Compendium of deliverables of the conservation agriculture course 2008

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conservation agriculture course 2008

Bram Govaerts and Antonio Castellanos-Navarrete

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International Maize and Wheat Improvement Center

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Foreword

This book is the result of the hard work of 8 CIMMYT trainees who participated in the visiting scientist 2008 Conservation Agriculture Course: "Laying the groundwork for sustainable and productive cropping systems". During 5 weeks, the scientists received an intense training program that combined mentoring and problem solving approaches. Each participant had to define a clear research objective for the period of stay. The scientists participated actively in the ongoing cropping systems management activities of the CIMMYT Mexico-based Cropping Systems Management team at both the experimental stations, located near to Mexico City at El Batan and Toluca, and in nearby farmers' fields. Emphasis was given to conservation agriculture and resource conserving technologies: conventional and reduced till permanent bed planting for both irrigated and rain-fed conditions, using alternative crop residue management strategies. Wheat, maize, barley and dry beans were the crops under study.

Strong focus was placed on the importance of interdisciplinary approaches. Breeders helped to provide a better understanding of the nature of crop management by genotype interactions. Similarly, plant pathologists were involved in order to better understand disease interactions with the new tillage and crop residue management practices. An economist shed light on the complex system interactions and market chain development related to conservation agriculture, just to mention some of the numerous interactions of several CIMMYT scientists. Upon completion of the program, the participants presented their plans to initiate activities in their home countries to do research on and to extend to farmers the new technologies encountered in the program. They developed the necessary skills for trial management and plant and soil monitoring as influenced by management practices.

The main objectives of the program were:

- To enhance understanding of the use and application of the conservation agriculture planting technologies and relevant agriculture implements (with emphasis on planters/planter modifications) for irrigated and rain-fed wheat and maize production systems.
- To encourage and develop participants' ability to synthesize and use the information and knowledge related to conservation agriculture technologies (seeding methodologies in the different planting systems, irrigation water management, crop nutrient management, weed control strategies, and the importance of crop residue management).
- To increase participants' knowledge of (long-term) trial planning and management.
- To develop skills for monitoring soil and plant parameters as they relate to cropping management systems, as well as their influence on physical, chemical and biological soil quality, their effect on climate change adaptation and mitigation, and their impact on water and nutrient use efficiency.
- To foster positive attitudinal changes, such as improved confidence, increased motivation, and heightened appreciation of the benefits of team work and interdisciplinary research.
- To create a minimum level of proficiency in order to generate scientifically-sound hypotheses, determine data collection strategies, and interpret data and summarize them into scientifically-sound conclusions and recommendations.

This book is the result of a training course and has to be considered as a product of the course rather than a reference book. The views expressed in the chapters are those of the corresponding author and do not necessary reflect the view of CIMMYT.

In order to achieve the last objective each participant has chosen a clear deliverable to work on during the 5 week course. Some scientists analyzed and summarized data they brought from their home country, others reviewed a specific theme of interest related to conservation agriculture. Some of the papers, in collaboration with and with follow up from the CIMMYT scientists, will be presented to national and international scientific journals.

We want to thank the participants of the course for the excellent work delivered. Each of you really did an excellent job. I know you had moments of sweating hands when you had to present your work, but I also enjoyed the relief on your faces when you finished it and said to yourself; 'I did it!'.

Congratulations

Bram Govaerts	**Antonio Castellanos**
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The influence of tillage, crop rotation, residue management and N treatments on wheat yields: a review

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Abstract

In developed and developing countries few farmers use planting practices that permit tillage reduction and retention of the crop residues on the soil surface. But in the Yaqui Valley, in northwest Mexico, more than 95% of the farmers have changed their opinion from the previous practices of planting most crops on the flat with flood irrigation, to the establishment of all their crops on tilled permanent beds using furrow irrigation. In the Yaqui Valley, wheat is grown as a winter crop from November to May and maize as a summer crop from June to October. Both crops were planted on 0.75 m raised beds with wheat in two rows seeded 20 cm apart and maize in one row. Irrigation was applied in furrows between the beds. Significant yield differences between the tillage, residue management and nitrogen (N) fertilizer have been observed for wheat. More stable, higher yields have been obtained with permanent beds combined with residue retention, whereas permanent beds combined with residue burning resulted in markedly lower wheat yields. Bed planning reduces costs and water use, and permits farmers to combine it with a pre-seeding irrigation . The advantages identified by farmers include higher yields, reduced costs, easier weed control, and reduced turnaround time between wheat and a summer crop.

Keywords: wheat, bed-planting, conventional and zero-tillage, nitrogen fertilizer

1. Introduction

The adoption of conservation agriculture technologies has dramatically increased in many countries over the past 25 years. They are characterized by minimal soil disturbance (tillage) before seeding (with the ultimate aim being zero-till seeding) and by diverse strategies to increase crop residue retention on the soil surface to ensure full ground cover (leading essentially to biological tillage) over time. For example, there are now over 28 million ha of zero-till (ZT) seeding in Latin America with the bulk concentrated in the southern cone countries of Brazil, Argentina and Paraguay. Much of this acreage is zero-till with residue retention. However, upon closer inspection, the adoption of reduced zero-till seeding combined with surface crop residue retention in the countries mentioned above, as well as other large area adopters such as the United States, Canada and Australia in particular for wheat production systems, has occurred mainly for rain-fed production systems with a few exceptions where sprinkle irrigation is used (Sayre et al., 2004).

Farmers adopt resource conserving practices only when near-term impacts on their well-being can be demonstrated. Thus, sustainable farming systems need to have an immediate positive economic impact for the farmer household, increasing agricultural production while reducing threats to the environment. Efficient management of the natural resource base is the key to these improvements (Govaerts et al., 2005).

In Brazil, sizable yield increases and income stability for the farmers led to a wide adoption of the zero-till technique (Saturino and Landers, 2001). Lawrence et al. (1994) reported consistent advantages in wheat grain yields for ZT compared with conventional tillage (CT) in all 4 years of their experiment in Australia. In a review of crop yield responses to tillage in western Canada, Lindawall et al. (1994) reported equivalent or improvement yields with common spring grain crops. A study in west-central Saskatchewan, Canada has shown that grain yields can be improved with ZT, providing there is an adequate weed control and plant stand (Brandt, 1992). Not all studies in Canada indicate higher yields under ZT, compared to CT. Barley grain yields with ZT were higher than with CT in dry years, less in excessively wet years and the same in other years (Arshad and Dobb, 1991). In addition to providing higher yields, ZT can reduce production costs: 15-20% by eliminating the 4-8 tillage operations practised under conventional tillage systems (Landers et al., 2001).

One of the main constraints for reduced tillage and crop residue retention for surface irrigation, especially for wheat, is linked to the widespread use of solid stand planting on the flat combined with flood and basin irrigation systems that are commonly used throughout the world, but especially for the major irrigated wheat producers in south Asia and China.

2. Bed planting in Mexico

2.1 Introduction

In Mexico, 255,000 ha of land are under irrigated agriculture. A big part of them are planted with wheat from November to May and followed by maize from June to October (Limon-Ortega et al., 2001). Farmers from Mexico have used permanent bed systems for centuries. The origin and use of permanent bed systems has been associated with soil erosion and declining soil fertility making agriculture unsustainable (Govaerts et al., 2007). The only tillage on the permanent beds is the use of shovel or disc tools in the furrow bottoms to reshape the beds. We have looked at the use of miniature subsoiling shanks that operate in the middle of the bed to a depth of about 15-20 cm to shatter potential shallow compaction in the bed that may have developed over time, but without inverting or destroying the permanent beds.

Agriculture in the altiplano of central Mexico is practised mainly in the high valleys (1,500-3,000 m a.s.l.). Rain-fed cropping predominates, with rainfall (350-800 mm) occurring during a 4-6 month summer period, followed by dry frosty winters. Crops, dominated by maize (*Zea mays* L.), wheat (*Triticum aestivum* L.) but including beans (*Phaseolus vulgaris* L.), barley (*Hordeum vulgare* L.) oats (*Avena sativa* L.) and potatoes (*Solanum tuberosum* L.) are planted at or just before the onset of the summer rains. Most rain events are intense afternoon storms with significant dry spells during the cropping season. The soil is bare for much of the year, with all crop residues removed for fodder, grazed and/or burned. Fields are tilled frequently, using mainly small, tractor-drawn disc plows/harrows and field cultivators. Sloping fields, heavy tillage and lack of ground cover lead to extensive erosion and run-off, resulting in loss of water and production potential (Fisher et al., 2002; Sayre et al., 2001; Scherr and Yadav, 1996).

The main motivation for initiating permanent bed planting systems has been to develop crop production technologies that can offer marked reductions in production costs and increased yields (Sayre et al., 2005). Bed planting provides a natural opportunity to reduce compaction by confining traffic to the furrow bottoms. The next step to increase the sustainability of beds is to make them permanent, reducing or avoiding tillage and retaining and distributing crop residue on the surface, reshaping the beds only as needed. Permanent beds permit the implementation of crop residue to maintain a permanent soil cover for greater rainwater capture and soil moisture conservation (Govaerts et al., 2005). Permanent bed treatments under rain-fed conditions combined with rotations and residue retention yield the same as the other conservation agriculture (CA) practices of ZT on the flat with residue retention and crop rotation over a period of 6 years (Govaerts et al., 2005). The extra advantage of permanent bed planting over ZT on the flat is that more varied weeding and fertilizer application practices are possible by trafficking in the furrow bottoms and the N fertilizer can be banded through the surface residues, reducing potential N volatilization loss (Limon-Ortega and Sayre, 2002).

Farmers who grow irrigated wheat on beds obtain 8% higher yields and save nearly 25% in production costs, compared with the conventional tillage systems (Aquino, 1998). In addition, for wheat, most farmers apply over 75% of the total N fertilizer (average N rate for wheat is 275 kg N ha) as an incorporated, basal application prior to planting, which results in a law (30-35%) uptake efficiency (Meisner et al., 1992). At present, most farmers in Mexico have adopted bed planting with two or three rows of the wheat seeded on top of beds 70-80 cm wide (furrow to furrow) with furrow irrigation as opposed to the traditional planting system of flat planting in solid stands and flood irrigation. The adoption of this new planting configuration has reduced the irrigation water requirement by 25%, provided new opportunities for mechanical weed control and afforded new opportunities to reduce tillage in addition to dramatically reducing the incidence of lodging (Sayre and Moreno Ramos, 1997).

2.2 Experiences in the Yaqui Valley

Until about 35 years ago, farmers in the Yaqui Valley practised basin/flood irrigation for wheat (the principal crop) as well as for other crops, with extensive use of heavy tillage and burning of crop residues. Occasionally, farmers would hill-up crops like safflower, maize, sorghum, soybeans, sesame and dry beans for subsequent furrow irrigation after these crops had been planted on the flat following a pre-seeding flood irrigation. In the middle 1970s, some farmers began to plant wheat on flat beds raised between irrigation furrows, with the innovations that only 2-4 defined rows were planted on top of each bed (referred to as raised bed or bed planting). Common bed widths ranged from 70 to 90 cm furrow to furrow, with 75 cm as the most common width. Use of wider beds was not possible due to irrigation problems associated with wetting across to the middle of the bed for crops like wheat. Once the move to planting wheat on beds in this fashion was adopted, farmers began to plant most other crops on similar sized beds, but still continued to use heavy tillage and excessive burning of crop residue before tilling, followed by the formation of new beds for each succeeding crop cycle (Sayre et al., 2005).

Few farmers, however, have adopted permanent bed planting, although some have taken the first true step towards the use of permanent beds, especially in the main cropping systems that involve wheat or barley in the autumn/winter cycle, followed by maize, sorghum or soybean in the spring/summer cycle. The principal reason that farmers have not yet implemented the system is the lack of suitable small grain seeders that can readily and reliably plant 2-3 rows of wheat or barley on the untilled top of the permanent beds, especially in the presence of high levels of surface-retained maize or sorghum straw (Sayre, 2005). However, the machines have recently been made available (Govaerts, personal comm., 2008).

The permanent bed planting system as a form of conservation tillage has been proposed for wheat and maize production in the irrigated areas of northwest Mexico in the Yaqui Valley (Ortega et al., 2000). This system consists of planting two seed-rows of wheat on the top of raised-beds, and retaining plant residues from the previous crop, which is chopped and left in the field as stubble. Bed planting provides a natural opportunity to reduce soil compaction by confirming traffic to the furrows (Ortega et al., 2005). Planting on conventional-tilled beds increases water use efficiency and decreases operational costs compared with conventional tilled wheat without beds (Aquino, 1998; Fahong et al., 2004).

Crop production practices such as tillage, plant residue management, N fertilization and crop rotation influence a number of biological and physical soil attributes. Reducing tillage combined with crop residue retention on the soil surface as stubble can increase water infiltration (Bruce et al., 1990; Carter, 1992; Azzoz and Arshad, 1996; Elliot and Efetha, 1990; Shaver et al., 2002), reduce soil erosion, increase water use efficiency (Johnston et al., 2002; McGarry, 2002) and reduce water loss by evaporation. Crop rotation, on the other hand, can break soil borne pathogen cycles and reduce weed pressure (Karlen et al., 1994).

2.3 The influences of tillage, residue retention and N fertilizer on the wheat yields

Permanents beds and residue retention as a stubble produced superior wheat grain yields in high-yielding environments; in low-yielding environments, permanent beds with residue burned produced greater wheat grain yields. The lowest grain yields were obtained in the conventional tillage bed with residues incorporated (Limon-Ortega et al., 2000). Full retention and partial retention of residues had similar yields, indicating that for irrigated systems with associated high residue yields, substantial amounts of residue can probably be removed for other economic uses without causing a yield decline. In addition, although the yields of properly-managed permanent beds are not markedly higher than conventional tillage beds with residue incorporation, as will be seen, permanent bed production costs are markedly lower (Sayre et al., 2004).

The highest yields were obtained for ZT with crop rotation and full retention in the rain fed areas of central Mexico. The lowest yields were obtained with ZT with rotation and residue removal: nearly 37% less than the same management with full residue retention. Mixed analysis revealed significantly higher yields for ZT with residue retention compared to conventional tillage with and without residue incorporation. Residue was significant only when practising ZT. The wheat-maize rotation system with ZT and removal of residue performed better than continuous maize treatment with residue retention (Govaerts et al., 2005).The permanent beds are promising. Yields levels are comparable to those of ZT treatments and residue retention is equally crucial. Planting wheat and maize on raised-beds is an innovative option that can help improve rainwater use and reduce soil erosion (Limon-Ortega and Sayre, 2003). Other advantages of permanent beds are that they facilitate weeding and the band application of fertilizers, and they control traffic, limiting compaction to furrow bottoms (Limon-Ortega and Sayre, 2003). The systems also allow the use of lower seeding rates for conventional, flat planting systems and reduce crop lodging, especially for small grains (Sayre, 2004).

Significant yield differences between the tillage and residue management treatments have been observed for wheat. Higher wheat yields have been obtained with permanent beds combined with residue retention. These yield differences from permanent beds with burned residue are associated with gradual changes in soil physical, chemical and biological parameters.

The permanent bed treatment with continuous crop residue retention has had, on average, the highest average yield, closely followed by conventional tillage with residue incorporation, then the permanent bed treatments with full removal for fodder by bailing and, considerably inferior, permanent beds with residue burning.

Nitrogen application at the 1st node stage of wheat had excellent potential to produce greater wheat yields. An adequate N fertilizer rate for wheat at the 1st node stage should be<300 kg N kg /ha. Nitrogen fertilizer application of 150 and 300 kg n ha at the 1st node stage of wheat increased grain yields compared with preplant N fertilizer applications (Ortega et al., 2000).

Conclusion

The permanent bed irrigated planting systems for wheat and other crops being developed in Mexico and elsewhere may finally provide a coherent technology to extend marked tillage reductions with appropriate management of crop residues for surface-irrigated production systems. Irrigation farmers must realize that some residue retention will be essential if they attempt to adopt permanent bed planting systems even though their primary goal may be simply to realize lower production costs. Both farmers and researchers in Mexico are firmly convinced that permanent bed planting technologies with furrow irrigation offer many improved opportunities. Farmers and researchers agree that permanent bed planting with rational surface residue retention and furrow irrigation offers the next step in improved technology to allow further cost reductions, such as providing more advantageous crop turn-around times and enhancing the soil biological, physical and chemical properties associated with long-term sustainable production opportunities. The implementation of permanent bed systems with crop residues can be considered an alternative practice that improves soil quality and yields with the concomitant reduction in operational costs.

Based on wheat and maize yield performance, small-scale maize and wheat farmers in the subtropical highland regions may expect yield improvements from 25 to 30% through adoption of ZT, appropriate rotations and retention of sufficient residues, as compared with the common practices of heavy tillage before seeding, monocropping and crop residue removal. Permanent bed planting with rotation and residue retention has the advantage that more varied weeding and fertilizer application practices are possible.

The average bed-planting wheat yield is about 10% higher than for flood irrigation.

