conservation agriculture, or more specifically direct seeding. Technology-driven OFR is closely related to the constraint driven approach, as the technology was developed in the first place to address certain constraints. The OFR workers must define the conditions under which the technology is likely to perform well, and even more important, identify those areas where there is a good chance of adoption. Testing sites are then chosen in high-potential areas. The delineation of the areas with high potential for the technology can be quite complicated because of many factors affecting the suitability and adoptability of a technology. Besides environmental factors, these are socio-economic factors, such as farm type, access to markets, etc.

3. OFR Process and Procedures

The development of appropriate agricultural innovations involves a number of equally important activities. Experimentation or testing of alternatives is a central stage in the process but neither the first nor the last one. The process can be broken down into five stages, or major steps:

1. Exploring the demand for innovations
2. Identifying potential technologies that could satisfy the demand
3. Testing identified alternatives (potential solutions)
4. Assessing the performance of the alternatives tested, and
5. Disseminating results.

3.1. Exploring the demand for innovations

The exploration of the demand for innovations sets the course for all subsequent steps. Care should be taken that the OFR process is steered off to the right direction. Unsatisfactory results in the development of innovations are often the result of a one-sided, superficial or incomplete approach in the first stage.

The demand for innovations that could overcome specific production constraints or make better use of the existing agricultural potential depends first of all from three major factors:

- Target zone (environment, topography, rainfall, soil type)
- Target group (farm and farmer type)
- Problems and potential to be addressed.

The (agro-ecological) target zone is often defined by a research institute's mandate zone; e.g., arid zones as in the case of ACSAD. Each agro-ecological zone has its specific constraints and the identification of technologies which could overcome these constraints is the first step in the OFR process.

The characteristics of the target group influence choice and implementation of the further steps of the OFR process. Commercial farmers, owning usually medium or large farms, can express their demands and priorities usually better than smaller farmers. They can conduct a great part of the observations and data collection themselves. This is especially valid for socio-economic variables like inputs, labour demand, production figures which allow them to also assess the production costs and revenues. They are usually more active partners than smallholder farmers, and their decision criteria follow more the line of researchers. In industrialised countries it is farmers or farmer associations that request research institutions to solve specific production constraints.

The target group is not always aware of a production constraint or of potential solutions. Thus, soil erosion is often regarded as a natural phenomenon that has always existed. Many farmers have never heard of conservation farming or its specific practice of direct planting, and are therefore not aware that it could be a solution to soil erosion. Consequently, they will not ask for it but this does not mean that there is no demand.

Most common methods of defining constraints and exploring the demand for innovations are exploratory or diagnostic surveys and rapid rural appraisals.

3.2. Identifying alternatives

The identification of potential options consists mainly of listing available technologies resulting from station research or known from successful adoption in other comparable regions. In a second step, these alternatives are screened systematically using a set of criteria to avoid an arbitrary selection of technologies for testing (= ex-ante analysis). Criteria for screening can be categorised under five headings:

- Feasibility under given socio-economic circumstances
- Correspondence with farmers' goals and preferences
- Feasibility under given natural conditions
- Economical viability
- Ecological sustainability.

3.3. Testing alternatives Experimentation

For many research institutions and agricultural services, the idea of installing experiments on farmers field was like a revolution and difficult to accept. It was feared that in case of failure of an option farmers would loose confidence in the competence of researchers and extension staff. Statisticians claimed that it was impossible to analyse the data from on-farm experiments properly as there were too many uncontrolled variables and that at least three replicates per field were required. In the meantime, most of these questions were solved and on-farm experimentation became almost routine.

Table 3: List of criteria of alternative technologies

(1) Feasibility under given socio-economic circumstances
- correspondence with farmers' skills;
- availability of input and produce markets;
- sufficiency of farmers' resources;
- sufficiency of research resources.

(2) Correspondence with farmers' goals and preferences
- correspondence with food/taste preferences;
- compatibility with cropping pattern/cropping calendar;
- interaction crop / livestock.

(3) Feasibility under given natural conditions
- expected production as compared to present situation;
- expected stability of production;
- expected production risks.

(4) Ecological viability
- expected effects on the natural environment;
- expected effects on the long term productivity;
- expected effects on diversity of agro-ecosystems.

(5) Economic viability
- profitability as compared to present situation;
- expected effects on produce markets.

(6) Further criteria

Cited from Werner, 1993

The usual on-farm trial consists of two or three treatments consisting of the farmer's practice as a control and one or two alternative options. There are no repetitions in the same field, but each farm is considered a repetition. The plot size depends very much on the options tested and the production system. In any case the plots are bigger than those on an experiment station due to greater border effects and a greater heterogeneity of most farmer fields. While 10m x 10m plots are sufficient for variety trials, larger plots are required for soil management trials, especially if managed with a tractor.

Each farm or site is regarded as a repetition. The number of repetitions required for a statistical analysis depends on the difference expected between treatments. The smaller the difference, the greater the number of repetitions required for a meaningful statistical analysis. “Site” or “Farm” can be considered as a factor in the statistical analysis. The treatment x site interaction gives an indication of the response of the options to the local environment, i.e., soil, topography, and perhaps microclimate.

On-farm trials should be clustered around a village or in a watershed in order to allow frequent visits that are required for keeping contacts with farmers and for monitoring results. Trials sites should be accessible throughout the year. Apart from reducing costs and time of field visits, clustering has the advantage of easing communication between cooperating farmers.

Monitoring and data collection

Different from station trials, agronomic and socio-economic data are collected for on-farm trials. Emphasis is on cost- and time-efficient monitoring methods. Whenever possible, easily monitored parameters, e.g., visual ones, are used. Extension agents and farmers can assist in monitoring much of the data after receiving some instructions (Herweg and Steiner, 2002).

Agronomic data, which are often the centre of attention, are important for assessing the suitability of a technology for the local environment. They are also an important basis for determining the economic viability. Agronomic data are not, however, the only important data. When testing conservation agriculture technologies, soil and water related data become important (e.g., visual sings of run-off and erosion, soil parameters). Apart from standard observations, indicator plants for soil fertility status, known by farmers, should be used, or signs of earthworms as indicators for abundant soil life.

Socio-economic data are equally important, as they are often decisive for adoption or non-adoption of a technology. Total production costs, labour requirements, and ease of labour are among the most important data.

Table 4: List of important agronomic data of conservation agriculture trials

Rainfall:	mm, no of days (per site or nearby village)
Surface run-off:	visual signs, importance, depth of rills (scores)
Soil erosion	visual signs, importance (scores)
Ground cover:	% ground cover, at sowing date, mid-season, end of season (use of photos)
Soil organic matter content:	% SOM
Soil nutrient status:	pH, N. P, K, Mg, (CA)
Soil moisture:	per gravity, at sowing date, mid season, end of season
Aggregate stability:	visual (scores)
Soil colour:	use of colour table
Soil life:	no-of earth worms/m2, optional also no. of collembolans or arthropods
Weeds:	main species, % soil cover; indicator plants
Crop development:	stand count, colour, date of flowering or tasseling, harvest date
Yields:	Total biomass, grains

Table 5: List of important socio-economic date of data of conservation agriculture trials

Production costs (inputs):	seeds, fertilizers, herbicides, fuel
Labour:	no. of days, costs, ease of labour
Product prices:	prices at local market or other selling points
Other observations:	records should be taken during field visits and discussion with farmers of all social factors that could influence adoption

3.4. Assessing tested alternatives

A new technology is often judged to be appropriate based exclusively on its productivity. As a consequence, many new technologies are not adopted by farmers because they do not comply with their goals and preferences or the circumstances they face. To be adopted by the target group, an innovation must fulfil a set of criteria:

- Correspond with farmers' goals and preferences
- Technical feasible under given environmental and socio-economic circumstances
- Ecological sustainable
- Economical viable
- Socially acceptable.

The assessment does not start with processing and analysing data, but begins during field visits and field days in discussions with farmers and extension workers. Farmers will report management constraints, their view of crop development, weed and pest incidence, etc.

Data processing

The appropriate type of statistical method depends on the number of repetitions and the quality of the data. Up to approximately five repetitions, simple means are satisfactory. But means tend to hide differences between farms. Therefore it is always recommended to also present the maxima and minima.

Analyses of variance (ANOVA) will only give meaningful results with 10 or more repetitions due to large differences between individual fields or farms, and the CV (coefficient of variation) will be rather high. As site x treatment interactions can be expected in most cases, these interactions need to be analysed. “Site” can be entered as a factor into the analysis.

Frequency distribution: a rather simple method of analysis, which gives a good indication of the superiority of a new technology, is to compute the frequency of yield in income advantages. The simplest analysis gives the number of cases where yield or income of the new technology is superior to the farmer's practice. More insight provides an analysis which uses classes, e.g., of 10, 20, 30 40 and 50 % yield or income increase.

Regression analysis: Yield stability of new varieties or soil management practices is an important criterion. A claim of conservation agriculture practices is more efficient use of rainwater and that this buffers the effect of drought and increases yield stability. A regression analysis will show when this is true.

Economic analysis: Even though most farmers are proud of a good crop and high yields, what really counts is the revenue. Yield increases are not interesting when they are gained with high costs.

Production costs:

Production costs are more or less the variable costs. As input prices tend to increase, for example fuel price increased drastically in recent years, while market prices tend to decline, more farmers are become interested in reduced production compared to yield increases. Thus, all innovations that help to reduce inputs, e.g., fuel consumption or labour, are of interest.

Returns:

The most common and simple economical analysis is the calculation of gross margins. Gross margins are defined as:

Gross margins = gross returns – variable costs

Gross return or output is the physical yield x product price. Variable costs are the costs of input such as seeds, fertilizer, fuel, and labour. Gross margins are usually calculated per ha or other surface unit. The same statistical methods used for analysing yield data also apply for analysing gross margins.

Further economical analyses often applied are cost: benefit ratio and marginal rates of return. These analyses are of interest when increasing rates of inputs are applied, e.g., fertilizer trials, or production systems requiring high capital inputs are compared.

Social acceptability: New technologies risk conflicting with social norms and customs. This is the case with crop residue management and growing cover crops in conservation agriculture systems. The desire to keep the soil always covered conflicts with the traditional right of free grazing after crop harvest. The reduction of labour requirements may conflict with the social responsibility of farm owners for their workers.

Data presentation and interpretation:

The presentation and interpretation of data depend on the needs of the target group. Farmers, extension agents, researchers, development workers and policy makers are each interested in different aspects and more or less details. While farmers are mainly interested in yields and production costs, researchers will be more interested in soil parameters, and politicians in more general aspects like yield stability especially in countries with periodical food shortages or impact on desertification. Graphs are easier to understand than tables.

Benefits of soil and water related innovations, like conservation agriculture, become visible often only with a certain delay. Increase of soil organic matter or more abundant soil life will only become visible after a couple or more years. In the first years weeds may be more abundant, increasing the labour demand for weeding, and weed population will only decline after several years. Thus, short term results are not very meaningful. More informative than annual results are trends, which can be presented in form graphs (Figure 5)

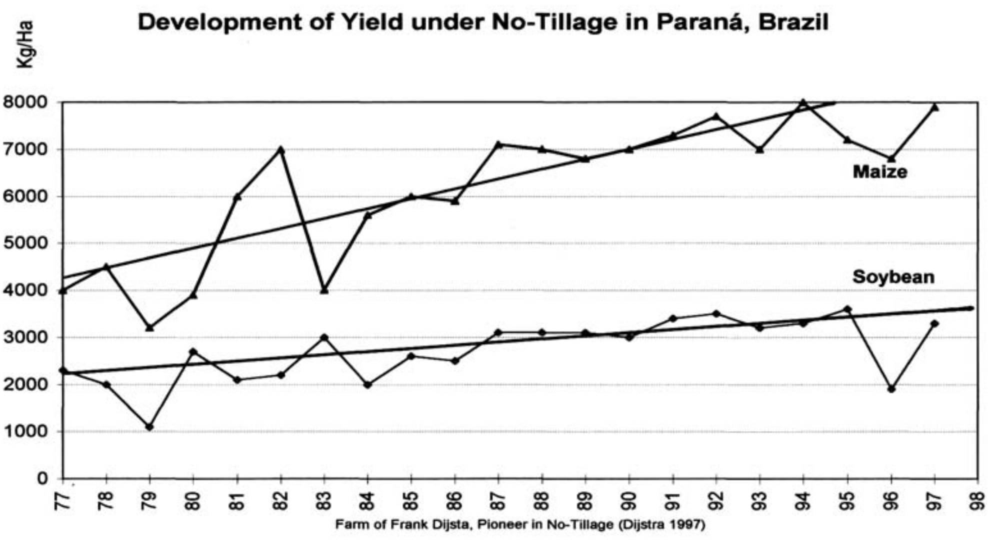
3.5 Disseminating innovations

The OFR process does not end with the publication of results. It is also the responsibility of researchers to ensure that the innovations developed reach the target group. Involving farmers and extension agents, whenever applicable also development workers, is already a first step towards dissemination.

