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Potential of conservation agriculture for irrigated cotton and winter wheat production in Khorezm, Aral Sea Basin

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ABSTRACT

Intensive tillage of soils leads to their slow but steady degradation. Therefore, scientists and farmers have been turning their attention to a more sustainable development in agriculture based on reduced tillage. Zero and minimum tillage have found widespread application under rainfed conditions. However, there is paucity of information on such conservation tillage systems in irrigated agriculture. In Central Asia, little experience exists with reduced tillage under irrigation. The objectives of this study were, in the irrigated land of Khorezm, Uzbekistan (1) to compare the effects of three tillage practices on crop development and yield, i.e., zero tillage (ZT), permanent beds (PB) and an intermediate technology (IT) vs. the conventional tillage (CT), with (+CR) and without (-CR) crop residue retention; (2) the development of a suitable seeder for local conditions in Central Asia; and (3) a financial analysis of the tillage systems studied. During three years in a cotton / winter wheat / cotton rotation (complete randomized design, four replications), data on plant development throughout their vegetative phase and on crop yields were assessed.

In the plant establishment phase, with CR, in 2004, the cotton was on average significantly higher under CT (7 cm), as compared to the ZT (5 cm). Without CR, the effects of tillage systems were insignificant. In 2006, cotton was higher under CT than ZT, in both, with (13 cm vs. 10 cm) and without CR (13 cm vs. 11cm, respectively). Cotton raw yield with CR was either significantly higher under conventional tillage (3422 kg ha^{-1} vs. 1790 kg ha^{-1}, 2004) or not affected by the treatments (average 3288 kg ha^{-1}, 2006). With CR, winter wheat yield under PB (6053 kg ha^{-1}, 2005) was significantly higher than CT (4278 kg ha^{-1}). Without CR, no tillage effects were observed for both crops.

The effect of crop residues on cotton growth for both cotton seasons, 2004 and 2006, were insignificant. Raw cotton yield in the third year after winter wheat on the plots was significantly higher where wheat residues were retained (3525 kg ha^{-1} vs. 2844 kg ha^{-1}). Neither winter wheat growth nor yield was affected significantly by the crop residues. Evaluation of a seeder imported from India showed that it had serious limitations. Its low clearance did not allow sowing cereals into the standing cotton and the seeder was only suitable for sowing de-linted cotton seeds. Therefore, a more universal seeder was newly developed and tested. This seeder is able to sow both cotton and wheat, has a high clearance, is capable of working with both linted and de-linted cotton seeds, and has two boxes, one for seeds, the other for fertilizers, which allows concurrent sowing and fertilization, thus saving fuel costs and labor.

Summing these results up, in general, there were no significant effects of the tillage treatments on cotton or wheat yields, but, at least, the initial yield loss commonly observed in the first years after introduction of conservation tillage could not be found here, while clear savings in operational costs were achieved.

Consequently, a cumulative gross margin (GM) analysis showed higher gross margins in all conservation agriculture practices as compared to the control (conventional tillage). The values were highest under intermediate tillage with crop residues (UZB 1,288,000 = USD 1074), followed by zero tillage without crop residues (UZS 1,177,000 = USD 980) and permanent beds without crop residues (UZS 1,158,000 = USD 965). Dominance analysis revealed the clear advantage of the conservation practices over conventional tillage because of the lower total variable cost and higher GM.

Thus, adopting conservation agriculture practices on the degraded soils of Central Asia can improve cotton and winter wheat production and make it more profitable to farmers.

KURZFASSUNG

Potential von nachhaltiger Landwirtschaft im bewässerten Baumwoll- und Weizenanbau in Khorezm, Aralseebecken

Intensive Bodenbearbeitung führt zu einer langsamen aber ständigen Bodendegradation. Daher richten Wissenschaftler und Farmer verstärkt ihr Augenmerk auf eine nachhaltigere Landwirtschaft auf der Grundlage von reduzierter Bodenbearbeitung. Direktsaat (no tillage) und eine minimale Bodenbearbeitung sind weit verbreitet im Regenfeldbau. Es gibt jedoch kaum Daten über solche bodenschonende Anbaumethoden in der bewässerten Landwirtschaft. In Zentralasien gibt es wenig Erfahrung mit reduzierter Bodenbearbeitung im bewässerten Landbau. Die Ziele dieser Studie waren , im bewässerten Landbau in Khorezm, Usbekistan (1) die Auswirkungen von drei Bodenbearbeitungsmethoden auf Entwicklung und Erträge der Anbaupflanzen, d.h., Direktsaat (zero tillage, ZT), permanente Bettenbepflanzung (permanent beds, PB) und eine partielle Bodenbearbeitung (intermediate technology, IT), mit konventionellen Methoden (CT) ohne bzw. mit Ernterückständen (-CR bzw. +CR) zu vergleichen, (2) eine Saatmaschine geeignete für die örtlichen Bedingungen in Zentralasien zu entwickeln, und (3) eine finanzielle Analyse der untersuchten Systeme durchzuführen. Während drei Jahre in einer Baumwoll-/Winterweizen-/Baumwollrotation wurde die Pflanzenentwicklung während der gesamten vegetativen Phase sowie Erträge beurteilt.

Während der Entwicklungsphase der Pflanzen war mit CR in 2004 Baumwolle im Durchnitt signifikant höher unter CT (7 cm) verglichen mit ZT (5 cm). Ohne CR waren die Wirkungen der Bodenbearbeitungsmethoden insignifikant. In 2006 war Baumwolle höher unter CT als unter ZT in in beiden, mit (13 cm vs. 10 cm) bzw. ohne CR (13 cm vs. 11cm). Der Baumwollrohertrag mit CR war entweder signifikant höher unter konventioneller Bodenbearbeitung (3422 kg ha-1 vs. 1790 kg ha-1, 2004) oder nicht von den Behandlungen beeinflußt (Durchschnitt 3288 kg ha-1, 2006). Mit CR, war der Winterweizenertrag unter PB (6053 kg ha-1, 2005) signifikant höher als unter CT (4278 kg ha-1). Ohne CR wurden für beide Anbaupflanzen keine Wirkungen beobachtet.

Die Wirkung der Ernterückstände auf Baumwollwachstum in beiden Anbauperioden 2004 and 2006 waren insignifikant. Der Baumwollrohertrag im dritten Jahr nach Winterweizen war signifikant höher auf den Flächen mit Weizenrückständen (3525 kg ha-1 vs. 2844 kg ha-1). Weder Wachstum noch Ertrag von Winterweizen wurde signifikant durch die Ernterückstände beeinflußt. Die Prüfung einer Saatmaschine aus Indien zeigte, dass diese erhebliche Einschränkungen aufwies. Durch die geringere Bodenfreiheit war es nicht möglich, Getreide zwischen den Baumwollpflanzen zu säen, und die Maschine war nur geeignet für die Aussaat von enthaarten Baumwollsamen. Daher wurde eine neue, universeller einsetzbare Maschine entwickelt und getestet. Diese Maschine kann sowohl Baumwolle als auch Weizen säen, hat eine hohe Bodenfreiheit, kann sowohl behaarte (linted) als auch enthaarte (de-linted) Baumwollsamen aussäen, und hat zwei Kästen, eine für Samen und eine für Düngemittel. Dadurch können Aussaat und Düngung gleichzeitig durchgeführt werden. Hierdurch können Energie- und Personalkosten gespart werden.