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The impact of tillage, crop rotation and residue management on Fusarium Head Blight in wheat: a review

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Abstract

Fusarium head blight (FHB) is caused mainly by Fusarium graminearum *and several other species in the genus,* Fusarium. *Disease epidemics result from the combination of inoculum, favourable environment and host susceptibility. Changes in the cropping systems as a result of adoption of conservation agriculture may increase the risk of Fusarium head blight. The residues of host crops, such as wheat, barley and maize are considered the principal reservoir of these fungi, providing the inoculum that generate FHB epidemics. The type and quantity of crop residues contribute to the inoculum load and disease potential. In order to reduce tillage to become more attractive for the farmers, additional controls are needed for pathogens. Resistance breeding combined with crop rotation, tillage, residue management, biological control or even fungicide utilization are part of the integrated crop management practices that can minimize losses. Rotation with nonhost crops, especially in the year before wheat, is important to reduce the risk of Fusarium head blight. A move to more resistant cultivars will also reduce the risk of FHB and high mycotoxin levels. Even the reduced tillage systems increase the incidence and severity of Fusarium head blight; however, the benefits of the reduced tillage make it a management that should be promoted.*

Keywords: conservation agriculture, ***Fusarium graminearum, Gibberella zeae,*** Deoxynivalenol

1. Introduction

Fusarium head bBlight, commonly known as scab, has become an important fungal disease in many wheat growing areas of the world. It is caused mainly by *Fusarium graminearum* and several other species in the genus *Fusarium*. Among *Fusarium* species, *Fusarium graminearum* Schwabe [telemorph *Gibberella zeae* (Schwein).Petch] proved the most aggressive species towards wheat ears during pathogenicity tests (Stack and McMullen, 1985; Mesterhazy, 1978). It is estimated that scab may affect up to 7 million hectares in China, and that 2.5 million tons of grain may be lost in epidemic years (Dubin et al., 1997). FHB is also present in parts of South America, in countries like Argentina, Uruguay and Brazil. In Rio Grande do Sul, Brazil, damage caused by wheat scab is around 12% of the potential harvest (Casa et al., 2004 cited by Duveiller et al, 2007). In China, the United States, Canada and some European countries *Fusarium graminearum* is the dominating *Fusarium* species, causing seedling blight, crown rot, foot rot and head blight in cereals, especially in wheat (Gilbert et al., 1995; Wong et al., 1992; Wilcoxon et al., 1988; Stack and McMullen 1985). *Fusarium graminearum* is also present in South Asia, but the wheat flowering there coincides with low relative humidity conditions and FHB is found only sporadically in the Himalayan foothills and in Bangladesh (Duveiller, 2007).

The disease incidence could reduce kernel set and grain weight, thereby causing significant yield losses which range from 30% to 70% under epidemic conditions (Meidaner, 1997). The disease incidence is correlated to the contamination of grains with fungal metabolites, mainly deoxynivalenol (DON) which is toxic for human beings and animals (Dill-Macky and Jones, 2000; Meidaner, 1997; Sutton, 1982). Of 114 isolates of *Fusarium graminearum* collected from soil or cereals on a world-wide basis, 95% were capable of producing DON (Mirocha et al., 1989). Approximately 50% of DON in naturally contaminated wheat remains after the milling process, in flour DON is very stable during baking (Dexter et al., 1996; Boyacioglu et al., 1993). In view of that, many countries have set legal thresholds of Fusarium toxin concentrations in food and feed, e.g. in Canada DON concentration should be <2 or <5 mg kg^{-1}, in the United States <1 or <5 -10 mg kg^{-1} in food and feed and in Austria <0.5 mg kg^{-1} in food (Gilgenberg-Hartung, 1999). European Union (EU) regulation 856/2005 establishes a maximum level of 750 µg/kg (0.75 ppm) for DON in cereal flour (excluding durum wheat, oat and maize flour). These kinds of regulations are not established in many countries and many people eat the cereal unaware of any danger. Beside the toxicological aspect, the germination percentage of infested grains is substantially reduced.

A widespread epidemic of Fusarium head blight cost wheat (*Triticum aestivum L.*) producers in Ontario over $100 million in 1996 (Schaafsma, 1999). In the United States the cumulate direct and secondary economic losses from FHB in hard red spring (HRS) wheat, soft red winter (SRW) wheat, durum wheat and barley is estimated at $ 7.7 billion from 1993-2001 (Nganje et al., 2004). The states of North Dakota and Minnesota account for about 68% ($5.2 billion) of total losses.

Conservation agriculture (CA), which consists of reduced tillage combined with retention of crop residues on the soil surface (30% or more) is becoming more widely used. This practice helps to reduce soil erosion, conserves energy and increases soil moisture and crop yields (Bockus and Shroyer, 1998). All Fusarium species are capable to surviving saprophytically on host residues (Perry et al., 1995), although FHB epidemics are generally considered to originate from inoculum associated with infested crop residues, mainly of maize and wheat (Sutton 1982). There is considerable evidence that continuous wheat cropping or wheat following maize in a rotation system significantly increases the incidence and severity of FHB. Potential inoculum for FHB is reported to be mainly ascospores produced on host residues that have remained at or above the soil surface (Khonga et Sutton, 1988). Practices for suppressing initial inoculum, especially rotation of wheat and maize with non-host crops and plowing infested residues, have long been recommended for managing FHB (Dill-Macky and Jones, 2000; Miller et al., 1998; Wiese, 1987). Crop rotation or residue management may not only reduce the primary inoculum and FHB but also influence the grain yield and grain quality (Lopez-Bellido et al., 1998).

Under fundamentally different conditions, tillage systems vary in their effect on the microbial community (Bockus and Shroyer, 1998). The microbial community under no-tillage is altered from that under conventional tillage. The community includes both plant pathogens and the microorganisms that are natural antagonists of these pathogens. Therefore, no-tillage cropping systems have very different pathogen problems than conventional-tillage systems. (Bockus and Shroyer, 1998). The interaction of tillage and *Fusarium graminearum* infection is a matter of particular interest. Contradictory data on the effect of tillage on Fusarium species are available. Under different depth and type of implement used no-tillage decreased (Webe et al., 2001), increased (Bailey and Duczek, 1996) or had no effect (Swan et al., 2000; Wildermuth et al., 1997) on FHB disease.

Crop residue placement, which is dictated by tillage practice, has a significant influence on crop residue decomposition (Holland and Coleman 1987). Hubbard and Jordan (1996) observed faster residue decomposition with residues incorporated in the soil than with residues placed on the soil surface. Plowing to reduce Fusarium inoculated crop residues on the soil surface may be a key to reduce the infection risk and protect grain yield and quality, since the efficient control of Fusarium by fungicides is not possible, yet (Mesterhazy, 1997).

The maintenance of soil health increases the biological control of pathogens. Some Fusarium species are well known plant pathogens, but also in this genus many saprophytic species are active biological agents (Janvier et al., 2007) which may be used to reduce or prevent plant disease caused by pathogenic Fusarium strains and other pathogens (Fravel et al., 2005). W.C. da LUZ (2004) studied the effect of the combination of bioprotectants with fungicide to control FHB of wheat, induced by *Fusarium graminearum* under field conditions. He found that the combination of the biological with the chemical control treatment significantly reduced the intensity of FHB and provided a significant increase in grain yield over the non-treated control in both years of study, 2002-2003.

There is no complete resistance to FHB in wheat, although many sources of partial resistance have been identified in a diversity of germplasm sources that frequently differed with respect to the chromosomal regions governing resistance (Liu and Anderson, 2003; Shen et al., 2003). Resistance to FHB has different components (Wisniewska et al., 2002; Masterhazy, 1995) and there is a strong influence of environmental conditions in the response of wheat to FHB.

Agronomic practices such as tillage, crop rotation and residue management all play important roles in determining the risk of this disease, by influencing the type, amount and location of inoculum. The objective of this overview is to identify agronomic practices, such as tillage systems, crop rotation and residue management options that might be associated with the development of FHB and DON content in wheat. Based on the knowledge outline above, the present overview focuses on the main questions:

Does the infection level of wheat crops with *Fusarium graminearum* differ after infected pre-crops of either maize or wheat?

Can we control FHB infection using different tillage systems (conventional versus zero-tillage), crop residue management options (removal versus retention) and crop rotation?

Is the reduction of crop residues on the soil surface after maize and wheat pre-crops a sustainable management practice to reduce the FHB disease level and DON contamination of wheat?

Which of several methods (technologies, right varieties, etc.) can be recommended for a fast, cheap and reliable assessment of the infection level and the toxin contamination of a wheat crop? The effective crop rotation coupled with reduced tillage or no-tillage, residue management, could reduce the incidence and severity of FHB disease correlated with DON levels, while improving soil quality and system profitability by reducing production costs and increasing wheat yield and stability.

2. The pathogen

The teleomorph (sexual state) of the fungus is *Gibberella zeae*, which belongs in the *Hypocreaceae*, a family characterized by brightly colored perithecia (sexual fruiting structure). Perithecia are dark purple or black and form abundantly on wheat and maize stubble. Ascospores (sexual spores) form within sacs called asci and are forcibly discharged from the perithecium through a single small opening known as an ostiole. Each ascus contains eight ascospores that have zero to three septa. Ascospores measure 20-29 x 3.5-4.5 µm. The ascospores are hyaline to light brown in color and slightly curved with rounded ends. The majority of the isolates of *F. graminearum* are homothallic, meaning that they are able to sexually reproduce without a partner. Heterothallic isolates, which require a compatible partner for sexual reproduction, are less common. Laboratory studies have demonstrated that many of the homothallic isolates have the ability to outcross with other compatible isolates. The degree to which this occurs in the field under natural conditions is unclear.

The anamorph (asexual state) of the fungus causing FHB is *Fusarium graminearum*. The asexual state of the fungus produces spores called macroconidia and microconidia. In agar culture *Fusarium graminearum* appears gray, pink, brown or burgundy. Macroconidia (asexual spores) are derived from conidium-producing cells called phialides. The phialides are clustered together in cushion-shaped masses known as sporodochia. The macroconidia are 41-60 x 4.5-5 µm, hyaline, canoe-shaped spores usually with five or more septa. Globose chlamydospores are produced mainly in macroconidia, but may also form in mycelia. Conidia, chlamidospores and ascospores are microscopio sizes.

3. Disease cycle and environmental conditions for the development of Fusarium head blight

The relation between the time of flowering of a wheat cultivar, weather and development of FHB was recognised early in the history of research on this disease. Arthur (1891) noted that the time of flowering of a particular cultivar could affect the amount of blight that developed in it.

Fusarium graminearum overwinters as chlamidospores or mycelia in the soil or in host crop residues which serve as a source of primary (initial) inoculum in the spring. The fungus can also survive on wheat seed. The main source of infection is ascospores formed on crop residues and conidia (Sutton, 1982). New fungal strains with increased pathogenicity may develop as a result of the sexual reproductive cycle (Figure 1). Temperature and water in the soil and environment greatly affect sporulation of *Fusarium graminearum* from residues (Garcia-Garza and Fravel, 1998; Wang, 1996). The most suitable temperature for producing conidia and ascospores is 15-20 °C and the most suitable soil moisture is 70-80% of field capacity (Wang, 1996). Bai and Shaner (1996) found that on potato dextrose agar in the dark, *Fusarium graminearum* grew not at all at 4 or 36°C, grew slowly at 8 and 32°C, but grew rapidly between 12 and 28°C. The maximal growth rate was at 28°C. Wheat heads are susceptible from anthesis until the soft dough stage, but the infections occuring during anthesis cause the most damage, resulting in shrivelled, lightweight kernels, reduced seed germination, seedling blight and poor stands. (Perry et al., 1995; Bai and Shaner, 1994). During warm temperatures (25 to 28 °C) and wet conditions blight symptoms develop within two to four days after infection.

Rainfall and wind are involved in the dispersal of Fusarium spores. Excessive rainfall during the growing season and especially during a one-to-three week period prior to anthesis can lead to epidemics of Fusarium head blight. Strausbaugh and Maloy (1986) found that many more ears were infected with *Fusarium graminearum* and other *Fusarium* species in wheat crops receiving overhead irrigation (89%) compared with crops which did not receive irrigation (0%). Wang (1996) showed that the airborne *Fusarium* spores in cereal crops were mainly ascospores and that their incidence was closely related to rainfall events. He found that ascospores were released actively only 1-2 cm above the soil surface, but they can be transported long distances by wind. Conidia were only released and spread under conditions of wind and rainfall. Other authors assume, from field observations of disease occurrence, that spores of *Fusarium graminearum* can be disseminated by wind up to 50 m in height and 30 m horizontally from the source (Fernando et al., 1997).

Plant pathologists use the *disease triangle* metaphor to describe the role of host, pathogen and environmental conditions in the development of a plant disease epidemic, but this model could be too simplistic to describe the complex interactions among these three elements (Leonard and Bushnell, 2003). Leonard and Bushnell (2003) use the idea of *epidemic credits*. For an epidemic to occur, a minimum number of *host credits*, *pathogen credits* and *environment credits* must be available. Host credits are represented by the abundance, spatial uniformity and inherent susceptibility of the host plants to the pathogen. Pathogen credits include its abundance, its ability to produce primary and secondary inoculum, its proximity to the host and its inherent pathogenicity. Environment credits include the frequency of rainfall or dew, the duration of wetness of plant surfaces and perhaps on the substrate on which the pathogen produces primary inoculum, wind speedand direction, and temperature.

The Fusarium species can survive on crop residues in the soil for more than 6 years as mycelium, ascospores and conidia or chlamydospores (Haware et al., 1996; Reis, 1990; Sutton, 1982). The inoculum level is reduced as stubble decomposition, but even under favorable conditions for decomposition the pathogen can survive for at least one year (Sutton, 1982). Under identical environmental conditions in two areas that differ in host or pathogen credits, epidemics of different intensity will develop, and in a favourable environment, an epidemic may develop from only a modest amount of primary inoculum or with only a moderately susceptible host (Leonard and Bushnell, 2003).

4. Relation of agronomic practices to Fusarium head blight in wheat

4.1. Incidence of FHB disease in different tillage systems, crop rotations and residue management

Adoption of zero-tillage in areas where wheat is rotated with maize or other cereals is probably one of the factors that has increased the incidence of FHB in some countries (Duveiller et al., 2007). *Fusarium graminearum* can persist on residues under both tillage and no-tillage conditions and infections can occur in subsequent years. Yi et al. (2002) underline the favourable effect of removing the crop residues of the pre-crops from the soil surface by plowing them into the soil. The authors found that plowing reduced FHB incidence comparatively with surface residues by 27-32% in the experimental years 1998-1999. At the same time disease severity was reduced by 19-21%. Fernandez et al. (2005) found that the FHB index was highest under minimum tillage and lowest under zero-tillage.

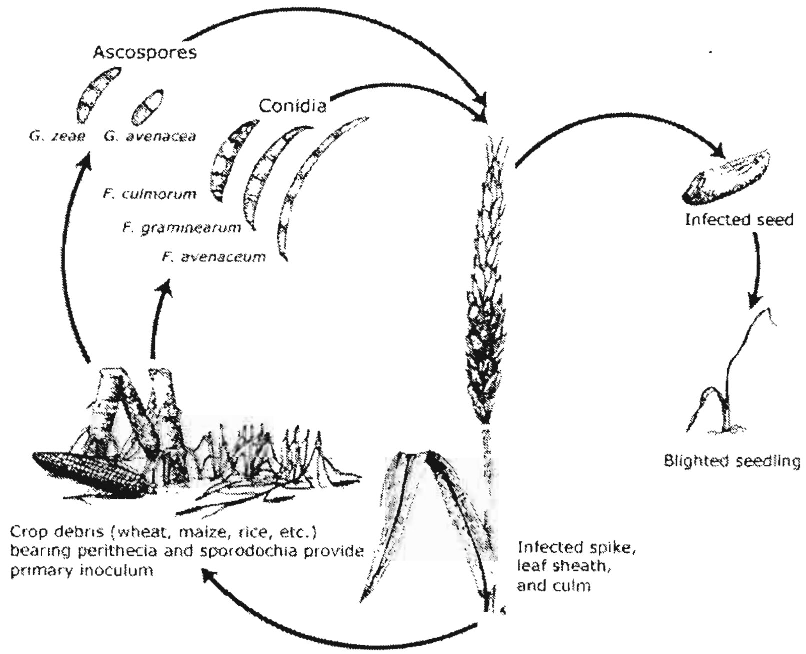

Figure 1. Disease Cycle (Courtesy A. Schilder and G. Bergstrom).

Crop rotation serves to *sanitize* the soil by utilizing the native microorganisms to weaken and kill residue-borne pathogens (Bockus and Shroyer, 1998). They thought that the single factor for the success of a continuous, reduced-tillage system is the simultaneous adoption of a proper crop rotation scheme, which involves no plant species that are susceptible to the pathogens. Rotation to non-host crops allows time for pathogen-infested residues to degrade in the absence of new host tissue. Pereyra et al. (2004) showed that in the Red River Valley, Minnesota, crop rotations that include a host of *Gibberella zeae* only once every three years may aid in reducing the in-field inoculum under reduced tillage systems. Non-host crops that can be incorporated into rotations in Minnesota include sunflower, beans, canola and forage legumes. Cultivation of maize and other susceptible grasses can have a great effect on the abundance and species composition of Fusarium species in soil (Burgess, 1981). The use of FHB-susceptible crops in rotation with wheat and the short time between crops increases disease risk.