Role of farmers

Of importance for later dissemination is the choice of farmer co-operators. Lead farmers, respected in the community as good farmers, can encourage other farmers to try the innovation. Another aspect is the farm type; small scale, subsistence oriented farms, or large, commercial farms. While the first type is the target group of development projects, it is often easier to develop new technologies with larger, commercial farmers. Larger farmers dispose of capital for investments and can take some risks. If the technology tested fits the objectives, larger farmers usually adopt an innovation more readily and can then serve as example for

Figure 5: Long term trend of yield development under direct seeding



Cited from Derpsch .

smallholder farmers, or even advise smaller neighbours how to apply the innovation to their own circumstances. Larger farmers have a better lobby and can influence agricultural politics. This may also benefit smallholders in the end.

Farmers observe each other and tend to listen more to the experience of their neighbour farmers than to extension workers. Often, successful farmers advise their neighbours in the use of innovations. In the frame of research and development projects, organised farmer exchange visits are an efficient means to disseminate innovations. Using farmer champions to promote innovations is a promising strategy.

Linking with national policies

In many countries a prime objective of conservation agriculture is to contribute to the prevention of desertification. Including the promotion of conservation agriculture in the National Action Plan (NAP) for implementing the Convention to Combat Desertification (UNCCD) can be an efficient means of speeding up the dissemination. In this context, focusing first on larger farms is justified as a larger area can be covered by sustainable soil management practices within a certain time frame.

Conclusions

On-farm research is a very effective research method which helps to increase the chances of adoption of innovations by the target group. The successful implementation of on-farm research requires, besides respecting the various procedures, specific skills of a mainly psychological nature. Listening to farmers, using a language that farmers can understand, and respecting farmers as equal partners are important aspects. Equally important is that the researcher is convinced of the idea, convinced that the idea is "on the right track" and devoted to the work. This is a precondition for convincing others, for gaining partisans amongst farmers, extension staff, and other government officials.

Choosing the right farmer-cooperators necessitates a certain feeling. Farmer-cooperators should be full-time farmers, interested in new technologies, and have good relations with their neighbours.

When identifying volunteers for on-farm experiments, it is of utmost important that farmers understand their role and also the nature of experimentation. It has to be stressed that the objective is to test options, and that one or all options may fail in the first run and that their expertise is required for adapting options to their conditions.

As farmers are equal partners and finally also beneficiaries of the research result, they cannot be paid for their participation. The question of compensation for crop failure should be raised only when there is an actual need. A careful pre-selection of technical options as well as starting with relatively small plots helps to eliminate or at last reduce the risk of crop failure.

If we analyse the successful widespread adoption of conservation agriculture practices, e.g., in a lead country like Brazil, it becomes evident that a few pioneers, farmers and development workers, convinced of going in the right direction have played a dominant role. It was those devoted individuals who started experimenting with direct seeding against all obstacles. It was those pioneer farmers who urged research institutions to initiate specific research and later on the government to support the further development and dissemination of direct planting practices.

And in all cases, pioneer farmers organised themselves in special associations, some of which were entitled association for sustainable agriculture, conservation agriculture, or direct seeding for sustainable agriculture. The objectives of these associations were for sensitisation, exchange of information, and to lobby for conducive conditions for sustainable agriculture. One example in the ACSAD region is APAD in Tunisia (Association pour une Agriculture Durable).

References

Drechsel P and Gyiele L (eds.) 1998. ON-farm research on sustainable land management in Sub-Saharan Africa: Approaches, experiences, and lessons. Proceedings based on papers from an international meeting held in Abengourou, Ivory Coast, 11-22-Augusr 1997. IBSRAM Proceedings No. 19. IBSRAM, Bangkok, Thailand.

Hagmann J 1999. Learning together for change. Facilitating innovation in natural resource management through learning process approaches in rural livelihoods in Zimbabwe. Margraf Verlag, Weikersheim, Germany.

Herweg K and Steiner KG 2002. Impact monitoring & assessment. Instruments for use in rural development projects with focus on sustainable land management. Vol. 1: Procedure; Vol. 2: Tools. CDE/GTZ. Bern, Switzerland.

Mutsaers H J W, Weber G K. Walker P and Fisher N M 1997.A field guide for on-farm experimentation. IITA/CTA/ISNAR.

Steiner K G 1986. On-farm experimentation handbook for rural development projects. GTZ/CTA, SP 203, Eschborn, Germany, 307 pp.

Steiner K G and Drechsel P 1998: Experiences with participatory in-farm research on erosion control in southern Rwanda. In: Drechsel P and Gyiele L (eds.) 1998

Werner, J. 1993: Participatory development of agricultural innovations. GTZ/CTA/DEZA. Eschborn, Germany

Dissemination Approaches and Networking in Enhancing Adaptation and Adoption of Conservation Agriculture Practices

Lessons from ACT Programmes in Sub Saharan Africa

Martin Bwalya

African Conservation Tillage Network; Regional Secretriat

No. 3, Janeen Close, Mount Pleasant, Harare, Zimbabwe

email: mbwalya@africaonline.co.zw

Abstract

Over 65% of the population in Sub-Saharan Africa (SSA) live in rural areas and depend largely on subsistence farming to meet their livelihood needs. This direct dependence on exploitation of natural resources has left them highly vulnerable to the effects of land degradation – significantly eroding their means to food security and income generation.

Successful adoption of sustainable land and water management practices in general, and conservation agriculture in particular is offering households and communities a lifeline. However, adoption rates are still low and increase at a very slow rate, only.

Experiences within the African Conservation Tillage Network (ACT) in SSA have demonstrated that ACCESS to appropriate information and knowledge contributes significantly to enhancing extent and rate of adoption of sustainable land and water management practices. In this context, ACT experiences highlight dissemination approaches and partner/stakeholder networking which are driven by the need to give farmers and all other stakeholders in the agricultural sector access to information and knowledge. This is a key factor in scaling up the adaptation and adoption of conservation agriculture (CA) practices.

This paper shares lessons from experiences in developing and sustaining networking as a tool in strengthening capacities of stakeholders to support adoption of CA practices. The paper highlights key principles of successful networking such as clarity on a common vision and purpose. Emphasis is placed on the values and objectives of "networking" as opposed to emphasis on the "network".

The paper also shares experiences in farmer participatory approaches, especially, through increased access to information and knowledge. Empowering and linking farmers to farmer-driven adaptation and innovation chain processes have proven to greatly influence adaptation of practices to the local environment. The paper highlights lessons from on-farm experimentation approaches that have evolved into valuable tools for self/social learning.

Keywords: Dissemination approaches; Conservation Agriculture, Networking, Participatory; farmer innovations; scaling up/adoption

1. Background and Rationale

1.1 Introduction

Ensuring that its peoples have access to basic livelihood needs including food remains an issue of priority concern for Sub-Saharan Africa (SSA). Food security (both in quantity and quality) and let alone income generation continue to evade the majority of the sub-continent's populations. Trends on these parameters are at best stagnant.

Agricultural productivity in SSA remains very low (grain yields averaging 300 to 500 kg/ha as compared to 8.5 tons/ha in the United States) and is declining in many cases. With over 65% of the continent's population rural and largely dependant on farming for their livelihood needs, poverty issues or on the other hand, food security and socio-economic growth can not be addressed without direct consideration of the agricultural productivity.

Performance of the agricultural sector remains a critical factor influencing trends in socio-economic growth. Therefore, enhancing and sustaining agriculture productivity becomes an important thrust in strategies aimed at achieving set targets in food security and poverty alleviation (MDGs) and underpinning a growth agenda.

Factors responsible for the stagnation /decline in agriculture productivity are many, complex and dynamically varied from area to area. However, there is growing acknowledgement that land degradation presents a major factor. It is also recognised that unsustainable farming practices are a major cause of land degradation. For example, intensive tillage and burning of crop residue contributes significantly to the loss of soil organic matter and exposes the soil to erosion and to high temperatures.

1.2 Trends in adoption of conservation agriculture practices

Success from the conventional soil and water conservation practices promoted in the 1960s through to the 80s has been limited, in most cases even with "heavy" related extension and input support. However, in the last decade there has been growing knowledge and experiences with practices that support natural resource resilience while at the same time sustaining high productivity. One practice or better concept is Conservation agriculture (CA) that minimises degeneration of natural resources while at the same time ensuring optimal productivity levels. This is also referred to as "farming in harmony with nature".

Farmers practicing CA have demonstrated the impact of CA both in viability of the production systems (e.g., reduced or more efficient use of external resources – labour, machinery, fuel, etc…) and in terms of higher and sustainable yields (Elwell, 1993; Oldrieve, 1993). Smallholder farmers in Tanzania's Arusha region and in several districts in Western Kenya at the very least doubled yields in the first 2-3 years after adopting CA (Bwalya, 2007).

Even more significant from the farmers' perspective, adoption of CA enabled them to get some yield even in "dry" years when neighbouring households using conventional practices had complete crop failure.

However, even with such success, adoption of CA practices remains low and slow. This has compelled critical re-consideration of the factors hindering or supporting increased adoption of conservation agriculture practices. It is also being recognised that scaling up of CA practices, calls for fundamentally radical changes in the way farming is done. This approach has highlighted the critical role of KNOWLEDGE in supporting and enhancing adoption.

1.3 Issues in enhancing adoptions

This paper shares two knowledge based aspects in the approaches to enhance the rate and extent of adoption of conservation agriculture practices, namely:

i. farmer driven social learning and on-farm experimentation in CA dissemination

ii. networking for knowledge and information support in enhancing the effectiveness and capacities of initiatives supporting the scaling up of CA practices

2. Farmer driven social learning and on-farm experimentation in CA dissemination

2.1 Background

Conventional extension approaches have, in general, narrowly focused on delivery of technical packages developed in on-station research processes. This is one factor that has rendered extension approaches ineffective in the dissemination of conservation agriculture practices. Most conventional extension approaches, e.g., the Training and Visit System, have largely been unsuccessful in enhancing and sustaining adaptation and adoption of technologies. These approaches have been inappropriate or largely ineffective outside commodity-based agriculture, especially in conservation agriculture and natural resource management in general (Hulme, 1991).

Among the alternative approaches developed in disseminating innovations in smallholders farming systems, recognise and are based on the understanding that successful innovations emerge out of adaptations. Despite their seemingly incongruous philosophical underpinnings, approaches such as "Farmer Field Schools" confirm the importance of knowledge and knowledge exchange/sharing systems in supporting analysis, rationalisation and decision making. This defines on-going innovation processes which inherently facili-

> **Box 1: The Concept of Conservation Agriculture:**
>
> Although interpretations and definitions vary, the term "Conservation Agriculture (CA)" is generally understood to refer to "a way of farming". CA is not just a technology, but a concept about how farming can and should be done. The CA concept draws its basis in the following two scientifically proven facts:
>
> i. that crop production is a natural process (integral in nature's life sustaining processes including air-cycle, water-cycle, nutrient cycle, etc…).
>
> ii. that "Farming" is a way humans have intervened in the natural crop production process to influence both the "rate" and "direction" of production to achieve levels of productivity that enables humans to meet their food and industrial needs.
>
> The application of this concept is underlined by the following THREE PRINCIPLES:
>
> i. minimum or no disturbance of the soil, e.g., by direct planting
>
> ii. soil cover: the more the fields are covered through the year the better
>
> iii. crop rotations/intercropping – in cycles and crop types that allow wide differential use of the soil.
>
> Farming practices developed on the basis of the three principles enables "farming in harmony with nature" at the same time maintaining high and stable yields. Effects/impact of practicing CA include:
>
> - optimal rainwater infiltration and in-soil retention (hence minimum erosion and water more available to the crop both in quantity and over a longer period of time),
> - "build up" of soil organic matter (SOM), which even in minute quantities has significant impact on the soil fertility in terms of soil structure, soil life and chemical condition. SOM has direct impact on the soil's ability to retain water; SOM also provides food to micro-organisms with the mineralization process (decomposition of organic matter) releasing nutrients for plants

tate self learning, collective problem-solving, and making choices in adaptation of practices. Strong social group dynamics are noted as essential in underpinning local innovation chains.

2.2 The ACT farmer based approach

The African Conservation Tillage Network (ACT) has in the last 6-8 years supported evolution of farmer based adaptation and technology innovation through farmer experimentation. Key principles that have driven these processes are:

i. strong local farmer (self) organisation which brings in the social dynamism and coherence that motivates and supports experimentation/innovation processes. This approach reduces the perceived risks and offers encouragement for many to attempt the new practices. ACT support includes stimulating and facilitating the recognition and rewarding of innovations. At the same time it enables the group/community to learn especially what activities /decisions underpinned the innovation. It is important that the social organisation is supported by local leadership systems and by the local "power" players. This includes recognising the usually complex local values and principles that underpin social responsibility, accountability, transparency, problem-solving and collective decision making. In many communities, a strong thrust on conservation agriculture and in general sustainable land management is built on a strong acknowledgement that management of natural resources is a social collective responsibility.