Zusammenfassend kann gesagt werden, dass im Allgemeinen keine signifikante Wirkungen der Bodenbearbeitungsmethoden auf Baumwoll- bzw. Weizenertrag zu beobachten waren. Jedoch wurden die anfänglichen Ertragsrückgänge in den ersten Jahren nach der Einführung der konventionellen Bodenbearbeitung nicht beobachtet, während es deutliche Ersparnisse bei den Betriebskosten erreicht wurden.

Die kumulative Bruttomargenanalyse zeigt höhere Margen bei allen konservierenden Anbaumethoden im Vergleich zur Kontrollfläche (konventionelle Bodenbearbeitung). Die Werte waren am höchsten unter parzieller Bodenbearbeitung mit Ernterückständen (1074 USD), gefolgt von Direktsaat ohne Ernterückstände (980 USD) und Dauerflächen (965 USD). Die Dominanzanalyse zeigt die klare Dominanz des konservierenden Anbaus über den konventionellen aufgrund der niedrigeren gesamten variablen Kosten und höheren Margen.

Die Ergebnisse zeigen, dass die Anwendung von konservierenden Anbaumethoden in den degradierten Böden in Zentralasien die Produktion von Baumwolle und Winterweizen verbessern kann.

LIST OF ABBREVIATIONS

Tillage treatments

CT	Conventional tillage
IT	Intermediate treatments
PB	Permanent beds
ZT	Zero tillage

Other abbreviations

CR	Crop residue
GM	Gross margin
GR	Gross revenue
GMA	Gross margin analysis
MAWR	Ministry of Agriculture and Water Resources of Uzbekistan
OblStat	Regional Division of the Ministry for Macroeconomics and Statistics in Khorezm
OblVodKhoz	Regional Division of the Ministry for Agriculture and Water Resources Management
RR	Rate of return
TVC	Total variable costs

1 BRIEF LITERATURE REVIEW

1.1 Introduction

The economic and environmental conditions of the irrigated drylands of Khorezm, Uzbekistan (Aral Sea Basin), and their impact on the agricultural sector, particularly in the search for sustainable agricultural systems, require new cultivation patterns as well as agricultural practices that aim concurrently at increasing productivity and improving the use of natural resources. Conservation agriculture practices are one approach that may help to address these aims. According to 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. Conservation agriculture is based on enhancing natural biological processes above and below the ground. Interventions such as mechanical soil tillage are reduced to an absolute minimum, and the use of external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with, or disrupt, the biological processes." Conservation agriculture consists of different crop cultivation practices such as zero tillage, sowing of crops on permanent beds, strip tillage, plant residue management, adequate crop rotation management, and others.

Research on different aspects of conservation agriculture is being conducted by many scientists in different parts of the world. The area of crops under zero tillage systems has increased significantly in recent years. According to Derpsch (1999), the area under zero tillage in 1999 was about 45.5 million hectares. But recent studies on conservation tillage systems show rapid spreading of these systems, and by 2006 the area reached up to 98.8 million hectares FAO (2006). The reason for the extensive uptake of no-till systems is that this technology has many advantages compared to conventional methods, including: (i) reduced production costs, (ii) sharply reduced energy needs, (iii) better moisture retention, (iv) reduced rainfall runoff, (v) less wind and water erosion, (vi) less soil damage from machinery, (vii) better timing in planting and harvesting, (viii) savings in labor, (ix) reduction of some weather risks, and (x) lower fuel use in agriculture. Another advantage of this method is that land that may have become inaccessible for conventional tillage because of wet conditions is usually accessible for direct seeding of crops. Using a zero-tillage system approach, the crop can be sown directly in one pass.

As studies show, conservation agriculture practices so far have mainly been applied under rainfed conditions. Nevertheless, the irrigated crop area under these practices has rapidly increased in the last decade. For instance, in Pakistan and India the irrigated crop area under zero tillage has increased over the last 10 years (Khan 2002, Indo-Gangetic Plain Bulletin 2006). According to the IGP Bulletin (2006), the area under zero tillage in India has reached 2 million hectares. The reason for the continuous increase is that farmers have seen the advantages of this system in practice and have been convinced that it improves yields, raises water and fertilizer use efficiency, and reduces weed germination.

Investigations done by many scientists on conservation agriculture practices under different climatic and soil conditions have shown that, in general, the following basic criteria must be observed for the approach to provide full benefits: 1) minimum soil disturbance (i.e., less machinery needed for crop production), 2) appropriate crop residue management (i.e., the amount of retained crop residues should correspond to the subsequent crop such that the sown crops can germinate and rise up through the retained layer of the crop residues), and 3) adequate crop rotation, which in many respects defines the success of this system. These three ‘pillars’ of conservation agriculture will be briefly explored in the following sections.

1.1.1 Minimum soil disturbance

Though intensive tillage systems have a number of advantages, such as incorporation of fertilizers, elimination of compacted zones, or weed control. At the same time, however, these tillage systems increase soil degradation and deteriorate soil fertility, intensify wind and water erosion and soil compaction. Kondratyuk (1972) stated that the tillage system is the determining factor for water-physical, biological and chemical processes, crop development and crop yield. The changes of soil properties under minimum soil disturbance are investigated in different soil and climatic conditions, and research has revealed that soil parameters correlate with tillage systems.

Excessive tillage reduces aggregate size. Because small aggregates are less stable than larger ones, soils with small aggregates are more prone to compaction, crusting, soil erosion and reduced yields. These in turn increase the cost of crop production and cause energy wastage (Stoskopf 1981). Researchers worldwide have conducted countless experiments under varying conditions to explore the impacts of different tillage systems on soil aggregation. Micucci et al. (2006) reported that the soil aggregate stability in the humid Pampas of Argentina was 10.1-46.8 % higher under a zero tillage system with a soybean crop than in conventionally tilled plots, though soil organic carbon recovery was low. Malhi et al. (2006) found that after a four-year trial on a Gray Luvisol (Boralf), the lowest percentage of wind-erodible aggregates, highest percentage of large aggregates and largest mean weight diameter of dry soil was observed using a no-tillage system.

Bulk density is one of the basic parameters of soil; compact soils have a high bulk density (Stoscopf, 1981). According to Robertson et al. (cited in Stoscopf, 1981), bulk densities of 1.46 to 1.66 g/cm^3 are too compact for rapid root growth and high crop yields. Silva et al. (2004) found a positive relationship between plant growth and air-filled porosity, and thus reported that better plant growth can be achieved using a zero tillage system. Moreover, this tillage system may increase the water-holding capacity of the soil, and simultaneously allow better water and air movement.

Conversely, during experiments with the aim of developing a soil quality index in India, Mohanty et al. (2007) observed that as bulk density in a zero tillage rice-wheat system increased, rice yield decreased significantly (R^2=0.73). Regression analyses between wheat yield and bulk density gave the same results as for rice, with yields for both crops decreasing significantly as bulk density increased. Similarly, in experiments conducted to evaluate the effects of tillage and crop residues on soil physical properties with wheat and rice crops under shallow water table conditions in India, Tripathi et al. (2007) showed that the bulk density in the wheat season was higher under zero tillage than under conventional tillage compared to the rice season, though the differences were not significant.