Peritecia represent the sexual stage (telemorph) of the fungus, *Gibberella zeae*, and are produced on wheat glumes. Peritecia play an important role in the pathogen's survival from year to year and coexist with mycelia in residues of the previous crop to constitute the initial inoculum source for scab. In the Red River Valley of Minnesota, North Dakota, South Dakota and the Canadian province of Manitoba, a significant increase in conservation tillage practices in the last 20 years has resulted in greater amounts of crop residues on the soil surface (McMullen et al., 1997). Crop residues in zero-tillage plots can provide a significant source of Fusarium inoculum (Miller et al., 1998). Fusarium species can produce conidia on blighted spikes; head blight is generally regarded as a monocyclic disease (Bai and Shaner, 1994) and the primary inoculum will considerably influence the intensity of the disease that develops in the field. If residue is the main source of primary inoculum, then the amount of the primary inoculum will probably be related to the density of crop residues on the soil surface. Abundance of inoculum depends on how long residue remains intact after the harvest of the crop and how well the fungi survive in this residue (Leonard and Bushnell, 2003). *Fusarium graminearum* and other species of *Fusarium* survive not only in the residue of the wheat and barley, but in the residue of maize (Sutton, 1982) and rice (Bai and Shaner, 1994). In the Corn Belt of the USA and in other areas where small grains and maize are grown, maize is probably the more important source of inoculum, because maize residue lasts so much longer than the residues of small grains (Leonard and Bushnell, 2003). In the northern Great Plains, infested residue of wheat and barley is a more important source of inoculum than maize, because not much maize is grown there, owing to the short growing season (McMullen et al., 1997). In the north of China, where wheat is sown after rice, rice stubble is a major source of inoculum of *Gibberella zeae* (Bai and Shaner, 1994). Fernandez et al. (1993) showed that *Fusarium graminearum* could survive in the wheat residues, under a subsequent crop of soybeans, maize, or on follow ground, into the summer after the wheat crop.

Pereyra and Dill-Macky (2008) examined the presence of the Fusarium species in the residues of wheat, barley, maize, sunflower, pasture and gramineous weed species common in wheat and barley cropping systems collected from no-tillage and reduced-tillage plots from Uruguay, during 2001-2003. *Gibberella zeae* was recovered from residues of wheat, barley, corn, sunflower, fescue, and the gramineous weeds *Digitaria sanguinalis*, *Setaria* spp., *Lolium multiflorum*, and *Cynodon dactylon*, except from birdsfoot trefoil or white clover. Of the Fusarium species obtained, *Gibberella zeae* was the most frequently recovered from wheat and barley residues, while other species were more common in other crops. *Gibberella zeae* declined over time in all residues examined. Pereyra and Dill-Macky (2008) observed that wheat and barley residues produced more ascospores of *Gibberella zeae* than maize and other gramineous residues. Sunflower residue did not support ascospores production. Wheat and barley residues supported *Gibberella zeae* colonization longer in no-tillage than in reduced tillage systems. In another experiment, Pereyra et al. (2004) observed that survival and inoculum production of *Gibberella zeae* was related to the rate of wheat residue decomposition. Infested wheat residues, including intact nodes, internodes and leaf sheaths were placed in fibreglass mash bags on the soil surface at 7.5 to 10 cm and 15 to 20 cm depths in chisel plowed plots and 15 to 20 cm deep in mouldboard plowed plots in October 1997. Buried residue decomposed faster than residue placed on the soil surface. Less than 2% of the dry matter residue remained in buried treatments after 24 months in the field, while 25% of the residue remained in the soil surface treatment. Surface residue provided a substrate for *Gibberella zeae* for a longer period of time than buried residue. Twenty-four months after the initiation of the trial, the level of colonization of nodes in buried residue was half the level of colonization of residue on the soil surface. Ascospores of *Gibberella zeae* were still produced on residue pieces after 23 months and these spores were capable of inducing disease.

In the experiment established at the University of Minnesota's Agricultural Experiment Station at Morris during 1994-1996, Dill-Macky and Jones (2000) showed that soil coverage with residues was the lowest in moldboard plow (MP) treatments (9%) and greater in chisel plow (CP) (31%) and no-tillage (NT) (65%) treatments. Residues were greater in plots following corn (MP: 9%; CP: 42%; NT: 67%) than wheat (MP: 9%; CP: 34%) except in no-tillage wheat (NT: 83%), where residues were the most abundant of all treatments examined. Soybeans generated less residue (23% coverage) than the other crops tested (maize: 41%; wheat: 42%). *Fusarium graminearum* was the predominant species isolated from maize and wheat, while other *Fusarium* species, especially *F. sporotrichioides*, predominated in the soybean residues. Disease incidence and severity were significantly influenced by previous crop and tillage in each year of the study. Disease incidence was greatly increased when wheat was planted on maize residues and least when wheat followed soybean. Disease incidence was lower in mouldboard plowed plots than in either chisel plowed or zero-tillage plots. Among the previous crop tillage combinations, disease incidence was significantly higher in the chisel plow and zero-tillage treatments of maize residues than in any other treatment combination. Disease severity was higher in wheat following maize than in wheat following wheat and soybean. Disease severity was lower in mouldboard plowed plots than in either chisel plowed or zero-tillage plots. Dill-Macky and Jones (2000) showed that the percentage of wheat residue pieces infested with *Fusarium graminearum*, which was generally higher than the percentage of infested maize residues, may reflect the use of the wheat cultivar Norm, known to be highly susceptible to FHB, and to the presence of favourable conditions for FHB development in 1994, 1995 and 1996 when the previous crops were established.

Although maize and small grain residues are generally implicated as the source of primary inoculum for *Fusarium graminearum*, Baird et al.(1997; Fernandez and Fernandes, 1990) found that this species can be isolated from soybean residues under conservation tillage systems. In several parts of Brazil, where wheat and soybean are commonly in crop rotation, *Fusarium graminearum* could be isolated in high frequency (12 to 65%) from soybean residues (Fernandez and Fernandes, 1990) and from wheat stems from the same fields at frequencies of 35 to 85%. Baird et al. (1997) noted that soybean residues harboured many fungi during subsequent crops of other legumes or cereals.

4.2. The influence of the incorporation depth to the level of colony forming units

A greenhouse pot incubation study realised by Yi et al.(2002) showed that the incorporation depth of crop residues has a significant influence on the growth of *Fusarium graminearum* on the crop residues. The number of fungal units on the residues decreased with increasing incorporation depth. After 90 days of incubation, the burial of crop residues at 10 cm or 15 cm reduced the number of Fusarium colonies by 16-28% or 39-42%, respectively, compared with surface incorporation at 5 cm. Under field conditions a deep burial might conserve pre-crop residues for a long period due to lower soil temperature and less aeration deep in the soil, incorporating crop residues as completely and as early as possible may reduce disease incidence and severity for the succeeding crop to the highest degree (Miller et al. 1998; Dill-Macky and Jones, 2000).

4.3. The influence of different tillage systems, crop rotation and residue management to DON level in wheat and yield performance

Byosinthesis of the mycotoxins depends on many factors, especially the strain of the pathogen, the substrate, the period of colonization of the substrate, temperature, moisture and competing organisms (Sutton, 1982; Cooney et al., 2001). For instance, it has been suggested that resistance to Fusarium head blight may be controlled by different genes (Bai and Shaner, 1994).

Several studies have examined the effect of tillage practices on DON levels (Dill-Macky and Jones, 2000; Schaafsma et al., 2001; Yi et al., 2001), but the findings vary with the impact that tillage and the amount of crop residue had on disease levels and often no difference among tillage systems was observed. Schaafsma et al. (2001) observed that less than 3% of the variation in DON levels was associated with tillage. The average DON levels in minimum tillage (3.9 ppm) systems were higher than in zero-tillage (3.3 ppm) and conventional tillage systems (2.5 ppm). It was observed that in 1997, which was an epidemic year in Ontario, tillage has evident effects on DON levels. Average DON levels were higher in minimum tillage systems (1.3 ppm) than those in either zero-tillage (0.7 ppm) or conventional tillage (0.5 ppm). Miller et al. (1998) observed that tillage in Ontario was not an influential variable for DON accumulation. Miller et al. (1998) suggested that modest inoculum levels from other sources (not from residue on the soil surface) are required for an epidemic, especially when favourable weather conditions occur during susceptible stages of wheat development.

Using an experiment during 1994-1996, Dill-Macky and Jones (2000) showed that the deoxynivalenol content was influenced by the previous crop residue and tillage treatments. DON was significantly lower in wheat following soybean than in wheat following wheat or maize. DON levels were higher in wheat following maize, than in wheat following wheat. DON levels were lower in wheat harvested from mouldboard plowed treatments and were higher in grain harvested from zero-tillage treatments than from chisel plowed treatments for the previous crop residues of wheat and maize.

Schaasma et al. (2001) found that average DON levels in wheat planted into maize stalk were over twofold higher that those in wheat planted following soybean, or in wheat planted after wheat. He observed that crops planted 2 years before wheat had less effect on DON levels than the crop planted in the year before wheat planting. Only 3% of the variability of DON could be attributed to the crop 2 years before wheat. The average DON level in the fields where maize and wheat were grown 2 years before wheat was at least 57% greater than in the fields where soybean was the crop 2 years previous to the wheat. Crops grown 3 years before wheat accounted for less than 1% of the variation in DON.

Dill-Macky and Jones (2000) showed that grain yields were significantly affected by previous tillage and previous crops. Grain yield was greater in wheat following soybean than in wheat following wheat or maize as in the table. For all wheat on wheat and wheat on maize residue treatments, excepting wheat on maize residue in the 1997 irrigated site, yield was greater following mouldboard plowed than in either chisel plowed or zero-tillage treatments Dill-Macky and Jones (2000). The highest test weights were generally recorded either in mouldboard plowed treatments or in treatments where soybeans were the previous crop.

Using different treatments, such as rotation (continuous maize or wheat and the rotation of both), tillage (conventional, zero and permanent beds), crop residue management (full, partial or remove), Govaerts et al. (2005) showed that zero-tillage with residue retention resulted in higher and more stabile yields compared to conventional tillage with or without residue incorporation. Conventional tillage with or without residue incorporation resulted in intermediate yields. Zero-tillage treatments without residue reduced yields significantly, except in the case of continuous wheat which still performed better than other treatments with zero-tillage and residue removal (Govaerts et al., 2005). Zero-tillage treatments with partial residue removal gave yields equivalent to treatments with full retention (Govaerts et al., 2005). The lowest yields were obtained with zero-tillage with rotation and residue removal, 37% less than the same management with full residue retention. Limon-Ortega et al. (2000) showed that permanent bed (PB) treatments and residue retention as a stubble produced higher wheat yields in high-yielding environments and the lowest grain yields were obtained in the conventional tillage bed with residues incorporated.

5. Conclusion

Disease management employing cultural control options could be a key component in the FHB management strategy. Cultural control options for FHB management principally are focused on crop residues, as the principal source of inoculum. Burying *Fusarium graminearum* infested crop residues in the soil can reduce the *Fusarium graminearum* population, but if decomposition is slowed down, the pathogen may survive for longer periods in the soil. Disease incidence and severity is significantly higher in the chisel plowand zero-tillage treatments of maize residues than in any other treatment combination. The DON level in minimum tillage is higher than in zero-tillage and conventional tillage systems, but is lower in wheat following non-host crops, than wheat following maize. The highest and more stabile wheat yields are obtained in zero-tillage with residue retention compared to conventional tillage with or without residue incorporation.
If there is a move to more intensive maize/cereal cropping or to conservation agriculture, the risk of FHB could increase through increased levels of inoculum, especially under favourable environmental conditions. A move to more resistant cultivars will reduce the risk of FHB and high mycotoxin levels.
Leaving large amounts of residue on the soil surface is a more desirable farming practice (Bockus and Shroyer, 1998). To reduce soil erosion from wind and water, crop residue needs to be maintained on the soil surface. There are many benefits from maintaining crop residues in addition to soil conservation. These include retaining more moisture , slowing water movement, increasing water infiltration, lowering soil temperature and improving habitat for wildlife. Because of these benefits, it is desirable to manage residue borne disease through methods that do not destroy crop residue. Even plant diseases become a yield. Under those conditions the benefits of conservation agriculture should be promoted. It is desirable

because reduced tillage limits soil erosion, conserves soil moisture, reduces production costs and increases yield and stability.

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The influence of different tillage and residue (mulch) on soil moisture for rain-fed crops

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Abstract
Water is the principle limiting factor in dryland cropping systems in many regions of the world. Surface soil physical properties influence infiltration,, and cropping systems under no-till management may affect these properties through residue retention. The objective of this overview is to summarize some experiences with the infiltration characteristics of conservation agriculture (CA) including no-till (NT) vs. conventional tillage systems, soil moisture content and the relative importance of surface residue mulch on infiltration rates, as well as the economical impact and limiting factors for conservation agriculture implementation. The application of surface crop residue mulch seems to be the best soil management practice for increased soil moisture conservation and improved crop performance in rain-fed areas. Soil and water conservation efforts should be seen as a priority and as an effective means of increasing agricultural production in many regions in the world. These factors increase production potential and should ultimately lead to a more efficient, sustainable, and economically viable crop production system. The farmers' inclination to use conventional tillage methods is a problem for the implementation of conservation agriculture and crop residue mulch, but they should be encouraged in this direction because the results are very hopeful.

Keywords: tillage system, residue management, soil moisture conservation

1. Introduction
In many regions in the world, water is the primary limiting factor for crop production (Johnston et al., 2002). Approximately 40% of the world's cropland area is affected by low and unpredictable rainfall, with 60% of these lands located in developing countries (Johnston et al., 2002). Globally, the most important agricultural research is focused on intensive and efficient utilization of the limited soil and water resources. During drought periods, efficient use of limited water is important for plants and soil, particularly in the context of a changing climate. Better practices to reduce costs caused by fuel, labour, equipment and irrigation should be found. Consequently 75% of the precipitation is lost to evaporation, runoff, weed use, etc. (Peterson and Westfall, 1996). One proposed solution to improve water use efficiency in soils is the promotion and use of conservation agriculture (CA) with reduced tillage (RT) or no-tillage, along with retention residue and crop rotation.

The CA principles of minimal soil disturbance, surface residue retention and crop rotation, along with profitability at the farm level, are increasingly recognized as essential for sustainable agriculture. NT alone is an insufficient condition for CA (Erenstein, 2002, 2003). If NT is used without residue retention and without suitable crop rotation, it can be more harmful to agro-ecosystem productivity and resource quality than a continuation of conventional practices (Sayre, 2000; Wall, 1999). In the semi-arid and rain-fed areas of central Mexico, positive effects were observed with no-tillage, crop rotation and crop residue retention, compared with common farming practices (Govaerts et al., 2006). Besides the struggle to reduce costs and fuel consumption, erosion control and increasing water infiltration are still the main driving forces for no-till adoption. Tillage practices and crop residue management affect the way water moves into and through the soil (infiltration), as well as the way water moves from the soil into the atmosphere (evaporation) (Gicheru, 1994).

Conservation agriculture (no-tillage with mulch and crop rotation management), can play a major role in managing soil moisture conditions. The absence or reduction of soil disturbance in no-till both minimizes soil moisture loss from the soil's surface and maximizes soil moisture storage. It enhances beneficial soil physical properties such as the increased infiltration rate, the maintenance of soil macropores and the reduction of surface runoff during rainfall, thus increasing soil moisture storage. Crop residues on the soil surface form a barrier to water loss by evaporation, increasing the amount of moisture stored in the plant root zone which is then available to the crop. Field research has shown higher moisture levels, decreased soil temperatures and more stable soil aggregates (improved soil structure) under zero-tillage (ZT) compared to conventional tillage (CT), (Carter, 1992).

Baker and Laflen (1983) reported that the observed effectiveness of no-till for the conservation of soil and water varies significantly. Runoff from no-till plots was reported to be as great as runoff from conventional tillage plots in some examples (Laflen and Colvin, 1981). However, several researchers have reported increases in infiltration and reduction in runoff due to no-till practises.

From the researcher's point of view, the primary objective of any dry-land farming in marginal rainfall areas should be a sustainable crop production by harvesting and conserving rain water. This calls for soil management practices that not only improve rain infiltration but also conserve adequate soil moisture for plant growth (Gicheru, 1994). Therefore, the present overview was conducted to answer the following questions:

Do reduced tillage and/or residue retention increase moisture in the soil?

Which is the combination of the technological links that contribute to increased soil moisture conservation and improved crop performance?

What is the social and economic impact of such management practices?

Reduced tillage coupled with residue retention and crop rotation would lead to increased water conservation through soil improvements and would, thus:

1. limit the devastating consequences of drought (tillage techniques are important for increasing and conserving the moisture in soil).
2. reduce soil erosion caused by rainfall (as residues protect soil from intense rainfall).
3. increase physical soil quality (better rainfall water infiltration in soil). Long-term no-till studies indicate that organic matter increases over time, further increasing soil quality.

2. Infiltration and soil moisture content

Knowledge of water infiltration under different farming systems is important, because water infiltration greatly influences root zone soil water content, runoff and erosion. Reduced soil erosion from tillage systems which leaves crop residue on the soil surface has been demonstrated by several researchers (Laflen and Colvin, 1981). Some research has demonstrated that reduced tillage and no-tillage practices increase soil moisture content, lower soil temperature and aggregate stability (Kemper and Derpsch, 1981). In Tanzania, some research showed that cereal crops on tied ridges with crop residue mulch performed better than those on open ridges without residue mulch., This performance is attributed to adequate conservation of soil moisture with minimal evaporation water losses (Jones and Mitawa, 1986). With residue mulch, the raindrop impact is absorbed, and erosion and crusting are reduced. The residue mulch slows the runoff, allowing more time for infiltration.