   Interactions through personal relationships and within local institutions and community networks are instrumental for shaping individuals' behaviours. This creates the necessary social space for people to innovate and develop opportunities for collective action to mobilise and manage local human and natural resources (Uphoff, 1992). Strengthening the local social organisation and farmers' management capacity becomes central to promoting sustainable adoption of conservation agriculture practices.

   ACT experiences highlight the importance of understanding the process of local organisational development as more than a one-time training experience in group dynamics for local groups and in leadership skills for leaders. Neither should it be confused with the use of Participatory Rural Appraisal (PRA) tools like Venn diagrams for the identification of local organisations and their roles. This is also not the same as establishing formal groups/organisations such as co-operatives or farmers' associations. It is an interactive facilitation process by which over time the various actors (local and external) reach a consensus on the basis of negotiated shared values. It is aimed at initiating a consultation process between individuals, agricultural and non-agricultural groups and their elected representatives for the development of a common development vision and for re-establishing linkages and synergies at the local level. It facilitates the formation of inclusive and self-governing bodies to foster representativity of all exiting community groups and nurture the formation of new ones. It also aims at strengthening existing leadership structures and developing new leaders based on commonly agreed criteria.

ii. Facilitating and enabling farmers to experiment: this recognises that farmers are inherently researchers and focuses on enhancing farmers' abilities to generate knowledge and progressively decide on adaptations and adoption. As small farmers cannot take any risk, they often experiment just in small corner of their fields. Record keeping is an important component of experimentation. This is usually a challenge owing to the poor and general weakness in record keeping in smallholder farming.

iii. Processes and tools for social learning: with emphasis on (i) knowledge as a product, (ii) tools and abilities to analyse information/data and (iii) modalities for interactive knowledge sharing and learning. Accessing and sharing resources has often been a key factor in group dynamics.

2.3 Key cornerstones in the evolution of the approach

The approach has evolved over time. It can be described by the following key cornerstones, which do not necessarily present a linear process:

1. Acknowledgement and common understanding on the problem: Awareness creation of the causes and consequences of land degradation by using appropriate learning tools to stimulate group exploration and self-discovery
2. Identification of innovations and possibly innovators from within the community/locality as sources of ideas
3. Local organisation: have to build on local cultural values. Identifying and strengthening social organisation values and principles constitutes the basis for social/self management in establishing and sustaining mechanisms for collective efforts to advance identified innovations
4. Experimentation: farmers trying out identified options fitting their production objectives. They watch what is happening to the various components of the production systems in response to their practices/actions.
5. Inherent on-going monitoring and self-learning
6. Mid and end of season evaluation and sharing

The first key element in this approach is to empower farmers/community to critically and objectively analyse issues related to productivity, resources, inputs, etc. Such analysis using various participatory techniques are facilitated (at farmers' own pace) into ultimately highlighting key limitations and their root causes. The facilitation at this stage includes strengthening farmers' understanding and appreciation of implications of land degradation on farm productivity and ecosystems resilience. This builds farmers' energy and desire "to act". At this stage, farmers are exposed to possible options in addressing the soil fertility and land degradation problems. The exposure can happen through a number of techniques including (a) specialised training, (b) farmer-to-farmer visits; or (c) field days /demonstrations (in some cases held by innovating farmers within the area). This enables farmers to make informed choices when it comes to deciding the action plan – a collective elaboration of what and how the group decides to proceed in responding to identified problems. It is also the individual and collective commitment to this action plan that strengthens group dynamics. Figure 1 illustrates the main benchmarks in the process being described above.

The main characteristics of these action plans include:

- build within the context of the household production-consumption systems; i.e., the plan does not become an extra "external" undertaking.
- it has to be understood and operated as a plan for the household (for the group) and not a plan for the project or ministry of agriculture
- a long term perspective, while ensuring that short term needs, e.g., immediate food needs, resource commitments are also taken into account

- even though with a strong learning element, the plan has to be "real", i.e., not just an experiment, but an opportunity to analyze the households' production and consumption systems
- allow and reward innovativeness
- enable farmers to see and understand what is going on at every stage with the chance to reflect on and share experiences,
- it is more than using new seeds, fertilizers or equipment, but a plan fundamentally about the way to farm

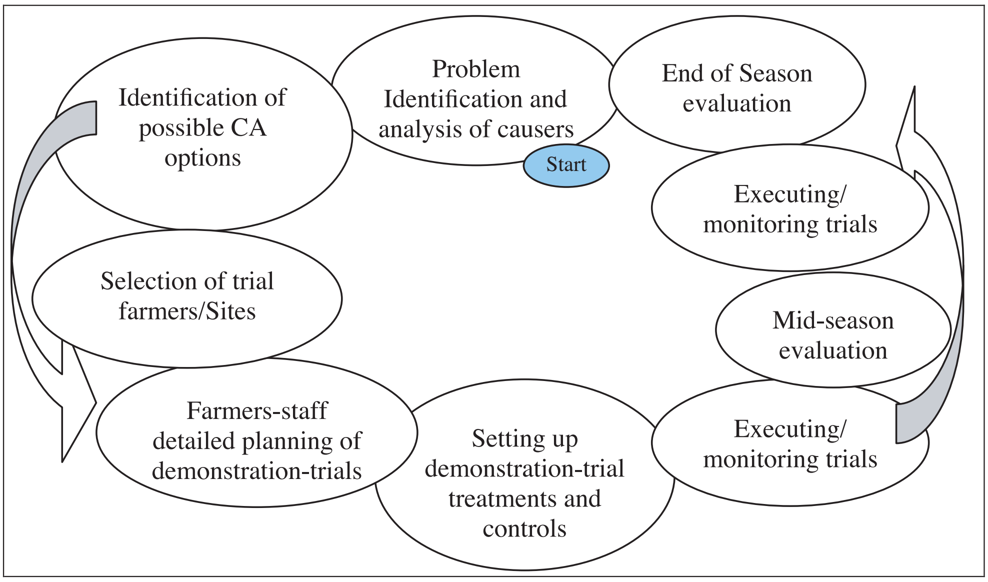


Figure 1: Conceptual framework for the dissemination of conservation tillage technologies

This whole process is induced through a learning curriculum built on the principles of social/self learning and experimentation. It embraces the self-learning principle and techniques as developed in the farmer field school approach. The learning curriculum allows a farmer group to strengthen its capacities to identify/analyse problems on natural resource management and adopt innovative solutions as part of an on-going learning process.

The curriculum is driven by farmers as an integral component in their own efforts to provide for their livelihood needs and address the growth agenda.

The approach as a whole is noted to positively impact on (i) technology adaptation and strengthening of local innovation chains, (ii) building social systems by which communities address issues of common interest especially issues such as natural resource management, and (iii) building social capital and memory support systems to scale up CA adoption.

In these circumstances, even the poorer and marginalised households find it feasible to participate in the process adaptation and finally adoption. The approach's success is also noted from its ability to allow farmers/households to identify problems/constraint progressing over time. Farmers learn to identify "entry points" – i.e. options presenting the least risks and highest possibilities for positive returns. Figure 2 illustrates this approach with the "transition phase" marking the most feasible entry point for many households.

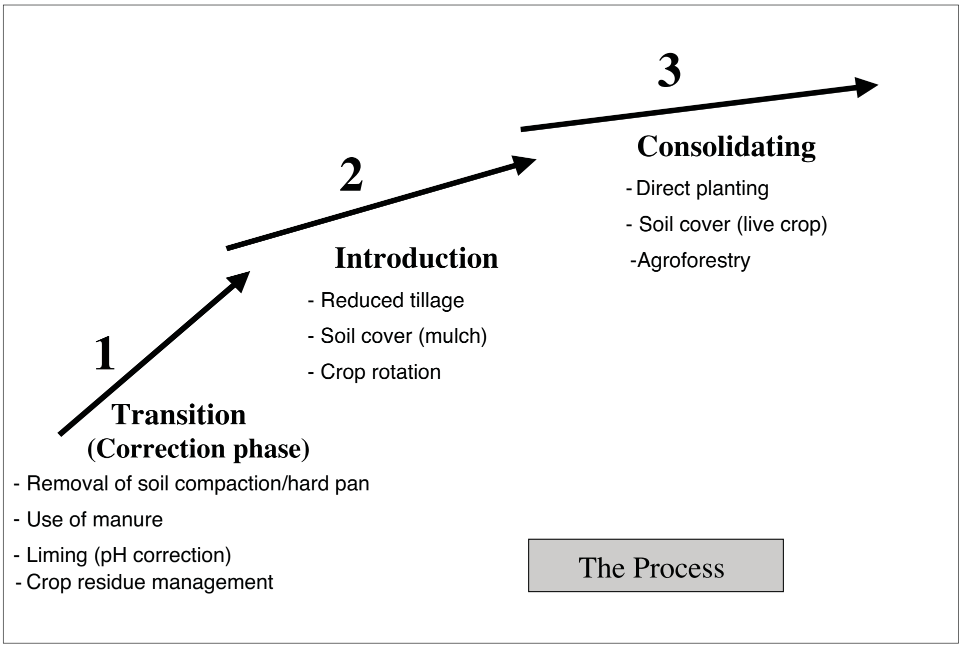


Figure 2: Progressive adoption of CA practices

A simple on-going Monitoring and Evaluation (M&E) process is a key component of the approach. It is clear that it is one thing to "effect" impact and another to "notice" the impact, let along capturing the lessons in the processes and activities that led to the impact realized. Key purpose of this M&E is three-fold, namely:

a. to identify and record (form and extent) effects/impact of the interventions with regard to (i) EFFECTS on soil quality/fertility and (ii) IMPACT on livelihoods (food security, incomes, etc…)

b. Noting and evaluating the dissemination approaches used: i.e. monitor and appraise the dissemination/extension approaches-techniques used

c. Capture lessons and evolving knowledge (and innovations) on both the CA practices and methodologies for dissemination: i.e. identify lessons and "new" knowledge resulting from the process of implementation of the project interventions. This reviews the reasons why something is working or not working based on methodologies/dissemination techniques used and technical options/practices being promoted.

The M&E process is also designed to:

a. Stimulate and facilitate social-self-learning, critical in enhancing innovations and adaptation of options, and

b. Motivate farmers by allowing them to follow through with experimentation of their own ideas

Table 1: Key parameters of the monitoring and evaluation (M&E) process

M&E Process	Parameters to be noted/established
Baseline exercise	1. Household and its context characteristics (family size, settlement patterns, livelihood status, food security, resources, interactions with world, etc…) 2. Agro-climate situation and trends (rainfall, temperature, soil, etc…) 3. Farming (crops, livestock, inputs-outputs, farm size, farm power, etc….) 4. Current CA/NRM practices – understanding (options, field sizes, crops, etc…
Main monitoring process (Technical)	1. Number of households practicing "what CA" options 2. Size of land/fields under what CA options 3. New knowledge/information among key players (farmers, private sector, policy makers, etc… 4. Effects/impact on soil quality (water holding capacity, soil structure, soil temperature, OM build-up, yields, etc… 5. Livelihood impacts (labour, incomes, food security – stability in supply, etc…
Main monitoring process (dissemination approaches)	1. Techniques and their influence/effectiveness on: - farmer participation - local ownership of "process" and "products" - farmer empowerment - technical capacities (skills and knowledge) in application of CA - capabilities in managing change/innovations

Roles and responsibilities for extension staff: Experience has also highlighted the place, roles and responsibilities of local extension staff/agents, especially in ensuring a relationship between them and other players built on trust and shared responsibility. This is usually more of a challenge to the extension staff who has mostly come up in conventional systems where "the extension staff knows and the farmer does not know". It is important that the extension staff recognises and embraces the values of facilitating and farmers being equally important to the solution and not just "the thing to be changed".

3. Networking in enhancing capacities for facilitating and support increased CA adoption

3.1 Networking in promotion of CA

Networking is a form of partnership that has proven useful and effective in rallying cross-sector, multi-discipline and cross boundary initiatives to consolidate synergies and complementarities. Networking enables players' access to information and knowledge gains in complementary initiatives.

Networking is driven by unit of purpose and shared goals and vision. Networking exploits key social values including cooperation, transparency and collectively responsibility. Cooperation is a fundamental aspect of community life (extended families) in Africa and underlines social interactions and responsibilities.

In the context of knowledge support on conservation agriculture, it becomes almost natural that networking will be a critical tool in enhancing the capacities of players and stakeholders promoting CA. Networking allows the players to concentrate on areas/aspects that have a comparative advantage and contributes in this aspect to a more holistic and integrated thrust with more results than would have been achieved from any of the players going it alone.