Various research experiments also investigated the impact of different tillage systems on soil organic matter. There is general agreement that reduced tillage can increase soil organic matter. There are three kinds of organic matter in soil: the visible root system, the partly decomposed remains of plants, and the well decomposed organic matter, commonly called humus. A dense, well developed root system is an indication of a well drained aerated soil. The amount of partly decomposed organic matter can indicate the resources available for maintaining soil structure and provide a means of holding nitrogen in the soils. Humus is usually well mixed with the soil and adds structural stability. However, humus is less able to produce products of decomposition that help to stabilize the soil than fresh or partially decomposed organic matter (Stoskopf 1981). Also, Mohanty et al. (2007) reported that regression analyses between crop yield and soil organic matter values for tillage and crop residues in rice-wheat systems revealed that both crops showed a positive yield response to increased levels of organic matter. Long-term experiments conducted in a semi-arid area of Spain using different tillage methods have shown that under zero tillage, the soil organic matter at a depth of 0 – 10 and 20 cm had the highest soil organic content compared to conventional tillage (Hernanz et al. 2002).

Investigations have revealed that intensive soil disturbance (tillage) is connected to reduction of organic matter in the soil (Vaksman 1937). It is known that the basic components of organic matters are carbon and nitrogen. Thus, depending on the tillage applied, the level of carbon and nitrogen contents can be changed. While experiments conducted in Canada with different crops under zero tillage in four crop seasons also found that the total organic carbon and nitrogen masses were greater than under regular tillage systems, this was found to be true only after four crop seasons (Malhi et al. 2006).

Long-term field experiments with zero tillage under rainfed conditions in subtropical highlands of Mexico (Govaerts et al. 2006) have revealed the positive effects of tillage, crop rotation and crop residues, compared with conventional tillage. The root rot incidence in maize was moderate, and parasitic nematode populations were low compared to common farming practices. For wheat, the root rot incidence appears intermediate. In both maize and wheat, no-till with rotation and residue retention gave the highest and most stable yields.

Thus, minimum soil disturbance during crop cultivation can be an advantage, since numerous studies have revealed its positive effect on soil aggregates, organic matter, bulk density. Improvement of soil aggregates have been observed under different soil and climatic conditions. This can be attested by the studies mentioned above. These studies showed positive effects of minimum tillage on soil organic matter, bulk density, thereby stable crop yields. However, some studies show opposite results. In India, Mohanty et al. (2007) and Tripathi et al. (2007) found the increased soil bulk density under zero tillage.

Thus, to obtain good results with reduced tillage, along with decreasing field activities, other aspects should be observed, e.g., keeping residues on the soil surface and an appropriate crop rotation.

1.1.2 Crop residue management

A permanent soil cover with a thick crop residue layer is a key factor in no-tillage systems (Derpsch, 2001) and represents the second pillar of no-tillage. For example, an adequate mulch cover has been the main factor in the success of zero tillage systems in Latin America, because it positively affects soil moisture and soil temperature and improves chemical, physical and biological soil fertility in this region. The practice of adequate mulch cover and rotations, including green manure cover, is probably the main factor of successful and widespread adoption of zero tillage in Latin America.

According to estimations, more than 100 million tonnes of cereals residues are being produced annually in developing countries (FAO, 1999). The larger share of the crop residues is either burnt or used as forage for livestock, while only a small amount typically remains on the fields. Better management of these residues could improve crop yields by increasing soil nutrient availability, decreasing erosion, and improving soil structure and soil water holding capacity (Singh et al. unknown). The positive impacts of crop residue management on soil moisture, soil temperature, and crop yield are described here.

The purpose of moisture conservation is to retain some of the available precipitation that has previously been wasted. It can be achieved using the following activities: capturing and retaining snowfall on fields, irrigation, and reduced evaporation (Stoskopf 1981). The mulch and standing stubble preserved under zero tillage-systems reduce evaporation and may increase water retention; thus soil moisture content is generally higher under reduced versus conventional tillage systems (Carefoot et al. 1990, Lafond et al. 1992, cited in Malhi et al. 2001). Soil moisture can also be a factor in reducing nitrogen (N) volatilization under zero-tillage systems. Losses of N will increase if the N is applied in both moist and dry soils. In order to reduce volatilization losses after fertilizer application, significant rainfall or irrigation are needed (Malhi et al. 2001). Investigations by Sarkar et al. (2007) under rainfed systems showed that soil surfaces with organic mulch can form a barrier against evaporation and can alter the microclimate. Consequently, soil moisture depletion occurs at a slower rate under organic mulches than under bare soil conditions.

A significant amount of research has investigated the impact of crop residue management on crop yield. Pulatov (2002) reported that experiences in Uzbekistan with zero tillage and winter wheat conducted in irrigated areas revealed comparable yields to those in traditional cultivation. Interestingly, comparisons of parameters of development stages have shown that the number of germinated plants is significantly higher than in the traditional method. Govaerts et al. (2005) reported that the yield differences in wheat under rainfed conditions in Mexico during the initial four years of zero tillage with crop rotation and full residue retention were significant. Lowest yields were achieved without the crop residues and were nearly 37% less compared to full residue retention. Comparison of obtained yields for maize under the same management system revealed that yields were 51% lower with continuous maize production and residue removal. A three-year field study conducted by Gangwar et al. (2006) in the Indo-Gangetic plains with three tillage types (conventional, zero tillage, reduced/strip) on wheat grown after rice showed that the best wheat yield was obtained at reduced tillage (5.1 t h^{-1}) followed closely by zero tillage (4.75 t h^{-1}) compared to conventional tillage (4.6 t h^{-1}). They stated that the reason for the high yield under reduced tillage was good aeration, better germination, more water penetration, less weed infestation and increased nutrition as compared to the other systems.

Angas et al. (2006) found that the average yield of barley under economically optimal N use and reduced and zero tillage systems in semi-arid Mediterranean conditions can reach up to 4 Mg ha^{-1}. This is 30% more (1.2 Mg ha^{-1}) than under conventional tillage. Investigations conducted on a Gray Luvisol (Boralf) soil in Canada (Malhi et al. 2006) showed that the combined effects of zero tillage and straw treatments on the yield of crops such as barley, pea and wheat over three years were insignificant. The crop yield in the fourth year of the experiment was 20 % higher with zero tillage compared to conventional tillage methods.

Monneveux et al. (2006) stated that despite the fact that zero tillage systems affect crop production favorably; nevertheless, this system has disadvantages. In experiments with maize, the negative effect of zero tillage was noted on grain yield in the wet season. The yield reduction was mainly due to a reduction in the number of grains per ear. Also, zero tillage was associated with lower biomass at anthesis and maturity and lower chlorophyll concentration in the plant. Conversely, in the dry season, there was no effect of tillage on grain yield, yield components, and biomass at anthesis and maturity. A two-year field trial on seeding of wheat, corn and soybeans conducted in Canada (Chen et al. 2004) with a low disturbance no-till drill using four different drill configurations showed that the speed of crop emergence and the plant population were reduced in normal and dry soils when the press wheel was removed, whereas the opposite was observed in wet soils. Singh et al. (2001) reported that the highest yield for a rice-wheat cropping system was obtained under zero tillage in rainfed conditions in India; the yield was 1.7 to 1.9 t h^{-1} higher than for direct seeded unpuddled rice. Tillage also significantly influenced the grain yield of wheat over that obtained with zero tillage in the first and second year; however, the effects of tillage in the third were not significant.