Edwards et al. (1990) reported that infiltration could increase by more than 100 mm yr^{-1} in a watershed farmed with no-till practices, as compared to similar fields that were conventionally tilled. They concluded that the soil's physical properties, possibly macro pores due to earthworm activities, caused the increase in infiltration. Increased earthworm activity has been found by several researchers to be the main reason for increases in infiltration in no-till systems. (Derpsch et al., 1986).

Savabi et al.(2008) conducted an experiment in 1992 to evaluate the infiltration characteristics of no-till vs. conventional tillage systems in different farms in Indiana and Illinois, and to study the relative importance of surface residues and subsurface macroporosity on infiltration rates for both tillage systems using simulated rainfall and the ponding infiltrometer method. In these areas, the results indicated that no-till farms had higher infiltration rates than those of conventional farms when earthworm activity and/or residue amounts were higher in the no-tillage farm. A current agricultural research effort in arid and semi-arid areas of Kenya was focused on intensive and efficient utilization of the limited soil and water resources. In this area the research is aimed at reducing any significant soil and water losses, increasing in situ moisture in the soil profile and, eventually, at increasing crop yields (Gicheru, 1994).

In North Dakota, no-till or direct seeding has many moisture conservation advantages over conventional tillage. No-tillage leaves the most stubble over winter to catch snow. No-tillage does not require tillage before seeding with the possible loss of seedbed soil moisture. No-tillage stubble protects the soil moisture with a mulch cover that limits moisture losses during the growing season. Long-term no-tillage studies indicate that organic matter increases over time, further increasing soil quality (Franzen, 1997).

To investigate the best way to perform fallow and its effect on soil water content (SWC) and root growth after fallow, an experiment was conducted on two soils in La Segarra, a semi-arid area in the Ebro Valley (Spain). Three tillage systems were compared: subsoil tillage, minimum tillage and no-tillage. Consequently, no differences in total water storage efficiency (WSE) were found between tillage systems. During the crop period, the differences in SWC between tillage systems were small. Regarding yields, the best tillage system depended on the year. No-tillage is potentially the best system for executing fallow, but residues of the preceding crop must be left spread over the soil (Lampurlanés, J., et al., 2002). In another semi-arid area in northern Spain, the effects of conservation have been determined. They studied no-till, with and without stubble burning (SB), and reduced chisel-plow tillage –(RT) versus conventional tillage (mouldboard plow –(MT)) on available soil water capacity (AWC) and related properties throughout 5 years of management on a clay loam calcic soil in rain-fed conditions. Available water capacity was greater with no-till than with RT and MT. Higher soil water capacity under conservation agriculture systems (no-till, NTSB and RT) than under MT was attributed mainly to greater available water capacity and to the mulching effect of crop residues. Crop yield in the driest year of the five-year period was lowest under MT, whereas no differences among treatments were found over the five-year period. Stubble burning did not affect AWC nor crop yield. Tillage had a greater impact on soil properties and on crop yield than crop residue management (Bescansa et al, 2006).

In a study conducted in India, in a sub-humid area, rice residue mulching in barley fields conserved 19-21 mm of moisture in a deep soil profile, compared with residue removal. (Sarkar and Singh, 2007). Since 1991, a rain-fed experiment has been conducted by CIMMYT in the central volcanic highlands of Mexico to generate information concerning the enduring effects of tillage/seeding practices, crop rotations and crop residue management on the performance of maize and wheat. The objectives were to determine the effect of different tillage (CT and NT), crop residue management (removal vs. retention) and different crop rotations on infiltration, moisture content, incidence of root rot and nematode populations. Water infiltration and soil moisture levels were greater under NT when residue was left in the field than when residue was removed. Higher infiltration rates and favourable moisture dynamics supported an up-to-30% yield increase (Govaerts et al., 2007).

In semi-arid areas of Kenya, the low crop yields are mainly influenced by variable rainfall. In an attempt to meet the increasing demand for food, cultivation has been extended into more marginal areas, leading to increased pressure on soil and water resources an d exposing them to greater risks of degradation. (Gitonga et al., 2008). Tillage methods such as mulching can play an important role in improving smallholder crop yield and increasing soil matter resources. (Gitonga et al., 2008).

The residue mulch reduces evaporation in several ways: by reducing solar heating of the soil, by keeping drying winds off the soil surface, by insulating the soil to keep it cooler, and by intercepting some of the water as it evaporates. Research has shown that the residue mulch can reduce water losses from evaporation by 50%, saving as much as 7 to 9 cm per year, increasing yields in dry land production or decreasing irrigation costs in irrigation production (Jasa, 2006).

3. The social and economical impact and limiting factors of conservation tillage implementation

Economics is one of the main considerations for accepting or rejecting any technology. The results in many places have shown that returns in no-tillage exceeded those in conventional tillage (Bhan and Bharti, 2008). Compared to conventional tillage, no-tillage has numerous agronomic advantages (Derpsch, 1999; Sayre, 1998). Garcia et al., (2001) record, numerous positive assessments of conservation agriculture by both farmers and scientists in many countries, who highlight simultaneous micro-economic advantages (e.g. increased farm incomes and reduced risk), social and environmental advantages (e.g. enhancement of soil resources, improved soil structure, better water infiltration and consequently reduced water runoff and soil loss). No-till increases flexibility in the timing of crop operation and crops can be planted closer to the optimal dates. Net savings in terms of the cost of fuel, herbicides and labour under no-tillage in wheat have been reported to be US$35-60/ha in Uttar Pradesh (Manhanta, 2002).

The inclination to use conventional tillage methods is a problem for implementation. Other factors included general lack of information and skills on conservation tillage methods among smallholder farmers and low incomes that hindered the farmers' capacity to access no-till machinery and purchase herbicides. An economic advantage is important. Conservation tillage (no-till) reduces costs by 20-25% compared to conventional tillage, improving the social and economic situation of farmers.

Conclusion

The infiltration rate and cumulative infiltration follow, in general, this trend: no-till + residue retention > till + residue retention > till with residue removed. Regarding soil moisture content, in general, no-tillage with residue retention associated with crop rotation had higher soil moisture, even in the deeper layers, than when residues were removed or the other tillage practiced. To improve moisture infiltration rates and soil moisture levels under no-tillage, it is critical to leave crop residue in the field. Farmers should be encouraged to leave the residue in the field after harvest to act as mulch. Residue mulching as a soil management practice would be recommended, despite the problems which can be associated with the time that its available. No-tillage reduces costs by 20% compared to conventional tillage, due to the reduced use of machinery and the increased yield, thereby creating a profit.. Efforts should, therefore, be made to promote conservation tillage among farmers.

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* **I would think that** "the primary objective of any dry-land farming in marginal rainfall areas" would be the production of a viable crop so the farmer can survive.

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The effects of conservation agriculture on runoff, soil loss and yield performance under rain- fed in Adigudem, Northern Ethiopia

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Abstract

Conservation agriculture (CA) is a technique that can mitigate the reduction in soil fertility, reduce runoff and top soil erosion and increase in situ moisture conservation, thereby increasing crop yield. This study was carried out in rain-fed fields in Adigudem in northern Ethiopia. The objective of this study is to evaluate the impacts of CA on runoff and soil loss, and on crop yield improvements. The CA practices were introduced on farmers' fields on vertisols in Adigudom (13⁰14'N, 39⁰32'E) in 2005. The experimental layout was arranged according to a randomized complete block design with 2 replicates. Treatments included conventional tillage (CT) which was plowed 3 times and residue removed, terwah (TER) plowed 3 times, residues removed and furrows made at 1.5 m distances, and permanent bed (PB) with 30% residue retention, zero-tilled with a 60 cm wide bed size. All the plowing and reshaping of the furrows was done using the local ard plow, maresha. *Data on soil loss, runoff and grain yield were collected. The crops in rotation were wheat and teff. There was a significant reduction (P<0.05) in runoff in PB under wheat in 2005, whereas the reduction was non-significant in 2006 and 2007. The soil loss was significantly lower in PB in 2005 and 2006. Soil loss in 2005 under wheat was reduced by 76% in PB and 61% in TER as compared to CT. Similarly, the reduction in soil loss in 2006 under teff was 86% in PB and 53% in TER. There was no significant difference (P<0.05) for wheat yield in 2005 and 2007. However, there was a significant difference among treatments in 2006 with higher teff yield in CT followed by TER. In summary, permanent bed reduced soil loss and runoff, hence increasing the wheat yield.*

Keywords: terwah, permanent bed, crop residue, wheat, teff

1. Introduction

Land degradation in northern Ethiopia is a great problem, mainly aggravated by overpopulation in the highlands, over cultivation, soil erosion and an unbalanced crop and livestock production system (Girma, 2001). Studies conducted at Dogu'a Tembien showed that the mean annual soil loss rate by sheet and rill erosion in the absence of stone bunds was 57 t $ha^{-1}yr^{-1}$ (Desta et al, 2005). As a consequence of the loss of the top fertile soil by erosion, there is a severe decline in soil fertility. The poor infiltration and water-holding characteristics of the soil makes water a key limiting factor for crop yield in this area. The soil needs to capture the rain water that falls on it, store as much of that water as possible for future plant use, and allow for plant roots to penetrate and proliferate for optimum crop yield (FAO AGL, 2004). Constraints due to one or several of these conditions cause soil moisture to be one of the main limiting factors for crop growth.

The livelihood of 85 % of the population of Tigray depends on agriculture, mainly on crop production. Small units of land have been extensively cultivated by subsistence farmers for centuries. The rain-fed farming agriculture is dominant and has low productivity. The rainfall in the region is erratic and insufficient during the growing season (Ermias et al., 2005). It is common to observe both water logging and drought in one cropping season (personal observation). Soil moisture in the vertisols is insufficient due to periodic drought, low moisture-holding capacity of the soils, high tillage frequency, periodic excess of rain water and high runoff rates from sloping lands (Mati, 2006). Tillage is done with a breaking plow, known locally as *maresha*. The custom is to plow frequently before sowing which may result in compaction, poor drainage and crusting in the vertisols. Besides, farmers harvest the straw of crops in order to feed their animals, leaving no residues as soil cover. There is also free grazing of animals on the stubble residue after harvest. This operation has led, in the long term, to reduced soil organic matter content which later increased soil erosion processes (FAO, 2006). Nyssen et al. (2006) reported that soil and water conservation structures such as stone and soil bunds have been effective. Recent policy in Tigray region favors further in situ water conservation, stubble management and the abandonment of free grazing.

Vertisols are hard when dry, sticky when wet and susceptible to erosion depending on how they are managed and on their top soil structure and texture (Deckers et al., 2001). McHugh et al. (2007) reported that ridges significantly increased soil moisture and grain yield, and reduced soil loss in north Wollo, Ethiopia. Experiments conducted in Mexico by Govaerts et al. (2005) with zero-tillage treatment combined with rotation and residue retention showed improvements in yield (average maize and wheat yield of 5,285 and 5,591 kg ha^{-1}) as compared to heavy tillage before seeding, monocropping and crop residue removal (average maize and wheat yield of 3,570 and 4,414 kg ha^{-1}). He reported that permanent bed with crop rotation and residue yielded the same as zero-tillage. Various studies on CA outlined the benefits as it allows early sowing, growing long maturing crops/varieties, reduces runoff and evaporation, reduces soil loss, conserves soil moisture, increases labor efficiency, reduces oxen and straw demand and enhances soil fertility (Nyssen et al., 2005). In contrast to traditional agriculture, conservation agriculture leaves residues from the previous crop on the surface. It may store a considerable amount of water and increase roughness, slowing down the runoff flow velocity (Gilley et al., 1986; Findeling et al., 2003). This will have a significant effect on the soil water balance and its components. Conservation agriculture technology retains water at the farm level through improving the physical and chemical properties of soils. Changes in chemical parameters are largely a function of changes in physical composition. However, the comparison of conservation agriculture and traditional agricultural practices over different time periods has not been consistent across soils, climate and experiments in different parts of the world (Ahuja et al., 2006). To improve the soil's physical and chemical properties, to increase the in situ water conservation and to increase crop yield, conservation agriculture and other CA based resource-conserving technology practices, like permanent bed and modified terwah tillage systems, were introduced in Adigudom in 2005 with the aim of conserving moistureand reducing runoff and soil loss on farmers' fields, hence increasing crop yields on the vertisols. In Tigray, farmers used to make contour furrows at 2-4 m intervals, locally called terwah, usually on teff, to trap water for later crop use instead of it being lost as runoff.Therefore, the objective of this study is to evaluate the runoff , soil loss and crop yield improvements under conservation and conventional agriculture in northern Ethiopia.

2. Materials and methods

2.1 Description of the study area

Tigray is characterized as a cool tropical semi-arid climate, with recurrent drought induced by moisture stress. Total rainfall is 500-800 mm falling from June to September. Sowing begins in mid-June and harvesting ends in December. The length of the growing period varies generally between 45 and 120 days (Krauer, 1988; CND, 2002).

The farming system in the region is mixed, with both crop and livestock. The main crops grown in Adigudem are teff (*Eragrostis tef.*), wheat (*Triticum sp.*), barley (*Hordeum sp.*), hanfets (a mixture of barley and wheat), sorghum (*Sorghum bicolor* (L).Moench), millet (*Eleusine coracana*), maize (*Zeamays L.*) and lentil. The sowing method is generally broadcasting manually.

2.2 Description of the field experiment

The experiment was conducted under rain-fed and started in 2005 in Adigudem ($13^0 14'$N, $39^0 32'$E) which is located in Tigray northern Ethiopia. The experimental layout was arranged in a randomized complete block design with two replications. The plot size was 5m wide and 19m long. The sowing method was manual broadcasting for both crops (wheat and teff). The slope gradient was 3%. The major limitations for crop production are periodic drought, periodic water logging and water erosion. The soil under the experimental trial was vertisols. The different treatments were: conventional tillage (CT) plowed three times without residue, terwah (TER) plowed 3 times without residue and furrows made at 1.5m intervals along the counter, and permanent bed (PB) with 30% residue, zero-tilled and 60cm wide beds. All the plowing and reshaping of the furrows was made using maresha. Fertilizer was applied uniformly to all treatments. Glyphosate was applied to control pre-emerged weeds in the PB treatment. However, hand weeding was used as post-emergence weed control in all treatments.

2.3 Data collected

Parameters such as runoff, sediment loss and grain yield were collected. Runoff was measured in 5m wide and 19m long trenches, which were located at the down slope end of each plot and covered with plastic sheets. The runoff amount was determined every morning after each rainfall that caused erosion by measuring the height of the water level in the middle and at both sides of the trench. Prior to the experiments, the trenches were calibrated for their volume by relating a known amount of water to the water depth at the same three locations. The collected runoff water was then stirred thoroughly and 4 liters was taken from each trench to determine sediment concentration. These were filtered in the laboratory using funnels and filter papers. The sediment in the filter paper was oven dried for 24 hours at 105°C and then weighed.

2.4 Statistical analysis

The data was analyzed using SAS statistical software (JMP5) and a standard error of means was used for the separation of treatment means using the Turkey HSD at 5% significance level.

Results

3.1 Soil loss and runoff

There was a significant difference ($P < 0.05$) in runoff among all treatments in the first year (2005) for wheat, with less runoff recorded in PB followed by TER. However, there was no significant difference for runoff among all treatments in the second and third years (2006 and 2007) when the crop was teff and wheat, respectively (Fig. 1). Even though non-significant, the PB treatment has revealed a reduction in 50% runoff followed by 16% in TER. There was a similar trend in 2007 when the crop was wheat, as compared to 2006.

There was a significant difference ($P < 0.05$) in soil loss in 2006 and 2007 in wheat and teff, respectively. The soil loss reduction in 2005 for wheat was 76% in PB while 61% in TER as compared to CT in Adigudem. Similarly, the reduction in soil loss was 86% in PB and 53% in TER as compared to CT in 2006 in teff (Fig. 2).

3.2 Yield performance

There was no significant difference ($P < 0.05$) between treatments for wheat yield in 2005 and 2007. However, there was a significant difference among treatments in 2006 with a higher teff yield obtained in CT followed by TER. The lowest teff yield was recorded in PB. Although the difference was not significant, the yield of wheat in 2005 and 2007 showed that there was a higher yield record in PB followed by TER. In contrast to the 2006 teff yield, the lowest wheat yield in both 2005 and 2007 was recorded in CT (Fig. 3).

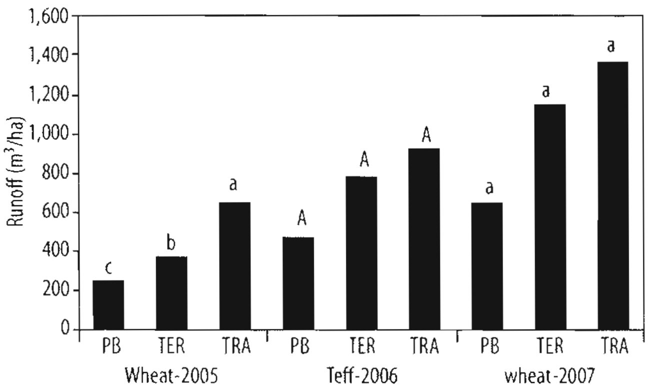

Fig. 1. Average runoff amount from each treatment during the whole growing period across 3 years in Adigudem.