Networking in promoting CA underlines the fact that sustainable adoption of CA is not about agronomy, or mechanization, or financing/economics; it is not about soils or rain/water. It is all of these and many others coming together exploiting the synergies and complementarities.

3.2 The African Conservation Tillage Network and Networking in promotion CA

The African Conservation Tillage Network (ACT) is a membership network establishment on sustainable natural resource management in general, and conservation agriculture in particular. The primary purpose in establishing ACT was to stimulate and facilitate knowledge and information sharing among various stakeholders and players involved in promoting CA* to enhance their capacities and effectiveness in ultimately supporting widespread CA adoption at farmer level. The evolution of ACT highlights lessons on strategic cornerstones which present key lessons in building/supporting effective networking

Some of these cornerstones (lessons) include:

1. Consolidation of the unit of purpose and shared vision: The formal start of the ACT idea is attributed to an international workshop held in Harare, Zimbabwe in 1998 (Benites et.al. 1998). This workshop, in discussing means and strategies to enhance adoption of conservation agriculture practices/sustainable land management, provided the rallying point for a felt need on addressing the low and slow adoption of CA practices. The workshop exposed the need and underpinned a collective responsibility to the networking functions as decided in the establishment of ACT
2. Development of the "network niche", its "value addition" and "networking modalities": The decision to establish ACT was followed by extensive consultations and dialogue to determine and ground as realistically as possible key functions of the network with clarity on how such functions would respond to members' information and knowledge needs and ultimately adding value to the efforts to promote CA. The key question for this exercise was "why would someone want to be a member of ACT? what benefits would ACT membership offer?". Logistical issues and administration of the network, though given attention, were in this exercise not as important as defining the key values of the network and practical modalities by which ACT was going to facilitate and support NETWORKING.

Four result areas were identified as the basis for ACT's operational agenda. These are:

- Result 1: Information (and experiences) on conservation farming in Africa and other continents is collected, synthesized and made available to a wide range of users
- Result 2: Functional and sustainable mechanisms for network countries and beyond to learn/share information and experiences on CA practices and dissemination approaches were set in place
- Result 3: Practical cases of sustainable CF adoptions identified or facilitated and lessons on technical CA options/practices and dissemination approaches were captured
- Result 4: Private and NGO establishments involved in manufacturing and supply of farm inputs to increasingly address and support farmers' accessibility to relevant inputs and resources for CA adoption were identified and asked to cooperate

3. Defining sharing "platforms": While networking is feasible and useful among institutions/individuals within a single subject matter, networking on conservation agriculture inherently implies networking across varied sectors, disciplines, geographical boundaries, national and international initiatives, and between small and large initiatives. Therefore, for a platform to evolve and be useful, it has to facilitate sharing among all the players without any of them feeling like they are

just around to support the agenda of others, or left alone to be “swallowed” by the bigger, more influential initiatives or organisations. The platform has two dimensions, namely (i) the products to be shared, i.e., what form of information/knowledge and (ii) and clarity on the sharing modalities. It is important in this case that the sharing platform is NEUTRAL and LEVEL for all schools of thought and levels of experiences to participate.

As to the products, ACT clearly highlighted “conservation agriculture” as the central subject matter. With the varied understanding/interpretation, ACT restrained itself to the definition of guiding principles. This allowed many key mutually rewarding and deep discussions on both sides about the understanding of CA concepts and principles.

On the modalities for sharing, ACT identified various ones that reflected the target group. This included specialised training, field days and demonstrations, publications – soft and hard copies of posters, flyers, magazines, policy briefs and other materials meant to either simply create awareness or inform decision making.

4. Network membership and targeting: ACT was established as a voluntary membership association with anyone, individual or institution, ideally welcome to join as long as they subscribe and are committed to share and cooperate in the efforts to promote widespread adoption of conservation agriculture. However, even in this scenario, it is important to reflect on key members as this affects the “packaging” of products and sharing /dissemination modalities.

   In the case of ACT, the immediate target groups included mediators in the agriculture sector; in particular the following:

   - farmers’ associations and cooperatives
   - agricultural service providers and manufacturers
   - agricultural research and development institutions
   - local civic and traditional leaders, central/local government decision and policy makers
   - agricultural training and extension/advisory services (state, private sector and local, national and international NGO's)

5. One other issue central to establishing and management of a membership Network is FINANCING: ACT was initiated with 3-year Project financial support from the German Government, through GTZ. When in 2004 this Project support was extended for an additional 2 years, it was clear that ACT needed to resolve in a more sustainable manner the issue of financing especially for core secretariat expenses. In theory, the Network was expected to draw its funding significantly from membership fees. This for many reasons, remained the theory and un-realistic expectation.

   Therefore, ACT resolved to identify clear “Products” and “Services” which the Network would “sell” as a means to raise funds for its own operations. The Products and Services identified include (i) training in CA which ACT offers to various clients at a cost to the clients; others are (ii) Project management and implementation with an overhead cost (iii) consultancy services using expertise from its membership

   Whiles the Network is further developing these Products and Services including making them “attractive and worthwhile the money”, it is clear that this approach has enabled ACT develop

* The term Conservation Agriculture (CA) evolved only later. When founding ACT the term commonly used in South-Eastern Africa was Conservation Tillage.

into a neutral platform (not viewed as a Project of a particular donor) – a characteristic desirable for a membership network.

3.3 Challenges to networking in Africa

Challenges to networking in Africa are many and usually complex. Many of them are inherent in the institutional arrangements and relate to operational structures in those institutions. There are also challenges that are rooted in the attitudes of some people.

Some key ones include:

- Most often “Project” and various institutions’ desire to define their “own” label and visibility becomes an impairment to willingness, transparency and sometimes genuineness’ in engaging in networking

- institutionalized compartmentalization of the science and practice of agriculture

- in most especially public sector employment structures, networking is not recognized as part of the staff’s employment terms (often has to do networking outside formal work time)

- limitations/ inabilities to document experiences (into shareable information). This is the case for many local institutions including NGOs where technical record keeping and documentation is simply not a priority. Much of the reporting done is only linked to securing funding

- the fact that there are so many networks directly or indirectly related to CA in Africa is not a problem; the problem is that little effort is made at realizing and exploiting comparative advantage and synergies

- if a network has an agenda (a product to sell), this may compromise the principles of networking

References

Benites, J, Chuma E., Fowler, R., Kienzle J., Molapong, K., Manu J, Nyagumbo I., Steiner K. and van Veenhuizen R. (eds) 1998. Proceedings of an International Workshop. Conservation Tillage for Sustainable Agriculture. 22nd – 27th June 1998, Harare, Zimbabwe. Vol. I and II. GTZ Eschborn

Bwalya M. 20072. The KCTI-ACT Pilot Activity Project. Field Visit Report

Douthwaite B., 2002. Enabling innovation – a practical guide to understanding and fostering technological change, Zed books Ltd, London

Elwell, H.A., 1993. Development and adoption of conservation tillage practices in Zimbabwe. In: FAO Soils Bulletin, Vol. 69 pp129-164. Food and Agriculture Organization of the United Nations, Rome.

Hagmann, J., Murwira, K and Chuma, E., 1996. Learning together: Development and extension of Soil and Water Conservation in Zimbabwe. Quarterly J. of International Agriculture 35, 2, 142-162. April-June 1996

Hagmann, J., Chuma, E., Murwira, K, Connolly M, Ficarelli P. 2002. Success factors in integrated natural resource Management, R&D: lessons from practice. Conservation Ecology 5 (2): 29. [online] URL: http://www.consecol.org/vol5/iss2/art29

Hulme, D. .1991. Agricultural Extension Services as Machines: The Impact of the Training and Visit Approach. In Agricultural Extension: Worldwide Institutional Evolution and Forces for Change, eds W.M. Rivera & D.J. Gustafson. Elsevier, Amsterdam, pp. 219-30.

Nyagumbo I. 1998. Experiences with conservation tillage practices in Southern and Eastern Africa. In: Benites, J, Chuma E., Fowler, R., Kienzle J., Molapong, K., Manu J, Nyagumbo I., Steiner K. and van Veenhuizen R. (eds). Proceedings of an International Workshop. Conservation Tillage for Sustainable Agriculture. 22nd – 27th June, Harare, Zimbabwe, Vol. II. GTZ Eschborn

Oldrieve, B., 1993. "Conservation Farming for communal, small scale, resettlement and co-operative farmers of Zimbabwe: A farm management Handbook," Prestige Business Services (Pvt) Ltd.

Röling, N and Jong de, 1998. Learning: shifting paradigms in education and extension studies, Journal of Agric. Education and Extension (5) 3

Uphoff, N., 1992. Local Institutions and Participation for Sustainable Development, Gatekeepers series No. 31 IIED publications, UK

Whiteside, M., 1998. Living Farms, encouraging sustainable smallholders in Southern Africa, Earths Publications, London [on line] www.earthscan.co.uk

Is Conservation Agriculture an Option for Vulnerable Households in Southern Africa?

Lewis Hove and Steve Twomlow

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)

P O Box 776, Bulawayo, Zimbabwe
Correspondence: L.Hove@cgiar.org

Abstract

Working with non-governmental organization partners, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has been promoting a conservation agriculture package for use by smallholder farmers in semi-arid areas. Central to the package are planting basins, measuring approximately 15 cm long, 15 cm deep and 15cm wide. The basins are prepared during the dry season when demands on family labor are relatively low. They are dug without having to plough the field, thus overcoming shortages in draft animal power. Basin planting works on the principle that rather than spreading nutrients and water over the entire field, it concentrates these in the basins to maximize yield for a given level of inputs. The basins collect rainwater and ensure good germination and a healthy crop stand, even if rains are erratic. This technology is combined with other crop/soil management practices, such as the spreading of crop residues over the field to protect the topsoil against erosion, or with manure and/or fertilizer. The basin technology was evaluated under smallholder farmer management for two cropping seasons from 2004 to 2006 in dry areas of southern and western Zimbabwe. This paper builds on an initial report on the same program (Twomlow et al. 2006a). Compared to traditional planting practices, basins significantly increased maize grain yield across eight districts in the first season. In the second season, data from 435 farmers across 10 districts showed that basins gave higher maize grain yield and water-use efficiency compared to ploughing. Yield increases for districts ranged from 15 to 72% with a mean of 36%. The basins yield advantage was maintained regardless of the soil fertility amendment used. This technology has potential for adoption by smallholders despite the challenges farmers face with respect to labor for basin preparation and weed control, as well as achieving soil cover using crop residues.

Key words: Conservation agriculture; planting basins; smallholders; semi-arid; maize yields

Background

To improve crop production in marginal rainfall regions of southern Africa, cultural practices that conserve fragile soils (or at least prevent irreversible damage to soil structure and characteristics) and extend the period of water availability to the crop must be developed. Governments, non-governmental organizations (NGOs), and others have tried to develop improved genotypes, tillage/soil management systems, and integrated pest/disease management packages. Unfortunately, many of the outputs, although technically sound, failed to perform well in the field. They were developed and tested in researcher-managed trials, with only limited consideration to the problems and priorities of smallholder farmers – the targets of these technologies (Anderson, 1992; Twomlow et al., 2006b; Ryan and Spencer, 2001; Shiferaw and Bantilan, 2004).

Conservation agriculture may sound like old hat, but it is breathing new life into African smallholder farming (Haggblade and Tembo, 2003). Basically, conservation agriculture is a suite of land, water and crop management practices to improve productivity, profitability and sustainability (IIR and ACT, 2005). The primary principles promoted for hand-based and draft animal powered cropping systems include:

- disturbing the soil as little as possible,
- performing operations, particularly planting and weeding, on time,
- keeping the soil covered with crop residues or other organic materials as much as possible, and
- mixing and rotating crops.

Working with NGO partners and the Food and Agriculture Organization (FAO), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has been promoting an easy-to-implement conservation agriculture package – known as basin tillage – which is ideally suited to vulnerable smallholder farmers in drought-prone areas of southern Zimbabwe with limited to no draft animal power. This initiative builds on the seed and fertilizer relief programs in Zimbabwe and is supported by the United Kingdom's Department for International Development (DFID) Protracted Relief Program and the European Commission Humanitarian Aid Office (ECHO).

Basin tillage in southern Zimbabwe

The central component of the basin tillage package is the planting basin. Seeds are sown not along furrows, but in small basins or simple pits. These basins can be dug with hand hoes without having to plow the field which is important given that the majority of smallholder farmers in southern Africa struggle to cultivate their fields in a timely manner due to a lack of draft animals. The initial basin tillage concept was developed by Oldrieve (1993) in Zimbabwe in the late 1980s, and was subsequently modified and promoted in Zambia by the Zambian Farmers Union Conservation Farming Unit, and also modified by the Zimbabwean Conservation Agriculture Task Force convened by FAO for southern Zimbabwe.