Thus, the availability of crop residues on the soil surface is favorable to soils and crop production. Although numerous studies in various soil-climatic conditions have shown that leaving crop residues on the soil can help to conserve soil moisture, improve soil properties and decrease soil erosion, some field investigations revealed disadvantages of residues. In some soil-climatic conditions, studies showed low crop germination, reduced plant development at early vegetative phases and low crop yields. Research has also shown that these disadvantages can be overcome or reduced by appropriate crop residue management, crop rotation and machinery ….

1.1.3 Crop rotation

Numerous studies examining crop rotations have clearly demonstrated the value of rotational systems, and have shown the yield advantage of a selected crop in a rotational sequence as compared to continuous cropping (Stoskopf 1981).

Fischer et al. (2002) found that in the central highlands of Mexico under zero tillage over many years with four types of crop rotation (maize-wheat, maize-vetch, wheat-vetch and wheat-medic) the best grain yield was obtained with wheat-maize compared to other rotations. According to Lenssen et al. (2006), the greatest constraint to wheat production in the northern Great Plains of the USA is water availability. Investigations conducted during six (1998 – 2003) years on water conservation in nine rotations (all rotations included spring wheat, two rotations included field pea, while lentil, chickpea, yellow mustard, sunflower, and safflower were present in single rotations with wheat) under two tillage systems – conventional and zero tillage – have revealed that despite drought conditions, zero tillage often provided a greater amount of soil water at planting compared to conventional tillage. Latta et al. (2003) reported on long-term experiments conducted in the semi-arid region of Australia on the impact of zero-tilled and traditionally cultivated fallow on the growth and yield of wheat with three rotation systems (fallow-wheat, pasture-wheat and pasture-fallow-wheat). Amongst these rotation systems, greater yields were achieved under long-fallow compared to short-fallow treatments. Long-term effects of tillage systems under a winter wheat-vetch rotation and continuous monoculture of winter wheat or winter barley in semi-arid Spain (Hernanz et al. 2002) showed that under such rotations, zero tillage can be considered more sustainable due to similar yields across rotations and improved soil properties.

Thus, the importance of crop rotation in conservation tillage is apparent, and if not applied, crop production maybe unsustainable. Many field investigations have shown that increased yields were due to appropriate crop rotation. Studies have also evidenced that under appropriate crop rotation soil fertility improves and root diseases can be eliminated.

1.2 Study area

The Khorezm region is located in the northwestern part of Uzbekistan in the low reaches of the River Amu-Darya, Aral Sea Basin, and is surrounded by the deserts Qaraqum and Qizilqum. The climate is arid continental. The total area of Khorezm is 6300 km^2, of which approximately 2750 km^2 are used for agriculture. The region has about 1.2 million inhabitants; approximately 80% of the population lives in rural areas. Khorezm is divided into 10 administrative districts with Urgench as the administrative center, with a population of 135,000.

The region's economy very much relies on agriculture. Major crops of the region are cotton and winter wheat. Since the mid 1990's, due to rapid expansion of the agricultural area with a sharp increase in water consumption and its inappropriate use, the region has been facing environmental and economic problems such as increased soil and water salinity, declining soil fertility, high groundwater levels, water scarcity, declining yields, and rising crop production costs.

1.3 Importance of conservation agriculture practices for the Khorezm region

Studies of conservation agriculture practices show that, on a global scale, research on and application by farmers of these systems has so far mainly been in regions with rainfed conditions. Extensive investigations by researchers to examine the advantages and disadvantages of different conservation agriculture practices under various soil and climatic conditions have shown that their implementation requires both knowledge and a comprehensive approach. Researchers agree that success in crop farming using these systems depends on the following cornerstones: a) 30% of crop residues from preceding crops should be left on the soil surface at planting time, b) an appropriate crop rotation for the region (climate, soils) in question must be found, and c) the use of proper machinery is imperative. Adherence to these recommendations has appeared as a basis for the further expansion of conservation agriculture practices under rainfed conditions.

A literature review of experiments conducted for conservation agriculture together with irrigation in different soil and weather conditions shows that the effects of crop residue management, rotation and soil compaction on crop production have not been investigated as comprehensively as the effects under rainfed conditions. However, investigations under irrigated conditions suggest that appropriate crop residue management and crop rotation can improve soil properties, reduce salinity and increase crop yield.

The potential for conservation agriculture under irrigated agriculture is particularly relevant to Uzbekistan, where most agriculture is conducted under irrigated conditions.

However, studies regarding conservation agriculture practices in the country are scarce, or remain unpublished to date. Those experiments on conservation tillage practices are carried out on relatively better soils, in the north-eastern part of

Uzbekistan. Soils in this area are less prone to salinity and are more fertile. The agricultural lands in the north-west of Uzbekistan (Khorezm region, Aral Sea Basin) are more prone to salinity and the soils are more degraded compared to other regions (ACSSRI, 2003). According to Pulatov (2002) and Egamberdiev, (2007), the reasons for the reduced in soil fertility and increased salinity and compaction include the presence of intensive tillage systems as well as an inadequate use of soil-water resources and crop residues. Application of conservation tillage systems, such as zero tillage (no-till, reduced till) and permanent bed systems could be one way to reduce the negative impacts of intensive tillage systems, and at the same time to improve water and machinery use efficiency and increase farmers' income.

1.4 Objectives of the study

This study investigates the application of conservation agriculture practices and the influence of crop residue retention on irrigated farming systems in the Aral Sea Basin. The overall research objective was to investigate and compare the effects of conservation agriculture practices and crop residues in a cotton-winter wheat crop rotation on loamy soil under irrigation in the Khorezm region of Uzbekistan.

1.4.1 Specific objectives:

The following four different planting systems were compared:

- Traditional farmer practices (control), which involves conventional tillage for all crops;
- A raised-bed system that provides an intermediate level of tillage: When cotton is planted, conventional tillage is used (new beds will be established), but these beds will be used for the other crops following in the rotation;
- Permanent bed planting, where the beds are re-used for each successive crop and are re-shaped only when required;
- A zero-till planting system.

Two different crop residue management systems were studied for each of the farming practices; crop residues were either removed from the field or retained.

The investigations included:

- Assessment of the effects of the different farming practices on crop production;
- Assessment of the effect of crop residue management on crop development and yield;
- Assessment of the economics of the studied conservation agriculture practices;
- Adaptation of imported seeder machinery for local conditions and development of a new universal seeder capable of sowing cotton and cereals into the standing cotton stems.

1.5 Outline of the thesis

The thesis consists of six chapters. Chapter 1 gives brief information on the main aspects of conservation agriculture and a brief literature review. This is followed by analyses of the effects of conservation agriculture practices (Chapter 2) on cotton and winter wheat production. The effect of crop residues in irrigated agriculture is analyzed in Chapter 3. Chapter 4 provides information on existing seeders in region, adaptation of the imported seeder and development of a new seeder. Chapter 5 deals with the economics of conservation agriculture. Chapter 6 concludes with a general discussion of the main findings.