A letter on the top of each bar graph indicates the significant difference among treatments per one year. PB = Permanent bed tillage; TER= Terwah tillage; CT= conventional tillage

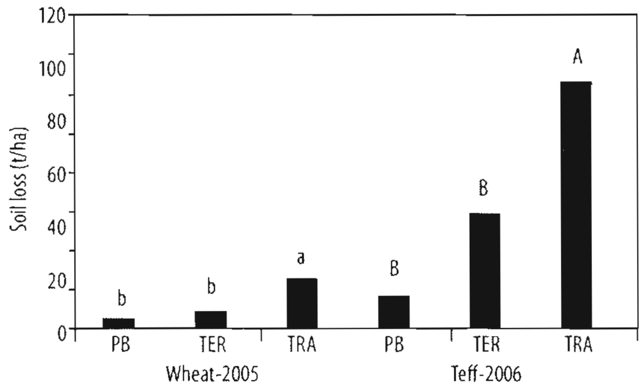

Fig. 2. Average soil loss from each treatment during the whole growing period in 2005 and 2006 in Adigudem.

A letter on the top of each bar graph indicates the significant difference among treatments per one year. PB = Permanent bed tillage; TER= Terwah tillage; CT= conventional tillage

Discussion

4.1 Soil loss and runoff

Soil erosion is one of the most serious environmental problems in Ethiopia (Bekele and Stein, 1998). The experiment revealed a significant reduction in soil loss across all years in PB as compared to CT, showing a potential for recovering the degraded lands in Ethiopia. Wakeel and Astatke (1996) reported that the Ethiopian Highlands are losing alarming amounts of soil, estimated at more than one billion tons annually. They reported that this loss, which is associated with nutrient losses, is manifest in declining agricultural production and biodiversity. They confirmed that about 80% of the annual soil loss had occurred from croplands during the rainy season. The introduction of stone bunds to the Tigray region has led to a 68% reduction in annual soil loss due to water erosion (Desta et al., 2005). Bekele and Stein (1998) reported a difference in soil loss from different crop farms, indicating a higher loss from teff as compared to wheat, which supports our results. Studies conducted on arid land in south-central Chile on no-till practices, including crop residue management, showed a reduction in the net erosion rate by about 87% compared to conventional tillage and, therefore, resulted in significant decreased soil and nutrient loss (Paulina et al, 2007). Kwaad et al. (1998) reported that a surface mulch of straw was the most effective measure in reducing runoff and erosion, by 46.5 and 89.5% respectively, compared with the conventional system in Dutch South-Limbourg. In Ethiopia, a similar trend was seen.

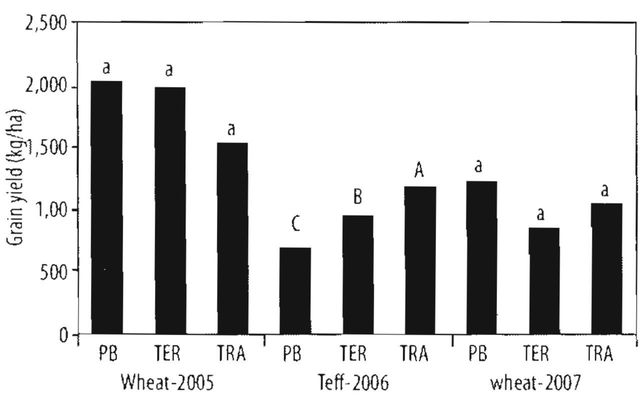

Fig. 3. Average grain yield (kg/ha) trend in conservation and conventional agriculture across 3 years in Adigudem

A letter on the top of each bar graph indicates the significant difference among treatments per one year. PB = Permanent bed tillage; TER= Terwah tillage; CT= conventional tillage

4.2 Yield performance

The total grain yield for wheat responded non-significantly ($P < 0.05$) in all treatments in 2005 and 2007. Although non-significant, PB showed a higher wheat yield followed by TER in all years. Govaerts et al. (2005) reported that conservation agriculture can take 5 years before the benefits are evident. We found a wheat yield increment of 33.3% in PB as compared to CT (Fig. 3) in the first year of the trial. Under subtropical conditions, Govaerts et al. (2005) observed a yield increment of 25 to 30% through adoption of CA as compared to CT. The wheat yield increment of 33.3% in PB in one year indicates the potential of CA in improving crop yield in the Tigray region. Gebreyesus (2003) also reported the importance of bed and furrow planting in increasing crop yields and increasing time for water to penetrate the soil, substantiating the yield increment in permanent bed.

In contrast with wheat, the yield of teff in 2006 was significantly higher ($P > 0.05$) in CT as compared to PB and TER. Farmers usually plow their teff farms 4-6 times before sowing to reduce weed damage for which this crop is found most susceptible. As well, farmers removed weeds by hand from the teff fields 2-4 times per season. Teff is the most frequently tilled and the most frequently weeded compared to any other crop in Ethiopia, which makes it the most labor intensive before and after sowing. After frequent tillage, teff is sown by broadcasting on top of the most recent freshly-tilled farm land and covered with soil by moving branched shrubs or goats and sheep over the sown teff.

Tigist (2007) reported a higher weed density in the PB as compared to CT throughout the season which substantiates the lower yield obtained in PB. Taddesse (1969) explained the need for well pulverized and smooth seed beds for sowing teff. However, Teklu et al. (2005) found that reduced tillage gave the highest grain yield of teff, compared to broad bed and furrows, green manure and traditional tillage practices with the application of non-selective herbicide, although the difference was not significant. Research on the Akaki vertisols of Ethiopia have showed that, with application of round up, the yield of teff was found to be similar to that of conventional tillage (SG, 2004).

Conclusion

Based on the three years of data, runoff was significantly reduced in PB followed by TER as compared to CT in 2005. Although not significant, there was lower runoff in PB in 2006 and 2007. There was a significant difference in soil loss reduction, which was lower in PB compared to CT. However, there was no significant difference in soil loss between PB and TER. Although the difference was not significant, the yield of wheat showed an increase in both in 2005 and 2007. The yield of teff in 2006 was significantly lower in PB compared to CT.

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Weed control in conservation agriculture

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Abstract

The effect of conservation tillage on annual and perennial weedsis reviewed here. This includes weeds that are spread by wind, plants from rangelands and pastures as weeds and volunteer plants as weeds. Current weed control methods with minimum tillage, herbicides, cover crops and other cultural practices in conservation agriculture are described. Successful conservation agriculture usually involves cropping sequences of three or more crop types and several herbicides. Until recently, the primary disadvantage of total no-till crop productions was an increase in perennial weeds that required primary and seedbed tillage for control. Most herbicides used pre-emergent in crops only controlled germinating weed seeds and not established perennial plants. Most post-emergent herbicides lacked selectivity for effective perennial weed control. Post-harvest or before planting herbicide treatments for perennial weeds were limited in efficacy because of possible soil residuals or improper weed size. The development of glyphosate tolerant crops and the use of pre- and post-harvest glyphosate have essentially eliminated the perennial weed disadvantage for conservation agriculture. Glyphosate controls annual weeds with excellent selectivity in tolerant crops. Other benefits of no-till crop productions, such as reduced soil erosion and greater stored carbon, can now be achieved, simply, effectively and economically through herbicides that are safe to the user and the environment.

Keywords: weed control, tillage, herbicides

1. Introduction

Weed control is considered a serious problem in conservation agriculture. One of the primary reasons for tillage is to control weeds. Perennial weed control requires multiple tillage operations to reduce the energy reserves in the roots or other storage organ (Todd and Derksen, 1986; Fawcett, 1987). Annual weeds are controlled with equipment which may encourage germination, bury seeds or sever roots (Holm and Kirkland, 1986; Peeper and Wiese, 1990).

Wheat is grown without tillage in the double cropping system involving soybeans or other summer crops in Brazil (Petten, 1990), Argentina (Marelli and Lattanzi, 1982), and the USA (Ritter and Kaufman, 1989). Eco fallow systems with wheat–sorghum or maize fallow rotations are successfully used in the Central Great Plains of North America. Although zero-tillage production systems occupy 1-2% of the total planted area on the Canadian prairies (Dyck and Zentner, 1990), individual producers are successfully controlling weeds in conservation tillage systems. Crop yields are generally equal for conventional and conservation tillage systems provided that weeds are controlled and proper crop stands obtained (Norwood, 1994).

Successful conservation agriculture, regardless of definition, is highly dependent upon effective weed control. In the past, attempts to implement reduced tillage conservation practices have often caused a loss in crop production because the reduced tillage did not adequately control weeds. The development of highly-active post-emergent applied herbicides and crop-tolerant to broad-spectrum herbicides provide for simple effective weed control for conservation tillage practices (Nalewaja and Ahrens, 1998). The use of selective herbicides on the crops and non-selective herbicides in place of primary tillage was the impetus for conservation no-till agriculture. Recently no-till crop productions has increased with the release of cultivars tolerant to herbicides or mixtures of herbicides with effectiveness for a wide spectrum of weed species. In 2000, 60% of the soybeans in Ohio were planted without tillage and no-till maize was planted to 24% in Ohio, 21% in Indiana (Soybean Digest.com, January 2001). This relatively large area of no-till production was possible primarily because of Roundup Ready and various effective herbicide programs for weed control in maize.

Several studies have indicated that conservation tillage (no-till and maintaining a crop residue on the soil surface) has caused an increase in the density of perennial weeds, annual grassesand plants with wind dispersed seeds (Pollard and Cussans, 1976; Fay, 1990). In spite of these difficulties, conservation tillage is successful in large areas.

The glyphosate and post-emergence herbicide applications decrease weed amounts. The development of selective post emergent herbicides greatly increased the potential for conservation agriculture. The earlier developed pre-emergent herbicides only controlled germinating weed seeds or required a timely rain for efficacy.

2. The effect of the tillage system on weed populations

Annual weeds have the ability to germinate, grow rapidly and produce seeds between seed bed tillage and harvest. Seeds from these plants often remain dormant for several years when they are buried by tillage and may germinate when brought to the surface and exposed to appropriate light, moisture and temperature (Fay, 1990). Populations of annual weeds that are adapted to the conventional tillage system, should decline if these weeds are controlled from the first few years that a no-tillage system is used, because viable seeds are not returned from deep soil layers to the surface by cultivation (Fawcett, 1987). In Brazil, Argentina and Norway annual weeds have declined in the no-till system (Roman and Dinonet, 1990). The same annual weeds are favored by the conservation tillage system. The winter annual, *Bromus tectorum*, is one example of a weed that is well adapted to continuous winter wheat produced under the conservation tillage system, because its seed germinates and grows successfully on the soil surface (Fay, 1990). Therefore, the use of crop rotations is crucial in order to be able to use herbicides with a different spectrum.

Biennial weeds are not well adapted to tillage systems as they are easily removed by tillage. These biennial weed problems may not be intrinsic to conservation tillage, but may be influenced by additional management factors (Derksen et al., 1993).

Conventional tillage, however, can be expected to favor the rhizomatous, stoloniferous and to a lesser extent, the top-rooted perennial weeds. Perennial weeds are often too small before seeding for maximum absorption and translocation of herbicides such as glyphosate. However, conservation agriculture and no-till maintain a crop residue on the soil surface that keeps the soil cooler and more moist, increasing survival of germinating small seeded weeds as compared to conventional agriculture (Ball and Miller, 1993).

3. Herbicides and conservation agriculture

Treatments in the autumn or spring before sowing wheat usually include glyphosate or paraquat in combination with 2,4D, dicamba, or bromoxinil. Glyphosate is used frequently between crops for the control of perennial weeds,which are a major problem in wheat in North America. *Convolbulus arvensis, Cirsium arvense* can be controlled or suppressed with herbicides such as 2, or suppressed with herbicides such as 2,4D, dicamba. Atrazine was registered for weed control on fallow for a short period in Canada, but cool dry conditions made the risk of residues damaging the following wheat crop too great and the registration was withdrawn (Brandt and Kirkland, 1980). Atrazine has been used in the Central and Northern Great Plains in the USA (Wicks and Smika, 1990). Sulfonyl urea herbicides such as chlorsulfuron have provided effective long-term, broad-leaved weed control on summer fallow. Use of these persistent herbicides, has led to the appearance of weed biotypes resistant to sulfonyl urea herbicides at several locations on the Northern Great Plains (Holt and LeBaron, 1990).

Selective herbicides, by definition, control weeds in crops without injury to the crops. The development of crop cultivars tolerant to herbicides with broad spectrum efficacy in various environments greatly simplifies and assures effective no-till crop production.

In the double cropping systems in Brazil, the time and the weather conditions in the interval between the harvest of one crop and the seeding of the next can determine the need for a non-selective herbicide application, especially before seeding summer crops. Under normal weather conditions a long intercrop period produces large weeds that are difficult and expensive to control. This problem is exacerbated when farmers leave fields fallow during the winter. Under fallow conditions, applications of 2,4D are recommended to prevent weeds from reaching advanced growth stages before the seeding of summer crops. The weeds of summer crops are more competitive, difficult and costly to control than those of winter crops (Roman, 1990). In wheat, most of these weeds begin to germinate in the spring and can continue through the summer season when conditions are wet and warm. Control can be achieved by applications of paraquat, paraquat plus diuron or glyphosate alone, or in a mixture with 2,4D (Roman and Dinonet, 1990).

Perennial weeds cause major problems in wheat in the Northern Great Plains. The top growth of *Cirsium arvensis, Convolvulus arvensis* can be controlled or suppressed with herbicides such as 2,4D, dicamba, dichlorprop and metsulfuron. Perennial grasses must be controlled after harvest, before seeding or in an alternate broadleaved crop. Producers are primarily dependent on the herbicide, glyphosate, for control of the perennial weeds in periods between crops.

4. Conclusions

Weeds respond to the environment, and no-till, greatly-reduced root and seed disruption increases soil moisture and decreases soil temperature. All of these conditions will influence the number and type of weed species. Thus, effective weed control for various species is essential for successful long-term conservation agriculture.

The availability of a wide range of selective and non-selective herbicides has made conservation tillage, crop rotation systems possible. Weed problems in no-till systems, particularly with annual grasses, seem to be associated mainly with continuous single crop production systems. In successful conservation agriculture, the soil is covered with a crop or a cover crop during most of the period that the climate is favourable for weed germination and growth. In conservation agriculture that includes crop rotations, continuous cropping or use of cover crops, and that limits the application of herbicides for perennial weed control to patches, herbicide use ranges from much less to slightly more than that used in conventional agriculture.

Weed scientists must be proactive in determining potential weeds and their control for long-term successful conservation agriculture. The development of herbicide-resistant crops used in conjunction with methods to prevent weed resistance will allow for large long-term increases in conservation agriculture.

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Maize production and soil properties as effected by tillage system and fertilizer management: a review

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Abstract

Traditional soil cultivation systems, with intensive soil tillage, will generally lead to soil degradation and loss of crop productivity. The conservation agriculture principles of minimal soil disturbance, surface residue retention and crop rotation along with profitability at the farm level, are increasingly recognized as essential for sustainable agriculture. Alternatively, no-till alone is an insufficient condition for conservation agriculture because, under some circumstances, it can be more harmful to agro-ecosystem productivity and resource quality than a continuation of conventional practices. Nitrogen (N) input is one of the most important factors in maximizing yields and economic returns to farmers. The crop nitrogen requirement is met from several sources, including mineralization of nitrogen from soil organic matter and crop residues and biological fixation of atmospheric nitrogen. It is also met from external sources such as irrigation water, precipitation, animal manure and commercial fertilizer. As the price of fertilizer increases, the importance of an accurate estimate of the most economical application rate increases. This review will demonstrate that no-till with crop residue retention, crop rotation and correct nutrient management influences soil physical, chemical and biological and that can impact the long--term sustainability of maize production systems.

Keywords: conservation tillage, no-till, maize, nitrogen fertilizer, soil quality

1. Introduction

A reduction in soil quality as a result of human activities can be defined as soil degradation. Water erosion, wind erosion, chemical degradation (including nutrient depletion and loss of organic matter, salinization, acidification and chemical pollution) and deterioration of physical properties are the four major types of soil degradation (Kenneth, 1999). Subtle changes in soil properties and subsequent effects on yield and input requirements illustrate the complexity of the relationships between soil quality and cropping system performance. Declining farm productivity resulting from escalating soil erosion and soil degradation in conventional cultivation cropping systems has now reached significant proportions. In response to this phenomenon, conservation agriculture has been developing rapidly in many parts of the world (FAO, 2008).

Conservation agriculture 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 (FAO, 2008). Conservation agriculture is defined as any management system that includes the following characteristics (Wall, 2006): first, a serious reduction in soil movement with the ultimate goal to eliminate it completely except for the disturbance caused when sowing i.e. no-till; second, the preservation of a permanent or semi-permanent organic cover, i.e. standing crop or a layer of stubble, on the soil; third, the rotation of economically viable crops. In conservation agriculture conditions, traffic on the field decreases, crop residues are not buried and soil structure is not vertically perturbed. It results in reduced compaction layer problems and less physical destruction of the soil structure and fauna habitat (Thomas, 2001, cited by Guedez, 2001). The highest biological activity and organic matter content on the top horizon results in a very good soil structure, with good porosity, drainage, absorption capacity and structural stability, and better trafficability (Basch and Carvalho, 1996). However, soil structure and compaction problems can still occur, depending on soil type, management and weather, particularly on unstable soils. Moreover, the impact of raindrops on the soil surface is limited by the physical protection offered by crop residues (Thomas, 2001, cited by Guedez, 2001). As a consequence, soils become much more resistant to crust creation, and the better infiltration rates obtained under conservation agriculture, which are positively correlated to a decrease in runoff speed, allow a huge reduction in global runoff (Lavier et al., 1997). Other benefits of conservation agriculture include reduced labor, fuel and machinery wear, increased soil organic matter, improved water and air quality and increased wildlife (McLaughlin and Mineau 1995).