In southern Zimbabwe it is recommended that the planting basins be dug each year from early August through October in the same positions. The recommended dimension of each basin is 15 cm (length) x 15 cm (width) x 15 cm (depth) and the basins are spaced at 90 cm x 60 cm. Available soil fertility amendments (organic and/or inorganic fertilizers) are then added to each basin which is then lightly covered with soil in September/October. Rain water is collected in the basins during the early season rainfall events (October and November). Planting follows in November/December after the basins have captured rain water at least once. Smallholder farmers without draft power can plant at the right time in terms of days after an effective rainfall event (30 mm for sandy soils and more than 50 mm for heavier soils), rather than waiting for draft animals to become available several weeks into the season. In addition, farmers are encouraged to spread any crop residues that might be available as a surface mulch to protect against soil losses early in the season, conserve moisture later in the season, and enrich the soil with nutrients and organic matter as the residues decompose.

Gains to vulnerable households

The basin tillage technology was field tested in the 2004/05 and 2005/06 seasons, and despite initial concerns as to whether or not farmers would invest in the labor needed, first for basin preparation and then for the additional weed control (an essential part of the package) associated with reduced tillage systems, the results were extremely positive (Figures 1 and 2). Although making the basins requires time and effort, once prepared, the same planting position can be used repeatedly. With each successive season preparing the basins and weeding should become easier.

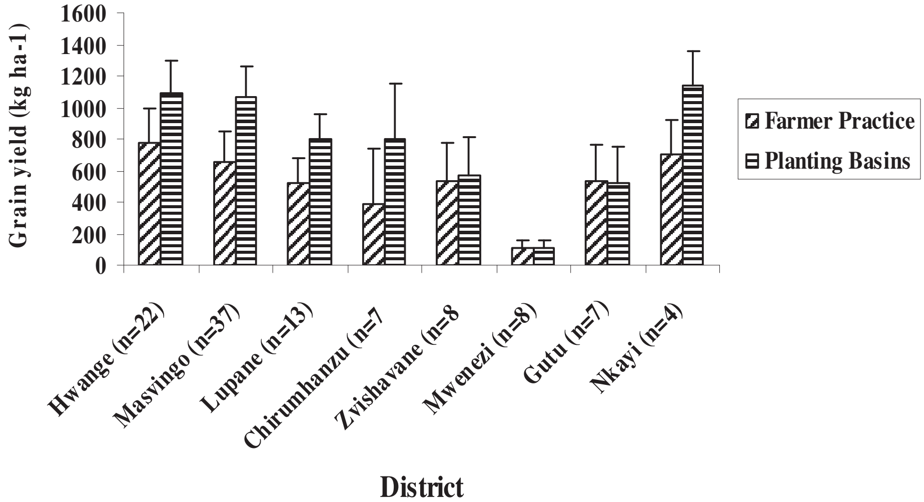


Figure 1: Maize yield responses to basin tillage compared to conventional farmer practice across eight districts in southern Zimbabwe in 2004/05.

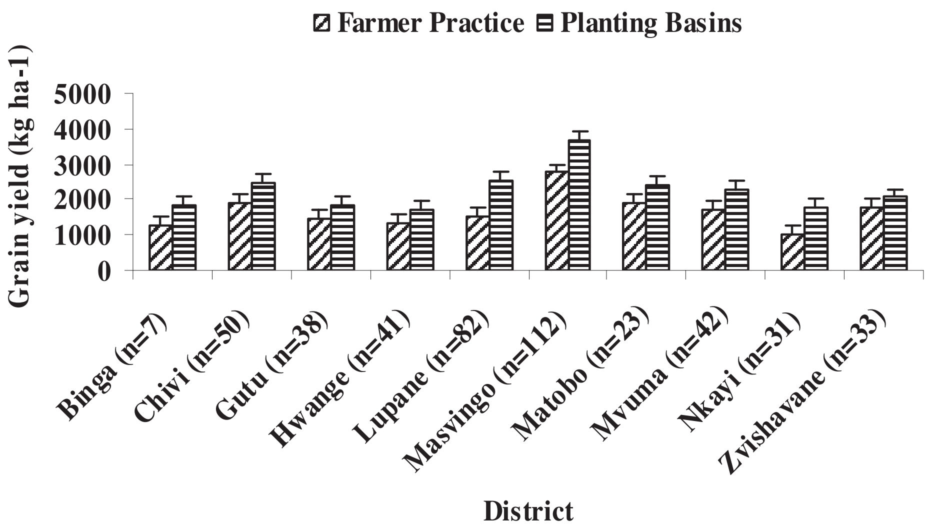


Figure 2: Maize yield responses to basin tillage compared to conventional farmer practice across 10 districts in southern Zimbabwe in 2005/06.

It is particularly remarkable that basin tillage benefits accrued to almost all the farmers applying this technology. Usually there are leaders and laggards in technology adoption. Often technologies are initially applied by only a subset of better-than-average farmers. It is well known that crop response to basin tillage depends on the timely application of complementary practices such as planting, weeding, fertilizer application, as well as the starting quality of soils and incidence of diseases and pests. Yet a wide range of farmers obtained significant yield gains from basin tillage that this technology appears remarkably robust, with positive yield increases observed in both below average (Figure 1) and above average rainfall seasons (Figure 2).

Failures observed during the 2004/05 season in Mwenezi and Zvishavane (Figure 1) were attributed to agriculturally inexperienced NGO headquarters and field staff, various logistical problems that led to delays in training, the late arrival of inputs, and fewer monitoring support visits than planned. One typical result of these problems was that over-eager and inexperienced NGO staff rushed the training, with basin preparation and planting in some instances occurring on the same day. In fact, germination and plant vigor were observed to be poorer in basins prepared and planted on the same day compared with the farmer practice.

The important elements of the package

Impact of mulch

Figure 3 clearly shows the additional yield benefits that accrue from mulching even in a wet year such as 2005/06. However, it is still questionable how much mulch farmers will retain on their fields, given that a major source of household income in these mixed crop/livestock systems is from the sale of goats and sheep.

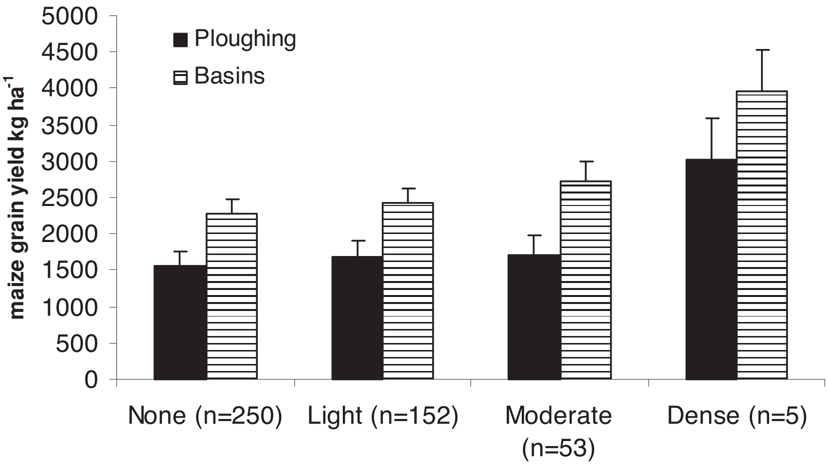


Figure 3: The impact of mulch cover of various levels on maize yield in response to basin tillage compared with conventional spring plowing for 11 districts in southern Zimbabwe in the 2005/06 season. Light – less than 1 t/ha, moderate – 3 t/ha (the target), and dense – more than 3 t/ha.

Impact of fertilizer amendments on maize yield responses

The impact of basal and top dressing fertility management regimes on maize grain yield responses to basin tillage and conventional spring plowing are summarized in Figure 4.

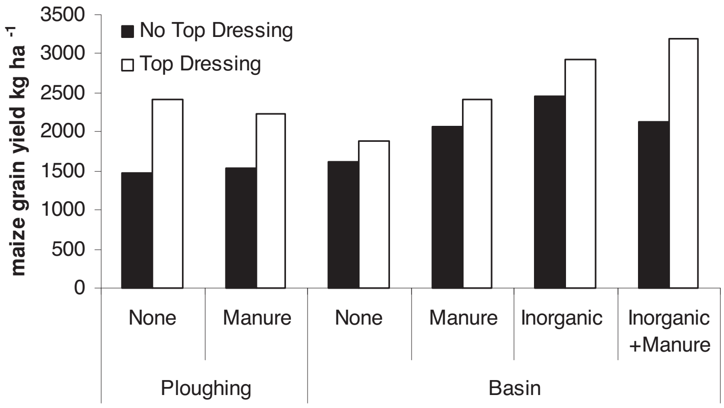


Figure 4: The impact of basal and top dressing fertilizer regimes on maize grain yield responses to basin tillage compared with conventional spring plowing for 11 districts in southern Zimbabwe in the 2005/06 season.

There is a strong synergistic effect between the type of basal fertilizer, top dressing and tillage system. Without any form of basal fertility amendments the basin tillage systems performed only slightly better than the farmers' conventional spring plowing – 1621 kg/ha compared to 1476 kg/ha. However, from Figure 4 it is clear that when farmers have access to a combination of manure and inorganic fertilizers, particularly inorganic fertilizer for top dressing, then significant grain yields can be achieved. Top dressing with inorganic nitrogen fertilizer increased yields by more than 30%. Thus, for smallholder farmers to derive long-term yield benefits from the basin tillage technique beyond the current relief and recovery programs, additional investment will be required to ensure that smallholder farmers have access to inorganic fertilizers locally, particularly inorganic nitrogen-based fertilizers for top dressing.

Sustained gains in food security from Conservation Agriculture

Figure 5 highlights the gains likely to be achieved if farmers continue to pursue basin tillage from 2006 to 2015. The initial data series summarizes the expected yield when farmers apply no fertilizer – the common current practice in semi-arid areas of the country. The second series highlights the gains achievable with sustained use of the full basin package. Basin tillage offers an opportunity for poor vulnerable households with no access to draft power to produce more grain per unit area than households with full draft power in the drier areas of Zimbabwe.

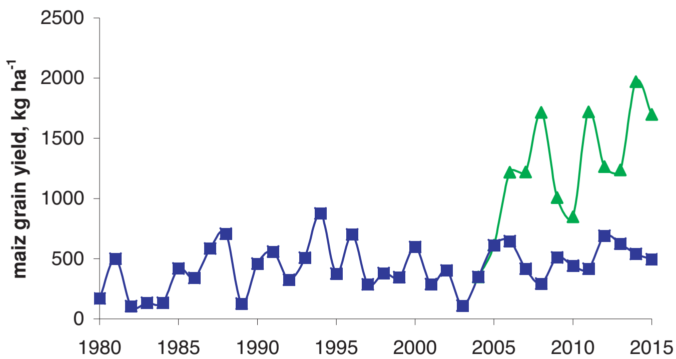


Figure 5: Maize grain yields obtainable in drought-prone, semi-arid parts of Zimbabwe with and without basin tillage technology, based on crop modeling confirmed by farmer-managed demonstration trials, 1980–2015.

If the use of small quantities of inorganic fertilizers can be sustained after the relief programs stop handing out free fertilizer, these farmers can achieve a sustained set of higher grain yields and a sustained improvement in food security. Even if severe drought occurs (e.g., in the upcoming 2006/07 cropping season) farmers will be better off than in previous drought years. If rains are more favorable, farmers, and the country as a whole, will be appreciably better off.

Next Steps

Conservation farming using basin tillage is a proven technology. However, one concern is that these gains will quickly be lost when the protracted relief programs end. Some of the questions and concerns to be addressed over the next two to three years include:

- Is the area under conservation agriculture changing - what are the factors responsible for the change?
- What will happen when NGOs withdraw their assistance?
- How can the role of the national research and extension department (AREX) be enhanced for sustainable adoption of conservation agriculture?
- How can the private sector participate in the promotion of CA?
- Is there evidence of declining weed pressure?
- Will labor demands decline over time?
- How do farmers rotate and mix crops in the dry areas, and what are the impacts of such conservation agriculture practices?
- What are the changes in soil chemical, biological and physical properties – is there opportunity for carbon trading?
- Undertake case studies of conservation agriculture successes.
- Revise training materials – AREX must be facilitated to own the process.
- Conduct detailed simulation work to look at climatic risk and long-term benefits.

References

Anderson JR (1992). Difficulties in African agricultural systems enhancement? Ten hypotheses. Agricultural System 38: 387-409.

Haggblade S and Tembo G (2003). Conservation Farming in Zambia. Conference Paper No. 11. Paper presented at the InWEnt, IFPRI, NEPAD, and CTA conference “Successes in African Agriculture” Pretoria December 1-3, 2003. pp18.

IIR and ACT (2005). Conservation agriculture: A manual for farmers and extension workers in Africa. International Institute for Rural Reconstruction, Nairobi; African Conservation Tillage Network, Harare. 250pp.