2 EFFECTS OF FOUR TILLAGE SYSTEMS ON COTTON AND WINTER WHEAT PRODUCTION

2.1 Introduction

The harsh environmental conditions of the Khorezm region in Uzbekistan have detrimental effects on the agricultural sector, which lead to increasingly unsustainable resource use. The search for sustainable agricultural systems requires implementing new cultivation patterns and agricultural practices that concurrently aim at increasing productivity – so that farmers can make a comfortable living – and improving the use of natural resources.

The advent of machinery has allowed increasing the depth of soil tillage to break up the most crop-relevant top soil layers; it also allows increasing the number of soil tillage operations. However, excessive tillage entails undesirable consequences such as the dispersion of soil aggregates, the reduction of the content of organic substances in the soil, and an increase in mineralization, evaporation, and salinity levels (Lal et al., 2007, Limon-Ortega et al., 2002, Egamberdiev, 2007). Therefore, research on soil conservation technologies has an enormous practical relevance for the agricultural production of Uzbekistan in general. This, of course, also holds true for Khorezm, the area under study here.

Khorezm is an irrigated “oasis” amidst vast deserts, which has a thousand-year-old history of agriculture. This has led to a soil cover with very specific morphogenetic attributes. Environmental factors such as climate, geomorphology, lithology, and hydrogeology have had an essential influence during the formation of soils, and particularly so as the area is strongly influenced by the Amu Darya river (Tursunov, 1981). The complexity of soil and climatic conditions and their interactions in Khorezm dictates the choice of land treatment (agrotechnical) activities such as tillage and soil fertility management. Furthermore, in all agricultural regions of Uzbekistan, very similar agricultural techniques are applied, irrespective of the soil and climatic conditions.

In Uzbekistan, in irrigated agriculture mainly bed-and-furrow systems are used for crop growing. In the bed planting system, crops are planted on the surface of the raised beds that are formed when the irrigation furrows are made between the beds. This system has been used widely and for a long time for cotton production in Central Asia, as it has shown advantages over sowing on flat fields. Previous studies (Pulatov et al. 2002) have shown that the use of raised beds can help conserving irrigation water and soil, improve root development and allow deeper root penetration. Information from farmers in many countries (FAO, 2005) shows that in recent years there has been a world-wide increase in crops planted on beds.

Bed planting systems for cotton, maize and other crops provide enough space between the plants seeded on the top of the beds, so that people and machinery can perform operations critical to crop development, the most important of which is mechanical weed control (Sayre 2006, Handbook of agriculture, 1999). With the traditional methods for planting wheat, for example, it is impossible to use mechanical weed control, since the land is completely covered with plants. For crops such as wheat, appropriate varieties must be identified that enable the wheat planted on beds to compete with weeds for water, space, light and nutrients (Sayre and Hobbs, 2004). Additionally, soil thermal and radiation regimes change positively in bed planting systems when compared with sowing on flat soil. Beds made during the winter and early spring periods when the sun still stands relative low over the horizon (30-35°) allow solar radiation to reach the ground surface at a better angle which, in turn, results in faster soil warming (Turapov et. al., 1987). This is crucial for early crop development.

Planting on permanent beds also offers more flexibility on irrigated lands (Beecher et al., 2004), as farmers can insert those crops into the rotation that are unprofitable on flat land (e.g., vegetables). In addition, this system reduces the cost of field activities (FAO, 2001). Field preparation is quicker on land where a permanent bed system is used, which increases the efficiency of land use and also the possibility of double-cropping. Furthermore, water use efficiency increases due to higher crop yields. A number of studies in different soil-climatic conditions have revealed the benefits of permanent beds. Singh and Sharma (2003), Malik et al. (2003), and Tripathi et al. (2007) in a rice-wheat cropping system in the Indo-Gangetic Plains (IGP), Govaerts et al. (2005), Sayre and Hobbs (2004), and Limon-Ortega et al. (2006) in rainfed and irrigated wheat in Mexico, and Fahong et al. (2003) in North China have all found beneficial effects of bed planting systems on crop production and soil properties.

The specific economic and environmental conditions of Khorezm appear suitable to use zero tillage as one approach to achieve the concurrent goals of increasing productivity and improving natural resource use sustainability. Zero tillage, also referred to as no-tillage, consists of planting crops "in previously unprepared soil by opening a narrow slot, trench, or band only of sufficient width and depth to obtain proper seed coverage" (Derpsch, 1999). No other soil preparation is done (Phillips and Young, 1973, cited in Derpsch, 1999). A no-tillage system does not allow operations that disturb the soil other than planting. According to Dickey et al. (1992), no-till planters and drills must be able to cut through residues and penetrate the undisturbed soil. When initially converting to a no-till system, weed control relies more heavily on herbicide applications at pre-planting, pre- or post-emergence stages, depending on the crops grown. No-till systems are more likely to be successful when appropriate crop rotations are followed.

No-tillage is applied mainly and successfully under rainfed conditions (Govaerts et al. 2005). Nevertheless, the irrigated crop area under this system has rapidly increased in the last decade, e.g., in Pakistan and India (Khan 2002, IGP Bulletin 2006); in India the area has reached 2 million hectares (IGP Bulletin 2006). The reason for this continuous increase is that farmers have seen the advantages of this system in practice and have been convinced that it improves yields, raises water and fertilizer use efficiency, and reduces weed germination. Also, Govearts et al. (2005), Balkcom et al. (2006) reported higher wheat and cotton yields compared with conventional tillage in Mexico and Tennessee Valley, USA.

As studies have shown, the assessments of tillage systems were done using phenological and yield parameters of crops (Rawson and Macpherson, 2000, Mirakhmedov et al., 1989).

This study investigates and compares conservation agriculture practices with conventional farming practices in cotton and winter wheat cultivation in the conditions of Khorezm, Uzbekistan, where the soils are prone to salinization, fertility is declining and resources of farmers are limited.

2.2 Materials and methods

Studies were carried out in 2004, 2005, and 2006 at the Research Farm (41°36'N, 60°31'E) of the Urgench State University near Khiva, Khorezm region, Uzbekistan. The research farm has a mean annual temperature of – 8 °C in winter and +32 °C in summer, and an average annual precipitation of 100 mm; about 70% of which occurs in winter and spring. The area is irrigated by canals (Akramkhanov, 2005). Khorezm has an average growing period of 180 days. Soils at the research farm are loamy and characterized by poor soil quality, e.g., high salinity levels (Egamberdiev, 2007). Another major limitation is the frequent lack of irrigation water. The main crops grown in the area are cotton (*Gossypium hirsutum L.),* winter wheat *(Triticum aestivum L.)* and rice *(Oryza sativa L.).*

The experiment started in 2003 and underwent some modification in 2004. Four different soil tillage treatments under irrigation were used on these plots:

1. CT: conventional tillage (used as control)
2. IT: intermediate tillage
3. PB: permanent beds
4. ZT: zero tillage

Each of these treatments was set up either with crop residues (+CR) or without crop residues (-CR). These 8 treatments were arranged in a complete randomized design with 4 replications.