Nitrogen (N) input is one of the most important factors in maximizing yields and economic returns to farmers. Of the essential nutrients, N is required in large quantities, and it is the most mobile and dynamic nutrient in soil systems. It is well documented that the soil's physical and chemical properties are spatially variable and affect N dynamics and the mechanisms for its losses. For example, N dynamics could vary from high denitrification N_2 losses from ponded areas with low drainage to high NO_3 leaching losses from coarse-gravely areas of the field (Khosla et al, 2002).

Conservation agriculture systems may increase both N immobilization (Gilliam and Hoyt, 1987) and N losses from leaching (Tyler and Thomas, 1977) and denitrification (Gilliam and Hoyt, 1987). Other authors report that synchronization of residue N mineralization, fertilizer N application time and subsequent crop demand for N can improve N use efficiency in crops planted in conservation agriculture systems (Reeves et al., 1993). Requirements for N in no-till systems differ from those in tilled systems and, depending on how N is managed, the efficiency of the use of fertilizer N may be either lower or higher than with tillage. At present, no significant differences have been found among tillage systems in terms of N application or tools for N management (Christensen, 2002). The N-cycle is linked to the C-cycle: the presence of mineral soil N available for plant uptake is dependent on the rate of carbon (C) mineralization. In the literature, contrasting results concerning the impact of the N immobilization have been reported. Nitrogen release is delayed when residues are left on the soil surface (Bradford and Peterson, 2000). Some authors suggest that the net immobilization phase, when no-till is adopted, is transitory and that, in the long run, the higher but temporary immobilization of N in no-till systems reduces the opportunity for both leaching and denitrification losses of the mineral N (Follet and Schimel, 1989; Lamb et al., 1985; Rice and Smith, 1984). Jowkin and Schoenau (1998) report that N availability was not greatly affected in the initial years by switching to no-till in the brown soil zone in Canada. Others report that conventional tilling systems accelerate organic matter mineralization, resulting in more nutrient availability than under no-till (Christensen et al., 1994; Doran, 1980).

Over the past years, various agronomic management systems have been proposed to improve the tillage systems and nitrogen management of maize in the context of sustainable agriculture. One proposed solution is no-till, with crop residue retention, rotation and correct nitrogen management, which are essential to maintain mineral nutrients within the soil, stop erosion, and prevent water loss from occurring within the soil, as well as increase N uptake and, thus, maize yield.

Maize is widely cultivated throughout the world and a greater weight of maize is produced each year than of any other grain. America produces almost half of the world's harvest of maize and represents over 90% of area under no-till conservation agriculture (wikipedia, 2008).

This review will look at the following research questions:

1) Is no-till better than conventional tillage?

2) Can fertilizer N management be greatly affected by changes in tillage?

The hypotheses formulated are:

1) The slowest plant growth, the lowest grain yield, the lowest proportion of fine aggregates, the highest bulk density and the greatest penetrometer resistance are expected in zero-tillage with residue removal. No-till planting systems with crop rotation and residue retention would lead to yield improvements through: (i) increased soil quality and (ii) increased N uptake.
2) Fertilizer N management can be effected by changes in tillage. Soil moisture and temperature, which are greatly effected by tillage, will impact soil N dynamics.

2. Influence of no-till on maize growth and yield

The delay in growth due to low soil temperature associated with the no-till system in the Corn Belt (USA) (Gupta et al, 1988; Imholte and Carter, 1987; Mock and Erbach, 1977) is not appreciable in the Southern USA. In a long-term study with continuous maize established in Ontario, Canada, on a moderately-drained no-till resulted in a 2 day delay in emergence and a 2-to-4 day delay in silk emergence, compared with fall plow (Vyn and Raimbault, 1993). Earlier studies in Ontario, on primarily coarse-textured soils, however, recorded no significant delay in emergence for no-till relative to fall plow (Vyn et al., 1979). Al-Darby and Lowery (1984) reported no differences in maize emergence in a continuous maize situation for fall plow, chisel plow and no-till on silt loam and sandy loam soils. No-till recorded higher plant heights, leaf area index and leaf numbers, on a Gleyic Luvisol in northern New York, while plow tillage recorded higher per plant leaf area, stem and root biomass (Karunatilake et al., 2000).

On well-drained soils, maize yields were less with no-till than with tillage in studies conducted in Iowa (Chase and Duffy, 1991), Indiana (West et al., 1996), north-western Iowa (Bakhsh et al., 2000), and Wisconsin (Lund et al., 1993). In contrast, yields were greater with no-till in Ohio (Dick et al., 1991). To further complicate the issue, no differences in yield between no-till and tilled treatments were reported for studies conducted in Michigan (Hesterman et al., 1988) and Wisconsin (Lund et al., 1993; Al-Darby and Lowery, 1986). Maize yield was greater with ridge-till than with no-till in Indiana (West et al., 1996) but not different in Nebraska (Cahoon et al., 1999) and Wisconsin (Al-Darby and Lowery, 1986). Griffith and Wollenhaupt (1994) summarized these differing results by stating that the probability of a maize yield increase with no-till is greatest on well-drained soil when grown in rotation and in southern latitudes of the United States. No-till with crop rotation and residue retention resulted in a stable, high yield of maize compared to conventional systems in the highlands of Mexico (Govaerts et al., 2005). In Brazil sizable yield increases and income stability for the farmer led to a wide adoption of the no-till system (Saturnino and Landers, 2001). A study in west-central Saskatchewan, Canada, has shown that grain yields can be improved with no-till, providing there is an adequate weed control and plant stands (Brandt, 1992). No-till systems can develop yields equal to or slightly less (3%) than conventional tillage, while maintaining significantly greater residue coverage. Maize growth and yield may respond positively to planting corn rows on beds (Govaerts et al., 2005; Limon-Ortega et al., 2002; McFarland et al., 1991; Harris and Krishna, 1989) .

3. Influence of no-till on soil properties (physical and chemical)

Soil water retention was greater under no-till, with residue retention compared with conventional tillage without dramatically altering bulk density due to redistribution of pore size classes into more small pores and fewer large pores. Soil organic C was greater under no-till combined with residue retention than under conventional tillage nearest the soil surface. Water-stable aggregation improved under no-till combined with residue retention compared with conventional tillage, perhaps because more soil organic C was sequestered within macro-aggregates under no-till combined with residue retention compared with conventional tillage and that helped to stabilize these aggregates. Steady-state water infiltration was greater under no-till combined with residue retention than under conventional tillage as a result of soil structural improvements associated with surface residue accumulation and lack of soil disturbance (Govaerts et al, 2007; Arshad, 1999). The lowest proportion of fine aggregates, the highest bulk density, the greatest penetrometer resistance and the worst chemical soil quality (the lowest soil pH in 0-5 cm depth, the lowest SOC) resulted in no-till with residue removal (Vyn, 1993).

Rapid acidification of the soil surface when high nitrogen fertilizer rates were used was the most obvious chemical change. Increased levels of exchangeable Al and Mg were associated with reduced soil pH. Exchangeable Ca was significantly lower for no-till at depths and all nitrogen fertilizer rates compared with conventional tillage. Exchangeable Mg in the 0- to 5-cm soil depths declined with increasing nitrogen fertilizer and was lower in no-till soil depth compared with conventional tillage (Blevins et al., 1983). Duiker and Beegle (2006) observed that tillage did not effect total extractable Ca or Mg levels. Potassium (K) was concentrated in the 0- to 5-cm soil layer under no-till and decreased with depth, where crop roots proliferate (Franzenluebbers and Hons, 1996; Blevins et al., 1983). Du Preez et al. (2001) observed increased levels of K in no-till compared to conventional tillage, but this effect declined with depth. Follet and Peterson (1988) observed either higher or similar extractable K levels in no-till as compared with mouldboard tillage, but Duiker and Beegle (2006) found no effect of tillage on available K concentrations. Astier et al. (2006) observed a significantly higher total N under no-till compared to conventional tillage in the highlands of Central Mexico. The same results were obtained by Borie et al. (2006), Atreya et al. (2006) and Govaerts et al. (2007).

Most comparative field studies have shown that no-till results in greater accumulation of soil organic matter (SOM) in surface layers (0-20 cm) than does conventional tillage (Govaerts et al., 2006; Kern and Johnson, 1993; Lal, 1989; Blevins et al., 1983). The higher SOM under no-till was attributed to reducing the amount of tillage and increasing soil water storage, which increases the amount of plant biomass returned to the soil surface (Tarkalson, 2006). Soil under no-till typically has increased soil organic matter content and improved aggregate stability in the 0- to 5-cm depth, but these properties often are not improved in deeper soil with no-till compared with deep tillage (Doran, 1987; West and Post, 2002). Soil compaction is a concern in no-till because of the absence of alleviation through tillage. The negative effects of compaction on plant growth (Nevens and Reheul, 2003), soil physical properties (Botta et al., 2006; Abu-Hamdeh and Al-Widyan, 1999), and maize yields (Lal, 1996) have been reported in no-tillage systems. Therefore, no-till systems have to be combined with controlled traffic. On the other hand, long-term use of no-tillage results in increased surface organic matter contents, more stable soil structure, and increased hydraulic conductivity due to worm holes and stable biochannels (Mahboubi et al., 1993; Dick et al., 1991). Reduced compactability due to high organic C contents in the surface soil suggests a lower surface-compaction threat in long-term no-tillage (Thomas et al., 1996).

Most soil physical and chemical properties were improved by conservation agriculture systems, but the rate of change differed due to climatic and soil differences among sites, with the difference due to tillage generally being greater at the more humid sites with loamy soils than at the drier sites with sandier soils (Buschiazzo et al., 1998). No-till with residue retention and crop rotation resulted in a soil with good physical and chemical qualities, and high, stable yields, compared to conventional tillage and no-till without residue (Govaerts et al., 2005; 2006 a; 2006 b, 2007).

4. Fertilizer nitrogen rate and N uptake on maize

The maize response to the fertilizer N application rate is highly dependent on the rainfall conditions: in wet years N uptake will be higher in conservation tillage, compared with the conventional tillage (Torbert, et al., 2001). At the six-leaf stage (V6) (Ritchie and Hanway, 1982), maize starts its most active growth and substantially increases N and water consumption. Fertilization at V6 is more efficient than the application at planting, particularly under no-tillage (Wells and Bitzer, 1984; Fox et al., 1986; Wells et al., 1992). The greater N uptake and yield in no-tillage maize observed when fertilizer is applied at the V6 stage could be due to the decrease in N losses due to denitrification (Wells and Bitzer, 1984), immobilization (Jokela and Randall, 1997), and leaching (Thomas et al., 1973), because of the reduction in soil water content (Linn and Doran, 1984; Jokela and Randall, 1997) associated with crop water consumption.

Maize under conservation agriculture is expected to increase the N application rate, and the fall application will result in losing yield potential (leaching, erosion, denitrification). In general, fertilizer nitrogen rate up to 168 kg/ha increased both the biomass yield and N uptake on maize (Torbert et al., 2001). Starter fertilizer should be considered an option to optimize maize production on well-drained areas (Jeffrey et al., 2002). No benefit was realized from the split application of fertilizer after planting, and the extra expense incurred with time and equipment would not be warranted in no-till systems (Torbert et al., 2001).

5. Conclusion

Compared to conventional tillage, no-till has numerous agronomic advantages, when combined with residue management and crop rotation: (i) it limits soil erosion; (ii) it improves water conservation by increasing infiltration and reducing evaporation; (iii) it improves soil quality by increasing organic matter content, improving soil structure, and preventing the formation of a plow-pan; (iv) it improves the mobilization of nutrients in the soil; (v) it improves nutrient management, facilitates weed control and reduces pest and disease incidence; (vi) it result in a higher and more stabile grain yield.. The economic advantage of no-till is: it reduces the cost of labor and fuel, extending the life of machinery. Finally, no-till has several important environmental benefits: the soil cover reduces erosion and favors water infiltration, diminishing the probability of mudslides in hilly areas and reducing environmental pollution. All together, these benefits give a good indication of how no-till is better than conventional agriculture.

Fertilizer N management can be affected by changes in tillage. Soil moisture and temperature, which are greatly affected by tillage, will impact soil N dynamics. On adequately-drained soils, nitrogen requirements for no-till maize are similar to those of a tilled cropping system. On imperfectly- to poorly-drained soils, nitrogen requirements for no-till will differ from tilled cropping systems. When following soybeans, 10 to 15% more fertilizer N is recommended for no-till corn. Continuous no-till corn has similar N requirements to those of a tilled system. Adequatelyfertilized no-till corn responds similarly to nitrogen fertilizer as to a tilled cropping system. There is no need to apply extra nitrogen in no-till and no change in selection of sources; all sources should be placed below the soil surface.

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The effect of tillage on different soil attributes and crop productivity

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Abstract

Crop production depends largely on the complex interactions between dynamic and static soil properties. There are notable changes in soil properties between different tillage systems, which affect crop performance in different ways and in subsequent yield. The objectives are to review the plant responses (root system and grain yields) and soil responses (soil temperature, soil water content, soil nutrients, soil bulk density and mechanical impedance, etc.) to different tillage systems; to find out what are the most important factors affecting crop performance in a specific ecological location; and how these factors exert their effects on crop performance. Changes in soil water content, soil temperature, and near-surface soil structural properties as a result of tillage methods may explain differences in crop yield. Lower temperatures and limited nutrient availability may be the main limiting factors in the early growth stage for no-tillage (NT) and, with the development of crops, the negative effects of lower temperature are decreasing or disappearing, and other factors, such as water shortage and nutrient stresses may become prominent. Soil properties such as soil organic matter, soil aggregate, soil bulk density, penetration resistance and soil microbial communities, etc., may have indirect effects on crop performances via changing water and nutrient availability.

Keywords: tillage system, soil temperature, soil water, soil nutrient, crop performance

Introduction

Crop production depends largely on the complex interactions between dynamic and static soil properties. With sufficient understanding of the response of plants to the environment (soil properties and climate), considerable improvements in plant productivity are possible (Boyer, 1982). However, most crop producing areas are still using inappropriate farming methods, such as frequently-tilled soil left bare for most of the year (with all crop residues removed for fodder, grazed and/or burned), often resulting in extensive erosion and the loss of water and production potential (Ismail et al., 1994; Kinlund, 1996; Cassman, 1999; Lal et al., 2000). Meanwhile, no-till with residues retained or partial residue removal can restrain this trend by significantly improving soil organic matter content and other properties, which current understanding asserts is positively correlated with soil quality (Pierce et al., 1992; Hussain et al., 1999; WCCA, 2001).

Enhanced crop yields with conservation tillage systems are commonly reported (Hargrove, 1985; Wagger and Cassel, 1992; Wagger and Denton, 1992); however, there are some cases of declining yield trends associated with an increase in soil organic matter (Cassman, 1999). In some soils, porosity under no-till (NT) decreases in the first few years until the soil recovers its natural structure (Kinsella, 1995). In well-structured soils or those in which biochannels are preserved (as in non-tilled soils), roots continue to extend even with increased soil resistance (greater penetrometer readings) because they can grow in the interaggregate spaces (Ehlers et al., 1983; Taylor, 1983; Klepper, 1990; Campbell and Henshall, 1991). Larger penetration resistance was found in NT than in subsoil tillage (ST) and in minimum tillage (MT) in both soils soon after tillage operations. However, root length density profiles sometimes showed greater values for NT than for the other tillage systems, revealing a good soil condition for root growth under NT (Lampurlanes and Cantero-Martinez, 2003). There are differences in crop growth and performance over time with different tillage systems. Early-emerging plants grew taller with conventional tillage (CT) than late-emerging plants with NT - up to about 50 d, and then the heights reversed (Blanco-Canqui et al, 2006a). Although there were no differences in plant height at 32 days after planting (DAP) in Reidsville, plant dry weight and stage of development were the least with NT. By tasseling at 56 DAP, however, plants in NT were taller, heavier and more mature than plants in either chisel plow (CP) or moldboard plow plus disk (MP) (Cassel, et al, 1995). The above mentioned indicate that there are complex relationships between soil properties and crop productivity. With the change of tillage systems, we need to reexamine the production practices under the new tillage systems for producers to obtain maximum yields.

There are notable changes of soil properties between different tillage systems. These soil properties include: physical attributes, such as the size and continuity of pores, aggregate stability, impedance and texture, etc.; chemical properties, such as organic matter content and composition, nutrient stocks and availability, mineralogy and the amount of elements and compounds, etc.; and biological attributes, such as the quantity, activity and diversity of microbial biomass and soil fauna. More or less, all of these soil properties have certain relationships with crop performance and subsequent yields, and there are a lot of relevant articles focusing on the differences between tillage systems. However, most of them paid more attention to the trends of parameters changing by mechanical description (e.g. "this increase and that decrease"). But what is (are) the most important factor(s) affecting crop performance and subsequent yields for a specific ecological location? Multivariate statistical approaches such as PCA may be an appropriate first step toward soil quality assessment within regions and cropping systems (Wander and Bollero, 1999) and it is a potential tool to identify the most sensitive soil attributes influencing crop yields (Jiang and Thelen, 2004). However, how and to what extent do these changed soil property parameters affect crop performance and subsequent yield? Until now, knowledge about the interactions between soil quality and crop performance using different cropping systems is limited.