Oldrieve B (1993). Conservation farming for small-scale resettlement and co-operative farmers of Zimbabwe. A farm management handbook. Rio Tinto Foundation, Harare, Zimbabwe

Ryan JG and Spencer DC (2001). Future challenges and opportunities for agricultural R&D in the semi-arid tropics. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 83 pp.

Shiferaw B. and Bantilan C. (2004) Rural poverty and natural resource management in less- favored areas: revisiting challenges and conceptual issues. Journal of Food, Agriculture and Environment 2: 328-339.

Twomlow S, Rohrbach D, Hove L, Mupangwa W, Mashingaidze N, Moyo M and Chiroro C (2006a). Conservation farming by basins breathes new life into smallholder farmers in Zimbabwe. Paper presented at the SADC Land and Water Management Scientific Symposium 'Land And Water Management For Sustainable Agriculture". 14 – 16 February 2006 in Lilongwe, Malawi.

Twomlow, S.J., Steyn, T. And du Preez, C.C., (2006b). Dryland farming in Southern Africa. Chapter 19. In: Peterson, G.A., Unger, P.W. and Payne, W.A. (Editors). Dryland Agriculture. Agronomy Monograph No.23 Second Edition. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, Wisconsin. 769-836.

From Conventional Agriculture to Conservation Agriculture

AbdelAziz Ben Hammouda[1]
and Riadh Ben Hammouda[2]
1, 2 Father & son, two farmers in the south-zone of Mateur
Corresponding author: abdelaziz_bh@yahoo.fr

Abstract

The size of the farm is 257 ha, with 25 % of the land for pasture to feed essentially cattle. The farm is located 21 km south of Mateur in the Governorate of Bizerte, a northern region of Tunisia where the average annual rain-fall is 450 mm. Most of the land is on a heavy slope (slope ~ 20 %) which generated serious erosion and enormous difficulties to use machinery for soil preparation.

Looking for an alternative to conventional agriculture, and after a field visit in 1999/00 of the 'Centre Technique des Céréales' head and a representative of SEMEATO [Brazilian firm specialized in direct sowing (sowing on a mulch/cover-crop) drills], a preliminary experiment was conducted over only 5 ha field. A local durum wheat variety was sown on residues of a 2 years Sulla. Result was positive with a yield 25 % higher than the average of farm yield. In addition, no new traces of erosion were observed on the tested field. Moreover, small galleys were no more visible. Consequently, direct drilling (DD) was adopted, and 25 ha and 50 ha were cropped in DD in 00/01 and 01/02, respectively. After 3 years of experimentation, DD was totally practiced over the whole farm, using only 1 SEMEATO drill of 3 m width.

Rotations such as: i) durum-wheat/oat, ii) triticale/sulla, iii) triticale/faba-bean, and iv) triticale/fenugreek, generated good profit regarding: i) production cost (decrease of machinery cost by 20 % and fuel use by 26 %), ii) soil (organic matter rate jumped from 1.7 % in 99/00 to 4.1 % in 05/06), iii) yield (grain yield increased by 12 % with gain of 2 units and 3 units for grain volume-weight and weight of 1000 grains, respectively), and iv) environment (no more galleys and erosion, decrease of pesticide use to dose, soil recovery through an active 'microbial pump' essentially of warms.

Key words: Farm, Conventional agriculture, Conservation agriculture, Direct drilling, Rotations.

Private Sector Involvement in the Diffusion of Direct Drilling

Abdelhak El-Khorchani

Experience of Société Cotugrain

Head of the Département des Grandes Cultures
Corresponding author: makhorium@yahoo.fr

Abstract

The private sector, eventually by supplying equipment, is able to play a major role in the transfer and the diffusion of direct drilling (DD). Import of specialized drills, either sold or rented to farmers, could be of great benefit for all actors. Therefore, the Tunisian case of the Société COTUGRAIN (S/C) may be an instructive example.

As a part of its commercial activity, the S/C took the lead in the import of a specialized drill from SEMEATO, a Brazilian firm known to be an international leader in DD equipment. The SEMEATO drill (S/D) appeared to be the most adapted to Tunisian soils and climate. Different models were introduced to meet special needs for a variety of agronomic scenarios. At the present time, 70 % of the total drill number in Tunisia is of SEMEATO model.

To better promote DD, the S/C was the first drill supplier to set up field experiments at large scale farms of cereal producers. Moreover, free use of drill was offered to small farmers willing to test DD. The S/C reserved 2 drills for rent to farmers willing to test a little more DD and those convinced but still unable to buy a personnel drill.

In addition to drill supply, the S/C offered a:

i) post sale service

ii) technical advisory

iii) up-dated technical documentation, and

iv) an annual national field day of DD. This kind of assistance is mostly done for cereal producers, making 80 % of the total cropped area sown with S/D.

Key words: Tunisia, Private sector, Direct drilling, SEMEATO drill, Diffusion.

Annexes

Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas

Workshop program; 7 - 9, May, 2007

Day 1: 7 May, 2007

08:00-08:45 **Registration**
08:45-09:45 **Opening**
09:45-10:00 **Coffee break**

10:00-12:50 **Session 1: Introduction to Conservation Agriculture (CA)**
Chairman: *Algelani Abdelgawad;* ***Reporter:*** *Ali Darwich*

10:00-10:30 "CA in the Arab Region Between Concept and Application"
Speaker: Abdelouahab Belloum (LWU - ACSAD)

10:30-11:00 "Conservation Agriculture: Impact on Farmers' Livelihoods, Labour, Mechanization and Equipment"
Speaker: Theodor Friedrich (AGPC - FAO)

11:00-11:30 "Direct Drilling; An Agro-Environmental Approach to Prevent Land Degradation and Sustain Production"
Speaker: Moncef Ben-Hammouda (ESAK - Tunisia)

11:30-11:50 **Coffee break**

11:50-12:20 "Crop Rotations Role in Conservation Agriculture"
Speaker: A. Fares *Asfary (LWU - ACSAD)*

12:20-12:50 "Weed Management in Conservation Agriculture for Sustainable Crop Production"
Speaker: Wilfred L. Mariki (SARI – Tanzania)

12:50-14:00 **Lunch break**

14:00-17:30 **Session 2: CA impact on the environment**
Chairman: *Theodor Friedrich;* ***Reporter:*** *Abderrahim Loulou*

14:00-14:30 "Water Conservation and Water Use Efficiency in Dry lands"
Speaker: Bob Stewart (DAI /W T. A&M Uni. –USA)

14:30-14:50 "Crop Roots and Water Use Efficiency in Conservation Versus Conventional Agriculture in Dry Lands"
Speaker: Ammar Wahbi (Aleppo Uni. – Syria)

14:50-15:20 "Lasting Benefits from No-Tillage Systems: Erosion Control and Soil Carbon Sequestration"
Speaker: Rachid Mrabet *(INRA – Morocco)*

15:20-15:40 Coffee break

15:40-16:10 "Soil Biology as an Essential Component of CA, with Particular Reference to Mycorrhizas and Nodulation in Dry Areas"
Speaker: Janet Sprent *(Dundee Uni. – UK)*

16:10-16:30 "Impact of Conservation Agriculture on Soil Fertility in Dry Regions"
Speaker: Isam Bashour *(AUB – Lebanon)*

16:30-17:30 POSTER PRESENTATIONS

1- "Soil Management and Soil Erosion"
Presenter: Sideris P. Theocharopoulos *(NAGREF – Greece)*

2- "Tillage Management to Reduce Soil Erosion on Hilly Olive Orchards Northwest Syria"
Presenter: Zuhair Masri *(IWLMP – ICARDA)*

Day 2: 8 May, 2007

08:30-11:25 Session 3a: CA in dry lands: A global overview
Chairman: *Sami Sabri;* ***Reporter:*** *Kurt Steiner*

08:30-09:00 "CA as an Innovation Process: Lessons from International Experiences and Implications for Conceiving CA Programs and Projects"
Speaker: Rabah Lahmar *(CIRAD – France)*

09:00-09:20 "Experiences with Conservation Agriculture in Semiarid Regions of the USA"
Speaker: Bob Stewart *(DAI /Uni.T&A –USA)*

09:20-09:40 "Evaluation of Conservation Agriculture Technology in Mediterranean Agricultural Systems"
Speaker: Cantero-Martinez C. *(CIHEAM – Saragossa - Spain)*

09:40-10:10 "Challenges and Opportunities for Conservation Cropping: ICARDA Experience in Dry Areas"
Speaker: Mustafa Pala *(DSIPS – ICARDA)*

10:10-10:25 "Conservation Agriculture Practices in the Dry Areas in Turkey"
Speaker: Engin Çakir *(ISTRO / Ege Uni. - Turkey)*

10:25-10:45 Coffee break

10:45-11:00 Video film on "International Implementation of CA; SEMEATO Experience"
Presenter: Didier Mealares *(Semeato Company –Brazil/Europe)*

11:00-13:05 Session 3b: CA in dry lands: Overview in Arab countries
Chairman: *Moncef Ben-Hammouda;* ***Reporter:*** *Ayman Al-Ouda*

11:00-11:30 "Zero Tillage, a Technology to Improve Yield, Farmers' Livelihood and Conserve Resources Towards Sustainable Agricultural Production (AAAID Experience)"
Speaker: Nashwan A. Abdulrazak (AAAID – Sudan)

11:30-11:50 "Direct Drilling Experience in Northern Tunisia"
Speaker: Khelifa M'Hedhbi (CTC – Tunisia)

11:50-12:10 "Conservation Agriculture in Morocco: A research review ﷲ
Speaker: Rachid Mrabet (INRA – Morocco)

12:10-12:30 "CA Experience in Algeria"
Speaker: Hamena Bouzerzour (Setif Uni. – Algeria)

12:30-12:50 "CA Experience in Syria"
Speaker: Afif Ghonaim *(GCSAR – Syria)*

12:50-13:15 **General Discussion**

13:15-14:30 Lunch break

14:30-17:30 Session 4: CA Potential in the Arab Region
Chairman: *Rachid Mrabet;* ***Reporter:*** *Mahmoud Sabbouh*

14:30-14:50 "The Role of Improved Regional Cultural Practices in the Implementation of CA in Arab Countries"
Speaker: Dr. Ayman Al-Ouda (PR-ACSAD)

14:50-15:10 "Impact of Direct Drilling on Soil Properties and on Wheat and Lentil Yields in Dry Areas (Northern Syria)"
Speaker: Ammar Wahbi (Aleppo Uni.-Syria)

15:10-16:10 POSTER PRESENTATIONS

1- "Effect of Subsurface Cultivation, and Organic and Inorganic Surface and Subsurface Fertilization on Organic Matter Decomposition, Soil Moisture Characteristics and Irrigated Wheat Production"
Presenter: Omar Abdurazzak (Al-Furat Uní.- Syria)

2- "Crop Rotations and Measures for Soil Conservation in Palestine"
Presenter: Raed W. Al Aghbar (MA – Palestine)

3- "The Impact of Soil Physical Properties on Its Productivity"
Presenter: Kadri Fouad Zaghloul (Cairo Uni. – Egypt)

16:10-17:30 General discussion on Machinery
Moderator: *Theodor Friedrich*

Day 3: 9 May, 2007

08:30-10:30 Session 4: Continues

08:30-08:50 "Application of Sustainable Agriculture Principles to Control Weeds"
Speaker: Hani Ghosha (J Uni.ST - Jordan)

0850-09:10	"The Use of Forage Plants in Landscape and Soil Conservation in Dry Areas" *Speaker: Ghofran Kattash (PR – ACSAD)*
09:10-10:10	**Discussion: Weed Management and Crop livestock interaction** ***Moderator:*** *Wilfred Mariki*
10:10-10:30	**Coffee break**
10:30-13:00	**Session 5: Joining efforts: Scientists, farmers and investors** ***Chairman:*** *Ali Darwish;* ***Reporter:*** *Abdelouahab Belloum*
10:30-11:00	"Farmer Participation in the Development of CA Technologies" *Speaker: Kurt Steiner (Consultant – GTZ- Germany)*
11:00-11:30	"Is Conservation Agriculture an Option for Vulnerable Households in Southern Africa?" *Speaker: Lewis Hove (CAP – ICRISAT)*
11:30-11:50	" From Conventional Agriculture to Conservation Agriculture" *Speaker: Abdelaziz Benhamouda (CA farmer – Tunisia)*
11:50-12:15	"Private Sector Role in the implementation of direct Drilling in Tunisia" *Presenter: Abdelhak Elkhorchani (COTUGRAIN Company- Tunisia)*
12:15 -13:00	**Discussion**
13:00-14:15	**Lunch break**
14:15-15:15	**Discussion: Conservation Agriculture in the context of the UNCCD.** ***Moderator:*** *Kurt Steiner* - To what extent can Conservation Agriculture contribute to the implementation of the UNCCD? - Does the UNCCD provide a frame for fostering the dissemination of Conservation Agriculture practices??
15:15- 15:30	**Coffee break**
15:30-16:30	**Discussion: How to ease exchange of information and experiences** ***Moderators:*** *Kurt Steiner* ***&*** *A. Fares Asfary* - The role of stake holders in Arab Countries? - ACSAD role in facilitating regional networking?
16:30-17:00	**Closing session** ***Moderato :*** *A. Fares Asfary* **- GTZ representative** **- FAO representative** **- ACSAD representative** **- Organising committee representative**

Checklist for Discussions

Day 2: Machinery + General Constraints to Adoption of CA Practices

- Access to implements
- Quality aspects – solidness, precision of seed placement, ease of calibration
- High prices of CA seeders
  - Solutions to high price: multi-farm use /service providers
- Supportive government measures
- Constraints realised or felt by farmers

Day 3: Weed Management and Crop/Livestock Interaction

- Role of cover crops and crop rotations as part of weed control measures
- Prevention of seed production (all year round weed control even after harvest)
- Development of resistance to certain herbicides- selection of resistant species
- How to achieve a sufficient groundcover (> 30%) in mixed farming systems
- How to control grazing on individual farms and on a community level
- Growing of forage crops to meet demand in quantity and quality

Day 3: CA and UNCCD

- Can CA prevent desertification?
- Inclusion of the promotion of CA in the National Action Plans (NAP) of the UNCCD
- Can the UNCCD help to create the favourable frame conditions required for a widespread adoption of CA practices?
- What could /should national government do to promote CA?
- How could conducive policies look alike?