Thus, 4 tillage practices with and without the crop residues were established on 32 plots. The individual plots were 75 m long and 11.3 m wide. On these plots, the effects of tillage practices, crop residues and their interaction were investigated. Crops were cotton (*Gossypium hirsutum L.* cv. *Khorezm 127*) and winter wheat (*Triticum aestivum* L. cv. *Mars*) (Tables 2.4. and 2.5).

Cotton seeds were sown at 60 kg ha^{-1} in 90-cm spaced rows and winter wheat in 4 rows in between the cotton at 180 kg ha^{-1}. Both crops were fertilized with 200 kg nitrogen ha^{-1} (ammonium nitrate 34% N), 140 kg phosphate ha^{-1} (ammonium phosphate 11% N and 46% P2O5) and 100 kg potassium ha^{-1} (potassium chloride 60% K2O). The crop rotation was cotton-winter wheat-cotton.

To assess the effects at various vegetative phases of the crops, phenological and yield measurements were conducted according to UZCRI (1981), Bell and Fischer (1994), Rawson and Macpherson (2000).

Field data were analyzed in a completely randomized design, separately for cotton and winter wheat. Mean values of each crop parameter at various vegetative phases over 3 years (2004-2006) were statistically analyzed (SAS Institute, 2003) for analysis of variance (ANOVA) at the 0.1 probability level.

In order to determine which soil properties influenced the crop yields most strongly, a stepwise regression analysis using SAS (version 9.1) was performed. Additionally, the maximum likelihood ratio test (Moore and McCabe 2006) using STATA (version 9.2) was conducted to confirm the reduction of the stepwise regression model. The independent variables soil parameters prior to crop seeding in 0-30 cm depth, soil organic matter (SOM), total N content, total P, total K, and total dissolved salts (TDS) were selected. Although plants can take up nutrients from deeper soil layers, maximum availability of nutrients for plant growth is expected in the upper 30 cm.

Table 2.1 Layout of experimental plots, where: CT=conventional tillage, IT=intermediate tillage,PB=permanent beds, Z T=zero tillage
+ Crop residues were left on the soil after harvest,
- Crop residues were removed from the soil after harvest

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
+	+	-	-	+	-	-	+	+	+	-	-	-	+	-	+
CT	PB	IT	PB	IT	ZT	CT	PB	IT	ZT	PB	ZT	IT	CT	CT	ZT

17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
+	-	+	-	+	+	-	-	+	+	-	-	+	-	+	-
PB	PB	IT	ZT	IT	ZT	CT	ZT	PB	CT	IT	PB	CT	IT	ZT	CT

Table 2.2 Measurements on cotton plots

Parameter	Time	Applied method
Plant population	June	Counted the number of emerged cotton plants in 1 m of row in 3 randomly selected areas
Cotton height, (cm)	June, July, August, September	Measured height of 100 randomly selected cotton plants from the first leaf to the top with a ruler
True leaves	June	Counted true leaves above cotyledons on the selected plants
Fruiting branching	August, September	Counted number of fruiting branches per plant on the selected plants
Fruits	August, September	Counted number of fruits on the selected plants
Dehisced fruits	August, September	Counted dehisced fruits on the selected plants
Cotton yield (kg ha^{-1})	September	Harvested cotton on 3 randomly selected subplots (1 m^2 each)

Table 2.3 Measurements on winter wheat plots

Parameter	Time	Applied method
Wheat population	November	Counted the number of emerged plants on 4 randomly selected areas on each research plot (1 m^2 each) 20 days after seeding .
Plant height (cm)	March, April, May	Height of 48 plants was measured in the selected areas. In each of the above 4 areas, 3 plants were randomly selected. Height was measured to the top of the spike, not including the awns.
Wheat biomass (kg ha^{-1})	June	In 3 randomly selected areas in each plot, plant matter was harvested at ground level. Fresh weight was determined and wheat bundles were then oven-dried at 75^0C, and weighed.
Grain yield (kg ha^{-1})	June	After threshing of harvested wheat, grains were weighed.

Figure 2.1. Cotton growth in permanent beds

2.3 Tillage systems

2.3.1 Conventional tillage (CT)

Although cotton was planted in spring, the upper 30 cm of the soil was plowed in autumn. Prior to leaching in March/April, the field was leveled to avoid patchy irrigation and fertilizer distribution. Following chiseling and leveling, the seeds were sowed on the flat surface. For winter wheat, all soil preparation was performed in autumn.

Cotton is conventionally cultivated in a bed-and-furrow system. Each row of cotton seeds were seeded on the flat soil at a depth of about 6-7 cm. Furrows were then drawn, thus creating a bed of 90 cm width. During the cropping period, three applications of fertilizer and three irrigation events were performed, together with additional reshaping of irrigation furrows, and removing of weed (Figure 2.1).

The winter wheat was sown into the standing cotton stems. After harvest, the stems were removed or chopped (depending on trial) and the raised beds were destroyed. Following soil preparation, seedbeds were shaped in the form of basins. No further tillage occurred during the season.

2.3.2 Intermediate tillage (IT)

This farming practice is intermediate between the conventional approach described above, and the permanent beds described below. The soil was prepared in the same way as in the CT for cotton, except that first the beds and irrigation furrows were established and then cotton was seeded directly on the beds. After the cotton harvest, these beds were reused for the subsequent crop in the rotation, without any soil tillage in between. Accordingly, winter wheat was sown in four rows on the existing beds. For the next cotton cultivation the following year, the soil was ploughed, leveled and chiseled again (which represents the major difference to the permanent bed planting where the beds were not re-shaped).

2.3.3 Permanent beds (PB)

The permanent bed planting was somewhat similar to IT, but in comparison to IT, where the soil was ploughed once every two cultivation cycles, the PB plots were never tilled. In fact the first crop was grown on already existing raised beds. Beds were reshaped before planting the next crop only if necessary.

2.3.4 Zero tillage (ZT)

Concerning the zero tillage, also referred to as no tillage, no previous soil cultivation was done before planting. During planting soil disturbance only occurred while when a thin slot for seeding was made, which then was closed by a press wheel. Hence, crops were planted on flat soil (Figure 2.2).

Figure 2.2: Winter wheat growth in zero tillage

Table 2.4 Brief description of cotton variety Khorezm 127

Parameter	Value
Vegetation period (days)	130
Yield (kg ha^{-1})	4000
Fiber length (mm)	34
1000-seeds weight (g)	124
Recommended cotton plants in 1 ha, (1000)	70-80
Fruiting branches	13-14

Table 2.5 Brief description of winter wheat variety Mars

Parameter	Value
Vegetation period (days)	220-230
Yield (kg ha^{-1})	up to 10000
1000-kernel weight (g)	38-40

2.4 Results

2.4.1 Crop emergence

Cotton emergence in 2004 was significantly ($P<0.03$) affected by tillage practices (Table 2.6). The highest and the lowest emergence rates were obtained with ZT and CT, respectively, both without residue retention. Cotton emergence in the other tillage systems did not differ significantly, and cotton emergence in 2006 was not affected by tillage practices. Comparisons of tillage practices separately with control (conventional tillage system without crop residues) showed significant differences for cotton (Table 2.6).

In the winter wheat season in 2005, the effect of tillage systems on wheat germination was significant ($P<0.05$, Table 2.8). The highest values were obtained on the IT and PB plots. The number of germinated wheat plants was on average 16-14 % higher compared with the control and 30-33% higher than zero tillage.