I am reviewing the hypothesis that tillage systems coupled with residue management can lead to yield changes through: (i) different nutrients and water uptake; (ii) changed soil quality (increased soil organic matter, soil structure, soil aggregates, soil microbial biomass; and optimal soil organic carbon/ nitrogen (C/N) ratio).

The objectives are to review the plant responses (root system and grain yields) and soil responses (soil temperature, water content, nutrients, bulk density and mechanical impedance, etc.) to different tillage systems, to find out what are the most important factors affecting crop performance in a specific ecological location and to discover how these factors effect crop performance.

In terms of the complexity of soil property and crop development processes and the interactions between soil and crop, it is impossible to enumerate all of the soil parameters relevant to crop performance even in a specific site. This article focuses mainly on the changes in soil properties and corresponding response roots. The main reason is that plant growth and survival rely upon continuous alterations by root system, in response to the varied soil environments they inhabit. Soil environmental conditions control the rate of extension and respiratory activities associated with root function (Smucker, 1993), and affect the crop growth and subsequent yields. New evidence confirms that root signals to shoots, including abscisic acid, nitrate flux and cytokinins, modify whole plant growth processes including leaf expansion, stomatal behavior and biosynthesis of photosynthetic enzymes (Aiken and Smucker, 1996). Root signals are thought to reflect soil water, nutrient and mechanical attributes, as sensed by roots. Meristematic activities in root tips initiate changes in root architecture, modifying the soil volume subject to root uptake, and may provide multiple sensory and signaling capabilities (Aiken and Smucker, 1996).

The adaptation of root systems to soil characteristics is complex, involving the interaction of multiple factors such as water and/or nutrient availability and absorption, aeration and temperature (Smucker, 1993). Here only some of the most important factors were chosen to be expatiated.

2. Soil properties and crop performances

Plants require a root system that delivers adequate water and nutrients for shoot growth, and to anchor them in the soil. Roots growing in soil encounter physical, chemical and biological environments that influence their rhizospheres and affect plant growth (Watt et al., 2006). The optimum distribution of root length depends mainly on the distribution of water and nutrients in the soil, and root growth in the field is often slowed by a combination of soil physical stresses, including mechanical impedance, water stress and oxygen deficiency (Bengough et al., 2006). Soil temperatures can also influence seed germination, plant growth, nutrient availability, insect populations and pesticide degradation (Gupta et al., 1984).

2.1. Soil temperature

Schneider and Gupta (1985) pointed out that the time to corn emergence was influenced by the independent variables in the following order: soil temperature> soil matric potential > soil aggregate size distribution, which means that soil temperature is one of the most important factors for crop growth.

2.1.1. Soil tillage and soil temperature

Much literature has reported the phenomenon of lower soil temperatures under NT (Vyn and Raimbault, 1993; Rasmussen et al., 1997; Weisz and Bowman, 1999; Mann et al., 2002; Stone and Schlegel, 2006). Lower soil temperature may be due to slow soil warming by the stover cover in NT (Drury et al., 1999; Mehdi et al., 1999; Stone and Schlegel, 2006[<-not in references]).

Johnson and Lowery (1985) pointed out that the reduction in soil temperatures observed with conservation tillage was attributed to differences in thermal admittance, heat flux to a greater depth and total heat input to the soil profile. The higher thermal admittance and heat flux in the NT treatment produced lower upper profile soil temperature. Soil thermal diffusivity (K') in the 5- to 15-cm zone was 20 to 25% higher in the no-till treatment than in the conventional (moldboard) tillage and chisel treatments, which were not significantly different (Johnson and Lowery, 1985).

2.1.2. Soil temperature and crop performance

Changes in root-zone temperature, as well as air temperature, have direct impacts on crop growth (Dehaghi and Sanavy, 2003; Moon et al., 2007). The most profound effect of temperature on corn development was the rate of root growth (MacKay and Barber, 1984).

Cooler soil temperatures in the fall and spring could delay emergence, seedling development and retard tillering, all of which have been observed under NT wheat production (Rasmussen et al., 1997; Weisz and Bowman, 1999). Lower early-season soil temperatures reduce early corn growth and final grain yields under NT (Vyn and Raimbault, 1993). If 100% of the stover was removed or added, corn emergence increased or decreased accordingly by about 3 d (Stone and Schlegel, 2006). Similar studies in temperate climates have also reported that increased stover cover hinders corn emergence (Mehdi et al., 1999).

Lower soil temperatures in NT did not delay the initiation of corn seedling emergence but did reduce the rate of emergence compared with CT plots (Beyaert et al., 2002). Differences in emergence rates among treatments were attributed to differences in cumulative growing degree days (GDD) from planting to the completion of emergence. Lower GDD in the seed zone in NT compared with CT resulted in a slower rate of emergence in NT (Beyaert et al., 2002). Relationships between percent emergence and seed zone growing degree days were approximately the same for three soils and varied with the soil matric potential. The corn emergence model indicated a requirement of 59, 62, 67 and 76 seed zone growing degree days for 75% corn emergence at soil matric potentials of –10, –33, –100 and –500 kPa, respectively (Schneider and Gupta, 1985).

Menhenett and Wareing (1976) suggested that low soil temperature may reduce the production of endogenous gibberellins important for leaf growth in *Dactylis glomerata*. Cytokinins are probably necessary for growth processes but their level may reflect, rather than direct, the rate of leaf growth. Trials conducted under controlled environments demonstrated that the delay of bud activity of Douglas fir (*Pseudotsuga menziesii*) seedlings occasioned by the low temperature of the soil could be eliminated by the application of gibberellic acid. Analyses of field-grown plants showed a parallel increase in bud activity, in the level of gibberellin-like compounds in xylem sap and in soil temperature during February and March (Lavender et al., 1973).

Delays in the rate of seedling emergence due to lower soil temperature at the planting depth were reported by Al-Darby and Lowery (1987) in a silt loam soil; larger delays in seedling emergence due to slow soil warming in NT have been reported for clay soils (Drury et al., 1999). However, the negative effect of reduced tillage on seedling emergence increases in finer textured soils, but has a small impact on seedling emergence in coarser-textured soils (Beyaert et al., 2002).

The trend towards higher growth-parameter values for the CT treatment found earlier in the growing season diminished by tasseling (Stone et al., 1999). The results agree with previous findings where significant differences in leaf area per plants among tillage systems in the early part of the growing season tended to disappear later (Mock and Erbach, 1977; Al-Darby and Lowery, 1987; Vyn and Raimbault, 1993). Stone et al. (1999) suggested that soil temperature controlled the rate of development while the meristem was underground and noted that the meristem remained underground until six fully expanded leaves had appeared. Thereafter, corn development was best approximated by air temperature. This means that, in the early crop levels present, while proper placement of fertilizer K may be critical for optimizing yields (Mallarino and Murrell, 1998). Three years of field research on predominantly medium testing soils confirmed that K needs are indeed higher with less tillage and that K placement can be critical (Vyn et al., 1999). However, the similar or higher crop yields for NT over CT without additional nutrient application implied that it is not the nutrient deficiency in NT; the lower nutrient availability may be mainly due to the lower soil temperature at early season.

2.4 Some other soil properties

2.4.1 Soil organic matter

Organic matter plays an important role in nutrient availability and soil aggregate stability. Wheat yields over all years increased as soil organic matter (SOM) increased (Diaz-Zorita, et al., 1999; Bell, 1993). Soil productivity decreases when SOM declines (Bauer and Black, 1994). Soil organic matter strongly affects soil properties such as water infiltration rate, erodibility, water holding capacity, nutrient cycling and pesticide adsorption (Stevenson, 1994; Campbell et al., 1996; Francioso et al., 2000). Soil organic matter contents have been found to be a reliable index of crop productivity in semi-arid regions because it positively affects soil water-holding capacity (Diaz-Zorita, et al., 1999) and was recognized as a central indicator of soil quality and health (Soil and Water Conservation Society, 1995).

Soil organic matter is of primary importance for maintaining soil productivity, and agricultural management practices may significantly influence SOM chemical properties (Ding et al., 2002). However, the soil fertility and SOM becomes stratified, with the highest concentration of SOM in the topmost soil layer under NT (Six et al., 2000). Most of the SOM content differences were observed in the 0- to 7.5-cm soil depth, with little change in the 7.5 to 15 cm, and the short and long-term influences of disturbance on C mineralization are complex and may vary depending on the types of soil and plant residues (Hu et al., 1995; Franzluebbers and Arshad, 1996; Alvarez et al., 1998).

Paustian et al. (1997) found in most cases an increase in C content under NT. They attributed this increase to a combination of reduced litter decomposition and less soil disturbance under NT. Six et al (1998, 1999) hypothesized and were convinced that the turnover of aggregates was faster in CT than in NT, resulting in a greater loss of 53- to 250-μm-sized intramacroaggregate particulate organic matter (POM) in CT.

2.4.2 Soil aggregate

Seed-soil contact, imbibition of water and germination all depend on the size and packing of soil aggregates (Brown et al., 1996). Dexter (1988) concluded that optimal soil structure for maximum root growth depends on the strength of soil aggregates. Increasing the spread in aggregate strength resulted in an increase in nutrient availability proportional, mostly, to the presence of small aggregates (Hewitt and Dexter, 1979). Furthermore, the effects of aggregation and water availability on root growth cannot be clearly separated because these two soil properties are interrelated (Vepraskas and Wagger, 1990). The pore system associated with a particular arrangement of soil aggregates or fragments has major effects on aeration, available water and soil strength, thus, consequently on root and shoot growth, and perhaps ultimately on crop productivity.

2.4.3 Soil pH

The pH of a soil is among the most important soil characteristics for crop production. Roots grow in this soil solution and take up nutrients from these layers of water around the soil particles. The pH of the soil water determines the solubility and, therefore, the availability of nutrients found in soil water. It has a profound effect on soil microbiology and alters the nutrient cycling that takes place based on the biological activity. Soil organisms, mostly microbes, are affected by soil pH. Soil bacteria that fix atmospheric nitrogen and those that break down organic matter and cycle the nutrients do well at pH values near neutral and are greatly impaired at acidic pH values below 6 (http://209.213.232.153/TR/articles/Soil_ph.pdf).

2.4.4 Soil bulk density and penetration resistance

No-tillage often results in a higher bulk density (BD) of the soil and, correspondingly, greater soil strength (Martino and Shaykewich, 1994), which can impede root growth, stimulate root branching and hinder the growth of the main axes (Goss, 1977; Cannell, 1985; Lampurlanés et al., 2001). On the other hand, NT results in a better soil structure and in an extensive system of macrospores (Ehlers et al., 1983; Martino and Shaykewich, 1994), which benefits root growth (Lampurlanés et al., 2001; Martino and Shaykewich, 1994). Some studies found that higher bulk density and higher soil water storage capacity in the long-term NT is consistent (Gantzer and Blake, 1978; Zhai et al., 1990). Blanco-Canqui (2006b) pointed out that stover removal consistently increased bulk density and decreased volumetric water content (∂v) across soils ($P< 0.01$) which might be another benefit for root growth.

Root growth decreases as penetration resistance (PR) increases (Taylor, 1983; Atwell, 1993; Gregory, 1994), and can also show a linear (Ehlers et al., 1983), inverse (Atwell, 1993), or exponential (Hamblin, 1985) relationship. The reduction in soil void space after the application of mechanical stress has major and mostly negative effects on root growth and has been reviewed extensively (Bennie, 1996). 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 in non-tilled soils); roots continue to extend at greater penetrometer readings because they can grow in the interaggregate spaces (Ehlers et al., 1983; Taylor, 1983; Klepper, 1990; Campbell and Henshall, 1991).

2.4.5 Soil microbial communities

Soil moisture conservation and a decrease in the fluctuations of soil temperature with residue retention generally improve the biological activities in the surface layers of the soil (Cattelan et al., 1997). Water appears to be the primary factor influencing microbial populations; soil pH and organic C and N levels may be as much the result of microbial activity as they are regulators of it (Doran, 1980). The residue treatments affected soil microbial biomass (SMB) in the 0-15 cm soil layer, but not in deeper soil layers and no effects of fertiliser-N application on SMB were found (Probert and Keating, 1996). Different amounts of beneficial rhizosphere bacteria may be one of the main causes of nutrient availability.

Conclusions

Conservation agriculture results in many dramatic changes in soil properties and crop performances. It is impossible to elucidate fully the factors responsible for the crop performances and subsequent yield differences. To understand the complex interaction between soil properties and crop performances, principal component analysis methods were often being used. Changes in soil water content, soil temperature and near-surface soil structural properties, as a result of tillage methods, may explain differences in crop yields. Lower temperatures and limited nutrient availability may be the main limiting factors in the early growth stage for NT and, with the growth of the crops, the negative effects of lower temperatures decrease or disappear, and other factors, such as water shortage and nutrient stresses, may become prominent. Soil properties such as soil organic matter, soil aggregate, soil pH, soil bulk density, penetration resistance and soil microbial communities may indirectly affect crop performances via changing water and nutrient availability. But maybe subtle forms of soil degradation could account for the lack of a positive yield trend in these long-term experiments, although, to date, there is no direct evidence to support this hypothesis and there has been little effort to investigate it (Ismail et al., 1994). Ding et al (2002) indicated that small changes in the SOM content are significant to the agricultural production of the region. Until now, we know little about the complex interactions between soil and crops, and further work is required to quantify the influences on crop growth and grain production in short- or long-term tillage systems.

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The effect of conservation agriculture on the soil biochemical characteristics in a semi-arid area of north China[1*]

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Abstract

A study on microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) content and soil enzyme activities (dehydrogenase, acidic phosphatase, β-glucosidase and urease) under different tillage systems was carried out based on a 4-year experiment in a semi-arid area of north China. Two different tillage systems were compared: zero-tillage (ZT) with straw mulching and conventional tillage (CT) with the crop residue removed. Soil biochemical properties were determined in samples collected at four depths (0-5 cm, 5-10 cm, 10-20 cm, 20-30 cm). In general, increases in the soil organic matter (SOC), MBC, MBN and enzymatic activities were found in the more superficial layers of the soil under ZT than under CT. Biological properties showed a pronounced decrease with increasing soil depth for both tillage systems. The soil enzyme activities were significantly correlated with the soil organic C and were correlated between each other. The ZT was the most effective practice for improving soil chemical and biochemical qualities and for forming a promising option for crop production in semi-arid, north China.

Keywords: conservation tillage, soil organic matter, soil microbial biomass, soil enzyme activities

1. Introduction

Soil biochemical characteristics such as soil organic matter (SOM) content, soil microbial biomass and soil enzyme activity are important indictors reflecting soil health. Soil organic matter plays a key role in the improvement of soil physical, chemical and biological properties (Elise'e Oue´draogo et al., 2007). Many studies have shown that the addition of organic material improves soil physical properties, which enhance root development, resistance to erosion, soil porosity and water infiltration, and decreases soil crusting (Mando and Miedema, 1997; Fernandes et al., 1997). Organic matter decomposition and nutrient turnover in arable soil are highly dependent on soil microorganisms (Timo Kautz et al., 2004). The microbial biomass is the living component of soil organic matter and it typically comprises 1%~5% of total organic matter content. Because of its high turnover rate, microbial C content can respond rapidly to changes in soil management practices (Gregorich et al., 1997). Soil enzymes are important soil components involved in the dynamics of soil nutrient transformations (Ebhin Masto, et al., 2006). The enzyme activity in the soil environment is considered the major contributor of overall soil microbial activity (Frankenberger and Dick, 1983) and soil quality (Visser and Parkinson, 1992; Dick, 1994).

Tillage and residue management have a direct effect on the soil biochemical characteristics. Soil organic matter distribution, nutrient cycling and microbial activity are usually influenced by the type and degree of soil tillage (Salinas-Garcia et al., 2002). Research has shown that soil organic matter, soil microbial biomass and activity responds to crop and soil management practices such as tillage and residue incorporation

[1*] This chapter has been offered in a reviewed version to Soil and Tillage Research for its possible publication in the journal.

(Drury et al., 1991; Kaiser and Heinemeyer, 1993; Staley, 1999). Traditional extensive tillage (mouldboard plowing with residues removed or burnt) often causes a rapid loss of soil organic matter (SOM) content leading to a decrease in soil biological activity. The efficiency of conservation agriculture systems (reduced tillage with residue retention on the field) reducing soil erosion and improving soil quality is universally recognized. Numerous studies have shown that decreasing tillage intensity or increasing amounts of surface residues retained on the soil surface result in higher organic C and N and improved soil quality (Bruce et al., 1990; Lal et al., 1994; Heeman et al., 1995; Salinas-Garcia et al., 1997; Soon et al., 2001).