Exchange of information and experiences

- Who needs better access to information and experiences of other Arab countries?
- What possibilities of information exchange exist already?
- How could the exchange be improved?
- Could a regional network be the answer?
- How should the network be structured, who should be member of such a network?
- Informal or formal network, network with or without central secretariat?
- Which institution could host a network secretariat?
- Funding a network secretariat
- Geographical coverage: Arab countries only; Mediterranean countries; North African/Near East branch of the African Conservation Tillage Network (ACT)

List of Participations in the Workshop on Conservation Agriculture for Sustainable land management to improve the livelihood of people in Dry Areas 7-9/5/2007

Name	Position	Organization	Address	Telephone	Fax	E-mail
Ali Darwich	**Representative** of GTZ	**GTZ / RO**	Beirut -Lebanon	00961 (0) 1 849 644	00961 (0) 1 849 644	**CODEL@inco.com.lb**
Kurt Steiner	**Consultant** Sustainable Land management	**GTZ**	Goethestr.7 69250 Schönau/ Germany	+49-6228-8457	49-6228-911386	**landconsult@kurtsteiner.de**
Theodor Friedrich	**Senior** Officer; Crop Production Systems Intensification	**FAO/** Crop and Grassland Service (AGPC)	Viale delle Terme di Caracalla, 00153 Rome - Italy	+39-065705 -5694	+39-065705-6798	**Theodor.Friedrich@fao.org**
Fawzi A. Taher	**Officer**, Crop production &Protection	**FAO/SEC**	Ivedik cad N. 55 06170, Yenimahalle, Ankara-Turkey	90-312 307 9509/ 327 1762		**Fawzi.Taher@fao.org**
Ahmad Ali Ghosn	**Officer,** Natural resources program & Regional coordinator for **UNCCD**	**UNEP/SRAP-WA**	Manama -Bahrain	973 178 12 777	973 178 25 110	**Ahmad.ghosn@unep.org.bh**
Nashwan A. Abdulrazak	**Head**, Division of Applied Agricultural Research	Arab Authority for Agricultural Investment and Development **(AAAID)**	P O Box:2102 Khartoum, Sudan	00249 (1) 83780777	+ 83772600 or + 83798405	**nashwan@aaaid.org**
Omar M. E. Marzoug	**Agronomy expert**	**AAAID**	P O Box:2102 Khartoum, Sudan	00249 (1) 83780777	+ 83772600 or + 83798405	**Yamarzoug1@hotmail.com**
Ali Shada	**Agriculture expert**	**AAAID**	P.O.Box: 35595 Syria	963 11 22 39 587	223 86 85	**alisheahadeh@mail.sy**

CA workshop 7-9/5/2007 T: LH☺

Abdelouahab Belloum	**Coordinator CA project Water uses expert**	**ACSAD**	P.O.Box: 2440 Syria- Damascus	O963-11- 574 3039/ 5743087	0963-11-574 30 63	**belloum_a@yahoo.fr , a-belloum@acsad.org**
A. Fares Asfary	**Soil fertility expert Soil Dept.**					**fasfary@acsad.org, fasfary@scs-net.org, fasfary@postmaster.co.uk**
Khaled BenMahmoud	**Head, Soil Dept. Soil pedology expert**					**k.benmahmoud@acsad.org**
Omar Jouzdan	**Research associate Soil Dept.**					**o-jouzdan@acsad.org**
Gofran Kattach	**Rangeland expert Plant Dept.**					**g-kattach@acsad.org**
Ayman Al- Ouda	**Plant physiologist Plant Dept.**					**iman@acsad.org**
Mahmoud Sabbouh	**Cereal breeder Plant Dept.**					**m-sabbouh@acsad.org**
Gilani Abdelgawad	**Soil Chem. &Water quality expert Soil Dept.**					**abdelgaw@acsad.org, abdelgaw@scs-net.org**
Sami Sabry	**Head, Plant Dept. Plant breeder & Genetics expert**					**s-sabry@acsad.org**
Wadid Erian	**Head, RS & GIS unit Soil expert**					**erian@acsad.org**
Richard Thomas	**Program Director Soil expert**	**ICARDA**	P.O.Box 5466 Aleppo, Syria	21-22 13 433	21-22 13 490	**r.thomas@cgiar.org**
Mustafa Pala	**Senior Cropping Systems Agronomist,**	**ICARDA, Diversification and Sustainable Intensification of Production Systems Project (DSIPS)**	P.O.Box 5466 Aleppo – Syria	21-22 13 433	21-22-13- 490	**m.pala@cgiar.org**
Zuhair Masri	**Research associate**	**ICARDA**	P.O.Box 5466 Aleppo, Syria	21-22 13 433	21-22 13 490	**z.masri@cgiar.org**
Janet Sprent	**Professor Emiratus in Biology**	**University of Dundee**	32 Birkhill rue, wormit, fife dd, 8PW	44 1382 541706	44 1382 542989	**Jisprent@aol.com**

			Scotland UK			
Boby.A. Stewart	**Director Dry land Agriculture Institute**	**West Texas, A&M University**	WTAMU, Box 60278, Canyon, Texas, USA, 79016			bstewart@mail.wtamu.edu
Sideris P. Theocharopoulos	**Director, Soil Science Institute of Athens**	**NAGREF**	I.S. Venizelon STR. 14123 Athens-Greece	+30 210 28 19 059	30 210 28 42 129	**Sid_Theo@nagref.gr**
Lewis Hove	**Postdoctoral fellow**	**ICRISAT/ Zimbabwe**	PO Box 776, Bulawayo-Zimbabwe	263 83 83 11	263 838 307	**l.hove@cgiar.org**
Wilfred Mariki	**Senior agriculture research officer**	**Selian Agriculture Research Institute,**	P.O. Box 6024 Arusha, TANZANIA	+255 744 888 563 Mobile: +255 744 888563		wlmariki@yahoo.com wmariki@sari.co.tz
Isam Bashour	**Professor, Soil fertility**	**American University of Beirut (AUB)**	Beirut -Lebanon	961 3 247 820	9611 744 460	**ib02@aub.edu.lb**
Rachid Mrabet	**Research director**	**INRA** National Institute of Agricultural Research	Regional Agricultural Research Center of Meknes P.O. Box578, Meknes 50000 Morocco	212 35 300243	212 35 300 244	rachidmrabet@yahoo.co.uk Mrabet_Rachid@hotmail.com
Rabah Lahmar	**Researcher**	**CIRAD Dpt. Persyst UMR System**	SupAgro, Bâtiment 272, place Viala 34060 Montpellier, France	+33 4 99 61 21 54	+33 4 99 61 30 34	Rabah.lahmar@cirad.fr
Jalel El Faleh	**FAO Program director**	**Minestry of Agric.**	Tunis -Tunisia	00216 98 510 736	00216 71 793 692	**Jalelf@yahoo.fr**
Med Adel Ghariani	**General Manager**	**Cotugrain Company**	Z.I. Saint Gobain, Magrine 2014, Tunis -Tunisia	00216 71 426 313	00216 71 426 644	cotugrain@gnet.tn
Med Abdelhak Khorchani	**Agronomist**	**Cotugrain Company**	Z.I. Saint Gobain, Magrine 2014,	00216 23 426 610	00216 71 4266 44	**makhorium@gmail.com**

Didier Mealares	**Europe and Arab countries manager**	**SEMEATO Company**	Lyon - France	+33 680 66 422 9		**Didier.mealares@semeato.com.br** , **dmealares@hotmail.com**
Moncef Ben-Hammouda	**Coordinator/Research Development Program on Direct Drilling**	**ESAK/Tunisia**	Tunis - Tunisia	00216 78 23 805 Mobile: 00-216-98531220	Tel/Fax: 00-216-78238038 / 78238338 / 78238035	**benhammouda.moncef@ iresa.agrinet.tn**
Abdelaziz Benhamouda	**CA. Farmer**	**Private Farmer**	4 Drive Procope, Carthage-Hannibal 2016, Tunisia	00-216.712 76 708		**abdelaziz_bh@yahoo.fr**
Khelifa M'hedhbi	**Director general**	**Center Techniques des Cereales**	B.P. 120, 8170 Bou Salem Tunisia	+216 78 602 964	+216 78 602 966	**Ct.Cereales@planet.tn**
Kadry Fouad zaghloul	**Head, Soil dept.**	**Faculty of Agric. Cairo University**		002010 75 69 50	00277 45 722	**Kfzaghloul@yahoo.com**
Izzat taha	**Research**	**Notational Center for Research**	P.O.Box 2404	+24 99 123 60 470	+249 183 77 070 1	**izattaha@yahoo.com**
Aljardy Ahmed	**Soil physist**	**Albaath University Fa. Agricultural**	Homs- Syria	031 214 71 63	031 211 58 28	**Agc.Fuc@scs-net.org**
Mouktar Ahmad Mouktar	**General Director**		Sudan	0912200222		**mukhtarahmed_2500@yahoo.com**
Radhouene Ben Belhey Bejaoui	**General Director**	**Private CA Ag-Company**	Menzel Bourguiba Tunisia	00-216-98440105	00-216-72466155	
Samir Ben Bechir Bouhali	**CA Farmer**	**Private Farm**	Tinja-Tunisia	00216- 98 273 201	00216-72466155	
Ella shiningayamwe	**Research trainee from Namibia**	**Aleppo university**	Aleppo – Syria	0933431453		**eshiningayamwe@yahoo.com**
Saa'd Mozher	**Head, Agric. Engin. Syndicate**	**Agriculture Engineers Union**	Baghdad - Iraq	07901827255		
Mahmoud El asker	**Head department of soil**	**Univiesity Elfurat**	Dier Ezzor – Syria	051 – 36 8442	051- 223 835	**Asker-m@scs.net.org**
Hamenna Bouzerzour	**Agronomist**	**Univiersty of Setif**	Setif - Algeria			**bouzerzourh@yahoo.fr**
Dietmar Franke	**Chief Executive officer**	**Rabe International Gmbh**	D-49152 Bad Essen-Germany	0049 54 72 77 12 10	0049 5472 77 1195	**d.franke@rabe-international.com**
Engin Cakir	**Agricultural Machinery**	**Faculty of Agriculture Ege University**	Tarım Makinalari Bölümü 35100 Bornova, Izmir - Turkey	90 232 388 40000	90 232 342 76 42	**engin.cakir@ege.edu.tr**

Carlos Cantero Martinez	**Agronomist**	**Universitat de Lleida Department de produccio Vegetal I ciencia Forestal**	Spain	+34 973 70 25 22	+34 973 23 82 64	**carlos.cantero@pvcf.udl.es**
Aoud Abdo Alsa'de		**Ministry of Municipal affairs & Agriculture**	**Qatar**	**9745500914**		**AWA5220022@hotmail.com**
Mansour Tebka	**General Secretary of Arab States farmers Union**		**Libya**	**00 218 213 633 179**		
Mouhamd Hussein Fahd	**Director of Steppe Department**	**Ministry of Agricultural and Agrarian Reform**	**Syria**	**031- 591 5671**	**031- 591 5675**	
Ammar Wahbi	**Soil-plant water relations specialist**	**Faculty of Agriculture**	**Aleppo University Aleppo – Syria**	**Mobile 0933680457**	**0963-021 222 91 84**	**Wahbi@scs-net.org**
Hani Zulkifl Ghosheh	**Weed Science Specialist**	**Faculty of Agriculture Jordan U. Sci, Techn.**	PO Box 3030, Irbid 22110, Jordan	962 2 720 1000	962 2 720 7810	**ghoshehhs@yahoo.com, Ghosheh@just.edu.jo**
Ra'ed W. Al Aghbar	**Director Soil department**	**Ministry of Agriculture**	P.O.Box: 911 Nablus -Palestine	+970 (2) 240 3304 41 -42	+970 0 02 24 0 33 12	**Ralaghbar@yahoo.com**
Seaf ben Ali Ben Salm Al koumice	**Agriculture Eng**	**Ministry of Agriculture & Fisheries minister's office**	Muscat P.O.Box: 5	+968 893 917	+968 268 93 087	**research@amantel.net.om**
Mohamd Ali Al Handi	**Agriculture Eng.**	**Ministry of municipalities affairs & agriculture**	Bahrain	17695849	17692106	