2.4.2 Crop growth

At plant establishment in 2004, the height of the cotton seedlings among tillage systems significantly differed ($P<0.05$). For the tillage treatments without crop residues, the highest growth occurred with intermediate and zero tillage. The cotton sown on permanent beds at this stage developed significantly faster as compared to that on the CT plots. At the same time, on those tillage systems where the crop residues from the previous crop were retained, the greatest growth occurred again with the intermediate tillage (3%), while in zero tillage the cotton was delayed and had the least growth (Table 2.6).

The development of the cotton plants in the following cotton season in 2006 (Table 2.7) appeared significantly faster as compared to the previous season ($P<0.001$). Comparison of the tillage systems revealed significant variation in cotton growth ($P<0.01$). The cotton development under tilled treatments was faster, while on untilled treatments cotton was delayed. This tendency was observed for both with and without crop residues (Figure 2.3).

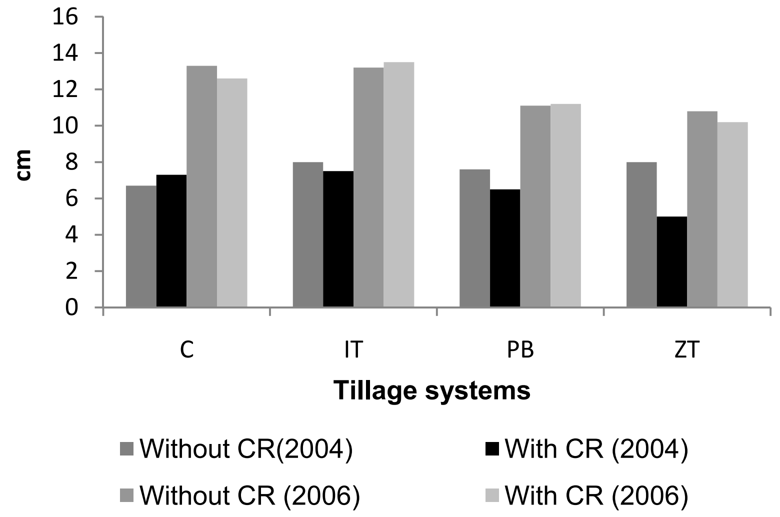


Figure 2.3 Cotton height, June 2004 and 2006

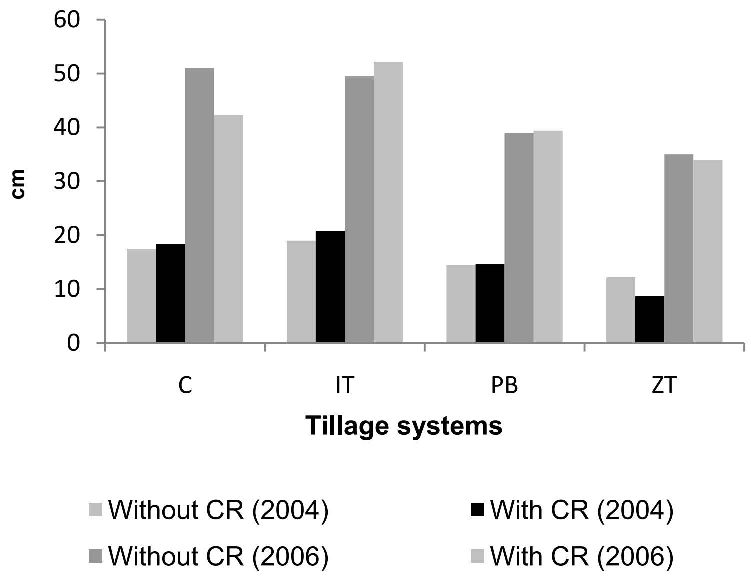


Figure 2.4 Cotton height, July 2004 and 2006

The cotton developed significantly slower in July 2004 compared with the same period in 2006 for all tillage treatments (Figure 2.4). Nevertheless, growth was faster in tilled treatments, i.e., on the conventional and intermediate plots in both with and without crop residues. In the next cotton season in 2006, the effect of tillage practices on cotton development was significant ($P<0.001$). As for the previous cotton season, growth was faster in the tilled treatments. Permanent beds and zero tillage in both without and with crop residues significantly showed delayed growth of cotton plants (Figure 2.4). In the following vegetative phases, the impact of tillage practices and their interaction with the crop residues (tillage practices*crop residues) were insignificant.

In the same cotton vegetative phase in 2006, the treatments also did not differ significantly for height (P<0.5), although the mean height was significantly greater in comparison with the same period of the previous cotton season (P<0.001). The mean height of cotton plants among tillage treatments slightly differed and was approximately at the same level.

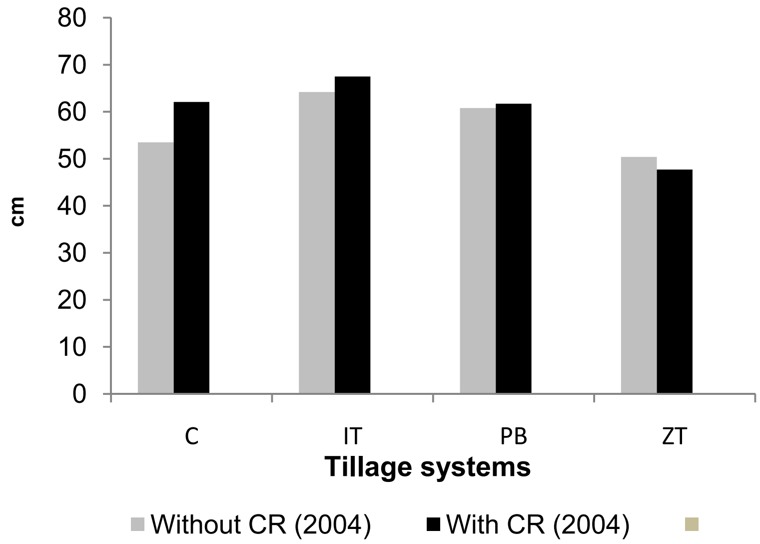


Figure 2.5 Cotton height, August, 2004

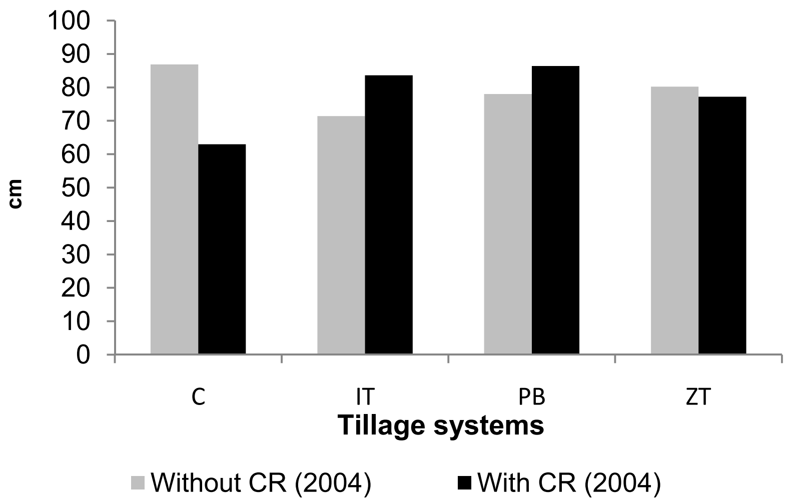


Figure 2.6 Cotton height, September, 2004

The height of winter wheat was measured in March, April and May. Except for March ($P<0.35$), height was significantly influenced by tillage practices, i.e., $P<0.01$ and $P<0.03$ for April and May, respectively (Table 2.8). In April, among treatments, higher growth occurred with IT with crop residues, while the least growth of wheat was for ZT (Figure 2.8). In the final vegetative phase in May, IT and PB were more favorable and showed higher growth (Figure 2.8).