Soil degradation is a concern in the semi-arid areas of north China due to serious soil erosion, especially in the agricultural soils. The conventional frequent tillage system has resulted in an increased overall susceptibility of the land to erosion. In recent years, conservation agriculture, as an efficient agricultural resource conservation technology (RCT), has been recognized. Numerous studies in this region have shown that conservation agriculture can increase soil water moisture, reduce wind erosion and increase crop yield (Wang et al., 2007; Meng et al.,2006; Fu et al. 2005; Li et al., 2005), but most of the research focuses on the change of soil physical and chemical properties associated with different tillage practices. In contrast, information is limited on the biological processes, such as soil enzymatic activities, which mediate nutrient cycling and influence their acquisition during active crop growth stages. The purpose of this study is to determine the effect of different tillage systems and residue management on the dynamic of SOC, microbial biomass characteristics and soil enzyme activity, as well as the effect of soil enzymes on the soil micro-organism activity and nutrient cycling under conservation agriculture in a semi-arid area of north China. Results were compared to those obtained under the conventional tillage system. The paper hypothesized that conservation agriculture systems would have a positive effect through improving the SOM and soil fertility, and enhancing soil microbial functionality.

2. Materials and methods

2.1. Site description and experiment design

The experiment was carried out in Shouyang county, Shanxi province, China (37°32′-38°6′N , 112°46′-113°26′E) at 1,300 m above sea level. The experimental area is a semi-arid, warm, temperate, continental climate with a mean annual precipitation of 474 mm, most of the rain falling between July and September. The evaporation is 1,714 mm and exceeds rainfall throughout the year. The mean annual temperature is 8.2 °C. The mean annual sunshine period is 2,679 h. The mean length of the growing period is 130 days. The soil is classified as *Cinnamon* (Liu et al., 1992). The main crops are maize, millet and sorghum.

The experiment was started in 2004 and was designed with two different tillage treatments with three replicates: the conventional tillage system (CT) consisting of a 30 cm deep mouldboard plowing with residues removed for fodder (RM) and the zero-tillage system (ZT) characterized by no tillage with the residues kept (RK) for surface cover. The plot area was 380m^2 (19m×20m). No disease or insect pest controls were applied. Every year, 300 kg ha^{-1} urea (46% N) was applied as top dressing. Maize was planted each year in late May.

2.2. Soil sampling

Soil sampling was carried out in October 2007, after harvesting maize. Soil samples from each plot were composed from ten sub-samples which were taken with a probe (5-cm diameter core) and divided into layers of 0-5 cm, 5-10 cm, 10-20 cm, and 20-30 cm. After carefully removing the surface organic materials and fine roots, each mixed soil sample was divided into two parts. One part of the soil sample was air-dried for the estimation of soil chemical properties and the other part was sieved through a 2 mm wide screen and adjusted to 50% of its water holding capacity and then was incubated at 25*f* for 2 weeks to permit uniform rewetting and to stabilize the microbial activity after the initial disturbances.

2.3. Soil chemical and biological properties analysis

Soil organic matter (SOM) was determined by wet oxidation (Black, 1965) and the percentage of organic carbon was calculated by applying the Van Bemmelen factor of 1.73 (Piper, 1950). Soil total nitrogen (STN) was determined by the macro-Kjeldahl digestion procedure (Bao, 2000). Soil total phosphorus (STP) in soil was measured using the colorimetry method (Bao, 2000). Microbial biomass C and biomass N were estimated by fumigation–extraction (Brookes et al., 1985; Vance et al., 1987). Dehydrogenase activity in soil was determined by monitoring the rate of production of tri-phenyl formazon (TPF) from tri-phenyl tetrazolium chloride (TTC) (Wu et al., 2006). Alkaline phosphatase enzyme activities were determined using the *p*-nitrophenol (PNP) method (Wu et al., 2006). β-glucosidase was determined using *p*-nitrophenylh-D-glucopyranoside (PNG) as substrate. This assay is based on the release and detection of PNP (Wu et al., 2006). Urease activity was determined using urea as substrate. Activity was determined as the NH_4^+ released in the hydrolysis reaction (Wu et al., 2006).

2.4. Statistical analysis

All statistical work was done using the SPSS 11.0 for Windows. One-way ANOVA was used to analyze means, to the least significant difference at the 5% level.

3. Results and discussion

3.1. Soil organic carbon (SOC), soil total N (STN) and soil total phosphorus (STP)

Soil tillage and residue management affected soil chemical properties greatly. Soil organic carbon under ZT was significantly higher than under CT to 10 cm depth (Table 1). Zero-tillage increased SOC content over CT 12.2% in 0-5 cm depth and 9.1% in 5-10 cm depth. The SOC content decreased with increased soil depth. No significant difference was found in SOC content between ZT and CT treatments in the 10–20 cm and 20–30 cm soil layers. The significant improvement of SOM in the ZT treatment was probably due to increased carbon input from residue retention (Brevik et al., 2002) combined with a reduced exposure of the organic input to decomposition because of the ZT system (Verachtert et al., 2008). For the CT, when soils are plowed, some standing wheat stubble is moved into deeper soil layers (10–30 cm), resulting in higher SOM content below the 10 cm depth than under ZT. The higher organic matter in the topsoil layer achieved by ZT are in line with previous studies in other arid regions (Li et al., 2006; Pang et al., 2006; Govaerts et al., 2007; Govaerts et al., 2006).

Soil total N had the same trend as SOC in relation to different tillage treatments (Table 1). Total N is known to be enhanced by increasing soil organic matter content (Salinas-García, 2002). The total N in the 0–20 cm layer under ZT was significantly higher than under CT. Below the 20 cm layer, the STN differences between both treatments were not significant. The results support earlier studies of Chowdhury et al. (2007) and Embacher et al. (2007), who demonstrated that total nitrogen decreased with increasing soil depth. The higher total N under ZT was consistent with the findings of other researchers (Rasmussen and Collins, 1991; Torbert and Reeves, 1995; Thomas et al., 2007). Increased total N apparently resulted from the increased accumulation of crop residues near the soil surface with ZT systems.

Long-term ZT management commonly leads to a stratification of phosphorus (P) in soils (Zibilske et al., 2002). Soil total P under ZT was significantly higher than under CT at 0–5 cm depth (Table 1). Below the top layer (0-5 cm), the difference of STP between the two treatments was not significant. The topsoil accumulation of P in ZT is attributed to the limited downward movement of particle bound P in zero-tillage soils and the upward movement of nutrients from deeper layers through nutrient uptake by roots (Urioste et al., 2006).

3.2. Soil microbial biomass carbon (MBC), microbial biomass nitrogen (MBN) and enzymatic activities

Microbial biomass C and N were significantly affected by soil depth and tillage system. MBC varied from 136 to 312 mg g^{-1} in the soil under ZT and from 120 to 166 mg g^{-1} under CT (Table 2). MBN varied from 25 to 64 mg g^{-1} in the soil under ZT and from 26 to 47 mg g^{-1} under CT. In the 0-5 cm and 5-10 cm soil layers, MBC and MBN under ZT were significantly higher than under CT. In the 0–5 cm layer, microbial biomass C and N were, on average, 88% and 73% higher under ZT than under CT. Microbial biomass C and N decreased with soil depth, particularly under ZT. Soil subjected to ZT accumulated crop residues and organic C, which are substrates for soil microorganisms near the soil surface. As a consequence, the soil microbial biomass and various soil microbial processes increased in the soil surface layer under ZT (Roldán, et al, 2007).

Since dehydrogenase activity is only present in viable cells, it is thought to reflect the total range of oxidative activity of soil microflora and consequently

Table 1. Soil chemical properties: Mean values of soil organic carbon, Total nitrogen and Total phosphorus under different tillage system at the different depths

Indicators	Tillage treatment	Depth (cm) 0-5	5-10	10-20	20-30
Soil organic carbon	ZT+RK	15.3*	14.6*	13.1	11.7
(mg g^{-1})	CT+RM	13.7	13.4	13.6	12.2
Soil total nitrogen	ZT+RK	6.93*	6.28*	5.17*	3.88
(mg g^{-1})	CT+RM	5.76	5.44	4.23	3.52
Soil total phosphorus	ZT+RK	0.83*	0.78	0.68	0.66
(mg g^{-1})	CT+RM	0.76	0.74	0.71	0.65

* Symbol identifies significant difference at the 5% level

may be considered a good indicator of microbial activity (Nannipieri et al., 1990). The tillage system had significant effects on soil dehydrogenase activity (Table 2). The dehydrogenase activity ranged from 5 to 45 mg TPF kg^{-1} $24h^{-1}$ in the soil under ZT and from 14 to 37 TPF kg^{-1} $24h^{-1}$ under CT. Zero-tillage resulted in a significant increase in dehydrogenase activity in the 0-5 cm layer. In the 5-30 cm layer, there was no significant difference in dehydrogenase activity between tillage treatments. Other authors have reported similar results under ZT or conventional tillage in semi-arid conditions (Madejón et al., 2007).

Table 2. Soil biological properties: Mean values of microbial biomass carbon, microbial biomass nitrogen and enzymatic activities in soil under different tillage system at the different depths

Indicators	Tillage treatment	Depth (cm) 0-5	5-10	10-20	20-30
MBC (mg g^{-1})	ZT+RK	312*	218*	152	136
	CT+RM	166	138	130	120
MBN (mg g^{-1})	ZT+RK	64 *	45	37	25
	CT+RM	47	36	32	26
Dehydrogenase	ZT+RK	45*	26	22	5
(mg TPF kg^{-1} $24h^{-1}$)	CT+RM	37	28	25	14
Alkaline phosphatase	ZT+RK	475*	351 *	310	209
(mg PNP kg^{-1} h^{-1})	CT+RM	289	228	217	112
β-glucosidase	ZT+RK	353*	316*	270	186
(mg PNP kg^{-1} h^{-1})	CT+RM	257	203	199	107
Urease	ZT+RK	13	12	11	8
(mg NH_3 kg^{-1} h^{-1})	CT+RM	10	10	9	8

* Symbol identifies significant difference at the 5% level
MBC= microbial biomass carbon, MBN= microbial biomass nitrogen

The phosphatases are a broad group of enzymes that hydrolyze esters and anhydrides of phosphoric acid. Long-term tillage had a significant effect on Alkaline phosphatase activity, particularly in the 0-5 and 5-10 cm soil depths, where ZT significantly improved Alkaline phosphatase activity by at least 54% compared to CT. In the 10-30cm depth, values for both treatments were similar, indicating that tillage effects on Alkaline phosphatase activity were pronounced in the topsoil. Kremer and Li (2003) showed that phosphatase activity in soils under organic management was greater than under conventional management.

The β-glucosidase activity varied from 186 to 353 mg PNP kg^{-1} h^{-1}in the soil under ZT and from 107 to 257 mg PNP kg^{-1} h^{-1}under CT. Averaged across the depths, β-glucosidase activity in soil under ZT was 47% higher than under CT. β-glucosidase, an enzyme already reported as an early indicator of changes in soil properties induced by tillage systems (Ekenler et al, 2003), catalyses the hydrolysis of various β-glucosides during the decomposition of organic materials. This fact could indeed explain the increase in β-glucosidase initially observed as a result of ZT with straw cover treatment.

3.3. Correlation coefficients between soil chemical and biochemical properties

Correlation coefficients (with their level of significance) between the different properties are shown in Table 3. TOC and soil nutrient contents were highly correlated ($P< 0.01$) with biochemical properties (enzymatic activities, MBC and MBN). Alkaline phosphatase, urease, dehydrogenase and β-glucosidase were significantly and positively

Table 3. Correlation coefficients between enzyme activities, microbial biomass, total organic C, nutrient content in soil samples

	SOC	STN	STP	MBC	MBN	β-glu	Pho	Deh	Ure
SOC	1	0.91**	0.90**	0.68**	0.85**	0.77**	0.65**	0.83**	0.89**
STN		1	0.95**	0.69**	0.86**	0.85**	0.76**	0.91**	0.88**
STP			1	0.73**	0.85**	0.85**	0.77**	0.91**	0.89**
MBC				1	0.78**	0.71**	0.78**	0.64**	0.72**
MBN					1	0.80**	0.73**	0.84**	0.83**
β-glu						1	0.90**	0.70**	0.86**
Pho							1	0.63**	0.74**
Deh								1	0.80**
Ure									1

SOC: soil total organic carbon; STN: soil total nitrogen; STP: soil total phosphorus; MBC: microbial biomass carbon; MBN: microbial biomass nitrogen; β-glu: β-glucosidase; Pho: alkaline phosphatase; Deh: dehydrogenase; Ure: Urease.
* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

correlated with Cmic and Nmic. Alkaline phosphatase was the enzyme most highly correlated with Cmic and Nmic. Grego et al. (1996) reported that alkaline phosphatase was the most satisfactory choice for determining the relative activity and mass of microbial population in soils. A positive correlation was found between alkaline phosphatase and protease and urease activities. Madejo'n et al. (2001) found a negative correlation between alkaline phosphatase and available P. However, we found a positive correlation. An explanation could be that the phosphatase activity in our soils was due to enhanced microbial activity.

4. Conclusions

After a 4-year experiment in a semi-arid area of north China, the zero-tillage system and the conventional tillage system had different effects on soil chemical properties, microbial biomass and soil enzymatic activities. SOC, STN and STP in the topsoil (0-10) were higher under ZT than under CT. The zero-tillage system promoted surface accumulation of crop residues and resulted in an improved soil biochemical quality compared to conventional tillage systems. The beneficial effects of conservation agriculture on soil quality were more noticeable in the superficial layer (0-10 cm depth) than in the deeper layers (> 10 cm depth). In addition, the microbial biomass and enzyme activity showed higher sensitivity to soil management practices than chemical properties. These variables might be used as soil quality indicators once their critical values have been determined for different tillage systems.

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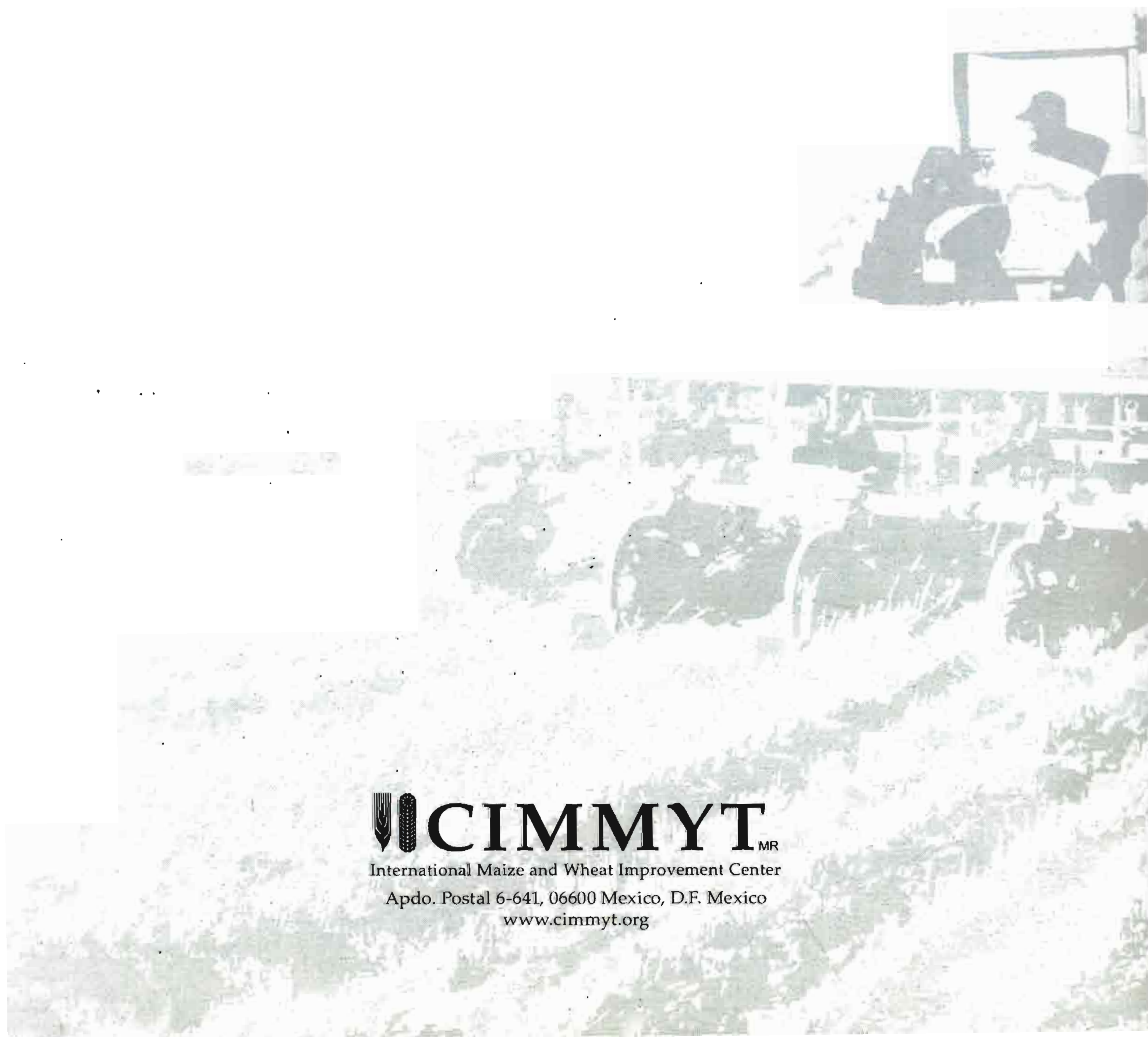

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