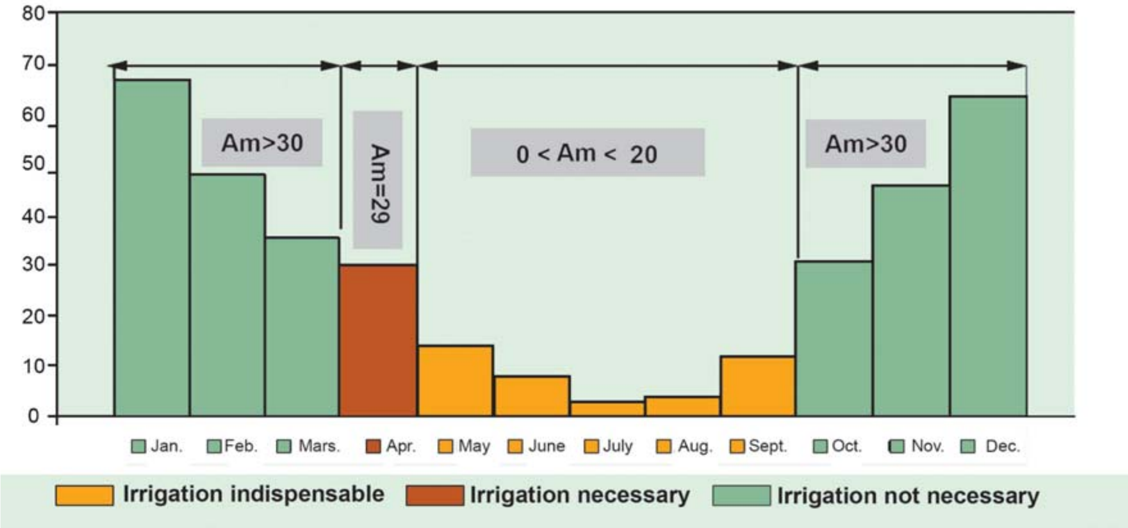


Figure 3. Monthly aridity indices of De Martonne and the irrigation seasons

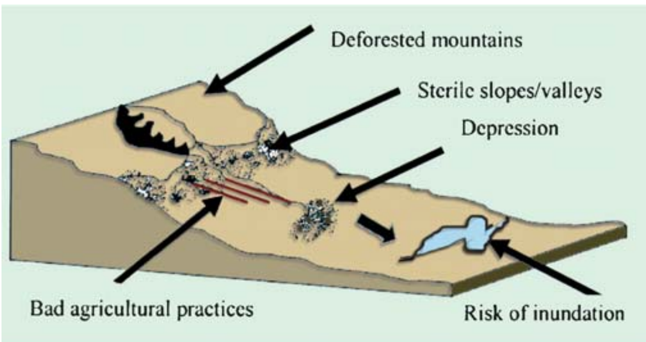


Figure 4. Hydrological and anthropogenic degradation in slopy areas.

Photo 1: The effect on water dynamics under CA (B) and conventional systems (A) is reflected on crop growth period. The difference in colour is visible. Zone A is at maturity (bright, whilst zone B is still in the dough stage (dark).

Site visit on June 28th, 2006, District of Zeghouane, Tunisia.

Photo 1. Slash and burn on a steep slope enhance soil erosion.

Photo 2. Rebuilt the soil by favoring reappearance of worms which are the soil labor.

Photo 3. Plowing down the slope is a common in conventional agriculture.

Photo 4. Heavy machinery originates soil compaction and makes clay pan, two barriers for water infiltration.

Photo 5. Growing oat on a dormant lucerne is one agronomy of opportunity scenario, possible under irrigation conditions.

Photo 6. Burning residues is going against conservation agriculture which requires a permanent mulching.

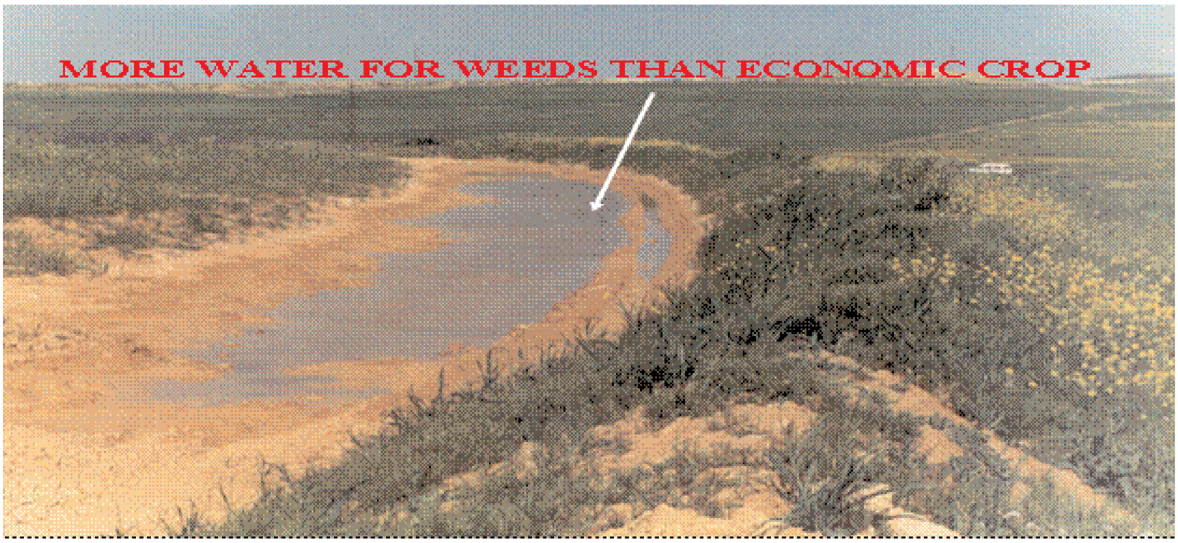


Photo 7. Terracing is a common technique for soil water conservation which often helps more weeds to grow than the economic crop.

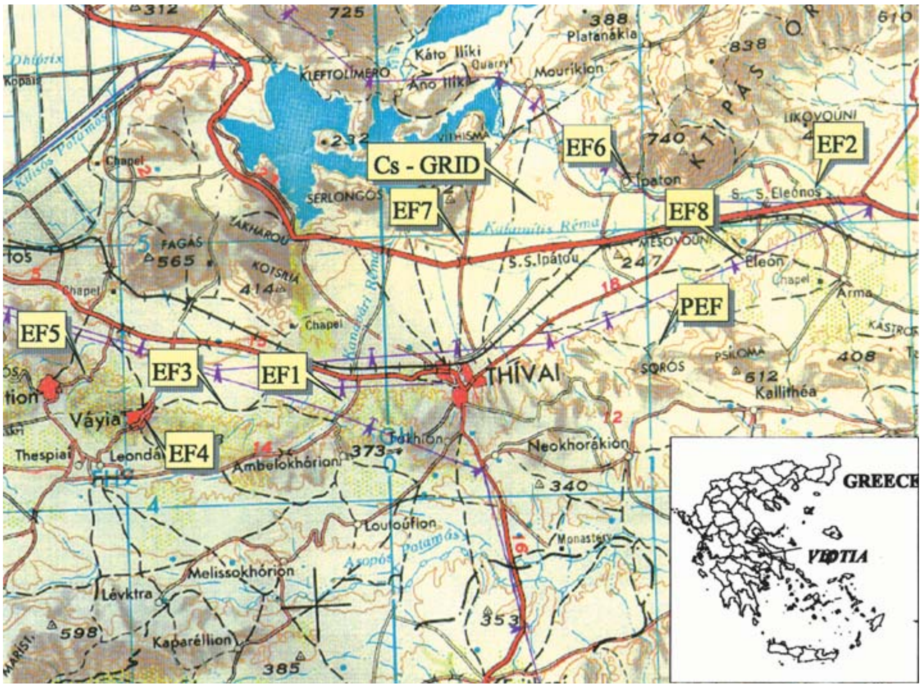


Fig.1. Greece, study area, experimental fields (EF1-EF8), field erosion plots (PEF) and Cs-137 study area (Cs-GRID).

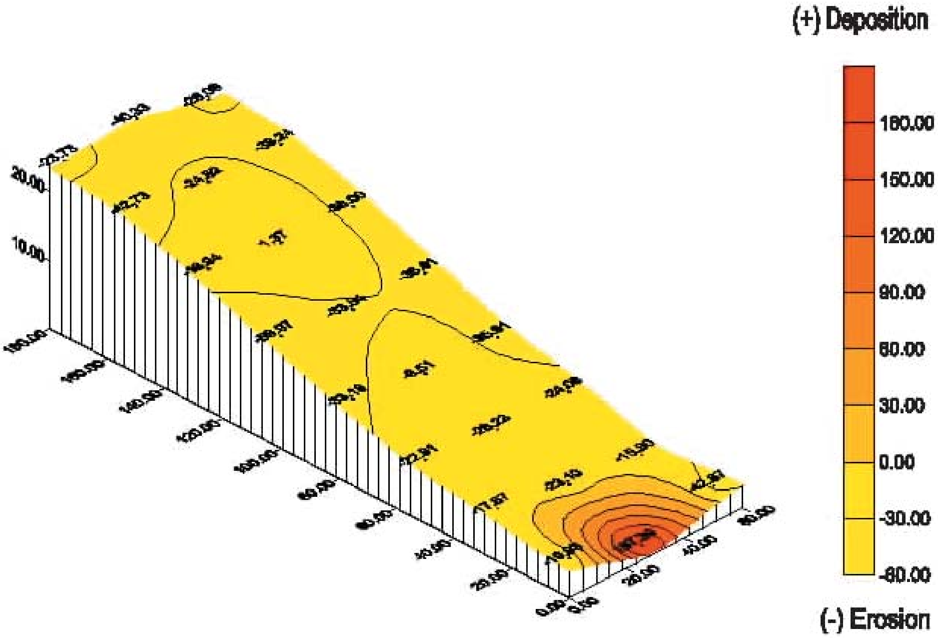


Fig.7. Soil erosion (-) and deposition (+) using the mass balance model 3 (t/ha/yr)

Figure 1. The Great Plains extends from Mexico on the south well into Canada on the north.

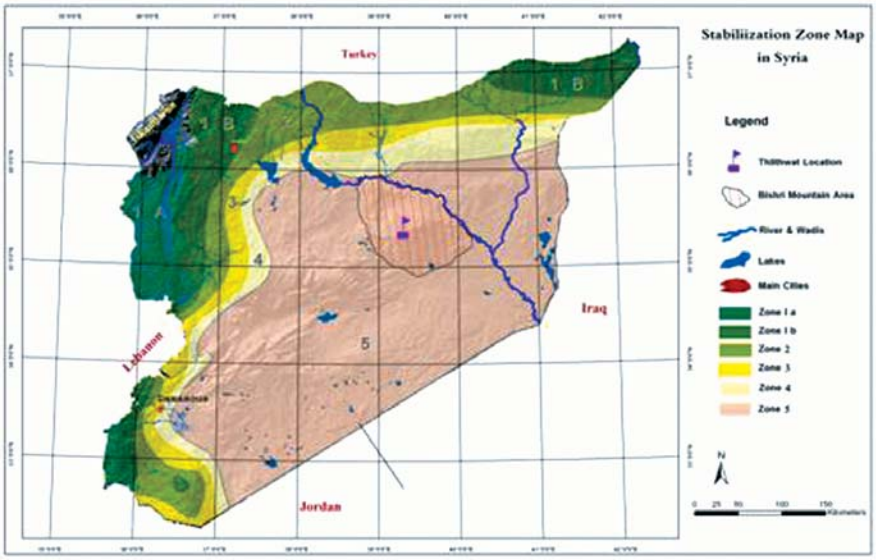


Figure 1: Location of Beshrri mountain within the stabilization zone map of Syria. (Source: Waad 2003.)

Design, Printing & Binding

Colours
PRINTING SERVICES

Haret Hreik, zone #3; Baajour Str. #53; Darwish Bldg. #31; Beirut - Lebanon;
Tel: +961 ;1 545475 **Fax:** +961 1 552505
info@coloursps.com www.coloursps.com