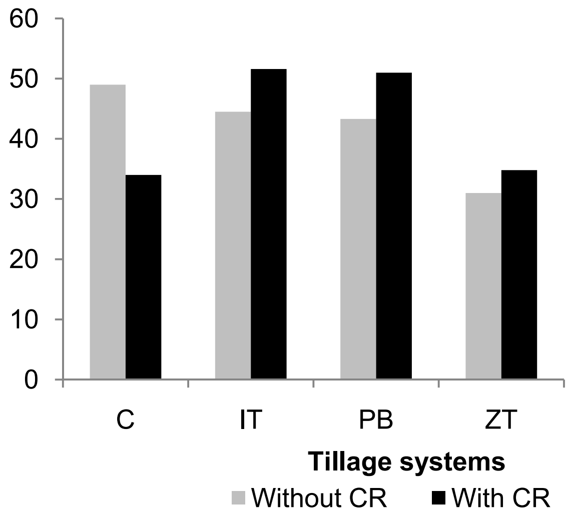


Figure 2.7 Winter wheat emergence, 2005

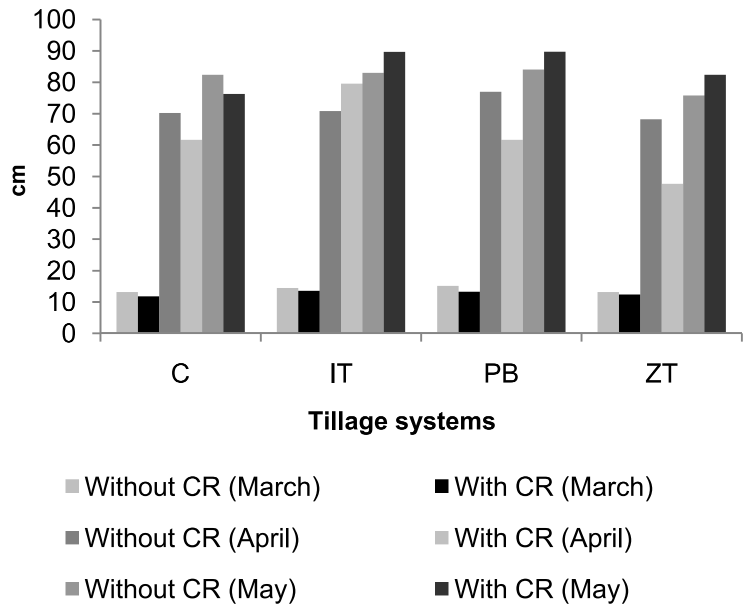


Figure 2.8 Winter wheat height, 2005

In 2004, the highest number of sympodial (fruiting) branches occurred on cotton plants grown on permanent beds and with intermediate tillage, the least number for zero tillage, while in 2006, the effect of zero tillage system appeared to be more positive for cotton development (Tables 2.6 and 2.7), as the number of branches was comparable to that of the control.

The effect of tillage systems in 2004 on fruit formation in the phase of maturity was significant ($P<0.004$). The highest number of branches occurred with conventional tillage, whereas with intermediate and permanent beds the number of branches was comparable. At the same time, the lowest quantity of cotton fruits was found with zero tillage (Table 2.6). In 2006, despite intensive cotton development and early maturing of cotton fruits, fruit formation was not affected by tillage systems ($P<0.2$). However, the number of already dehisced fruits at this stage was significantly higher compared to the previous year ($P<0.01$). The influence of tillage practices on dehisced fruits significantly differed only in 2006 ($P<0.03$).

2.4.3 Crops yield

The raw cotton yield in 2004 was affected by tillage practices ($P<0.01$). Without crop residues, yield with conventional tillage was similar to that of zero tillage, and yields on PB and with IT were lower; however, the values were all not significant. With crop residues, cotton yield was highest with CT, followed by that of PB (from which it did not significantly differ). However, both differed significantly from the IT and ZT, i.e., were twice higher.

Stem biomass among tillage practices did not differ significantly ($P<0.1$), while the total biomass was significantly different ($P<0.05$). Among tillage systems with crop residues, the highest total biomass was found with conventional tillage, followed by permanent beds, while lowest total biomass was with zero tillage (Table 2.6). Without crop residues, no tillage effects were observed.

In 2006, despite intensive growth and early maturity, among tillage systems, raw cotton yields were not significantly different between the treatments ($P<0.28$). The highest yield was with conventional system with crop residues and the lowest for zero tillage with crop residues (Table 2.7); values were not significant.

Results among tillage systems for stem biomass also did not differ significantly ($P<0.15$) Nevertheless, higher yields were obtained with IT without crop residues and PB with crop residues.

At the same time, the effect of tillage systems on total dry biomass was significant ($P<0.03$). With crop residues, yields with CT and IT were higher as compared to PB and ZT (Table 2.7). Without crop residues, no tillage effects were observed.

Grain yield and total biomass for winter wheat significantly differed ($P<0.02$ and $P<0.03$, respectively). Among tillage systems, stem biomass did not differ significantly ($P<0.28$) (Table 2.8). With crop residues, the highest yields were on permanent beds and the lowest with conventional and zero tillage. Without crop residues, there were no tillage effects.

Despite an insignificant difference between tillage systems regarding stem biomass, higher values were observed for intermediate without crop residues and the permanent beds with crop residues.

For total biomass among tillage systems with crop residues, intermediate and permanent beds showed higher values, while lower values were observed with conservation tillage. Without crop residues, no tillage effects were observed.

The stepwise regression analysis [1] and maximum likelihood test [2] gave soil organic matter (SOM) as the main predictor of cotton yield in 2004. Similar results were obtained for winter wheat in 2005. Although in the stepwise regression the results were insignificant, the maximum likelihood test showed SOM as the main predictor for cotton yield in 2006. All other soil parameters did not significantly (at $P<0.1$) improve the model's ability to predict crop yields.

[1] Stepwise regression analysis:

Yields (crops, years) = $a_1SOM+a_2TDS+a_3N+a_4P+a_5K+C$

Yield (cotton, 2004) = $a_1SOM+a_2TDS+a_3N+a_4P+a_5K+C$

Yield (w.wheat, 2005) = $a_1SOM+a_2TDS+a_3N+a_4P+a_5K+C$

Yield (cotton, 2006) = $a_1SOM+a_2TDS+a_3N+a_4P+a_5K+C$

[2] Maximum likelihood test:

Yield (crops, years) = aSOM+C

Yield (cotton, 2004) = aSOM+C

Yield (w.wheat, 2005) = aSOM+C

Yield (cotton, 2006) = aSOM+C

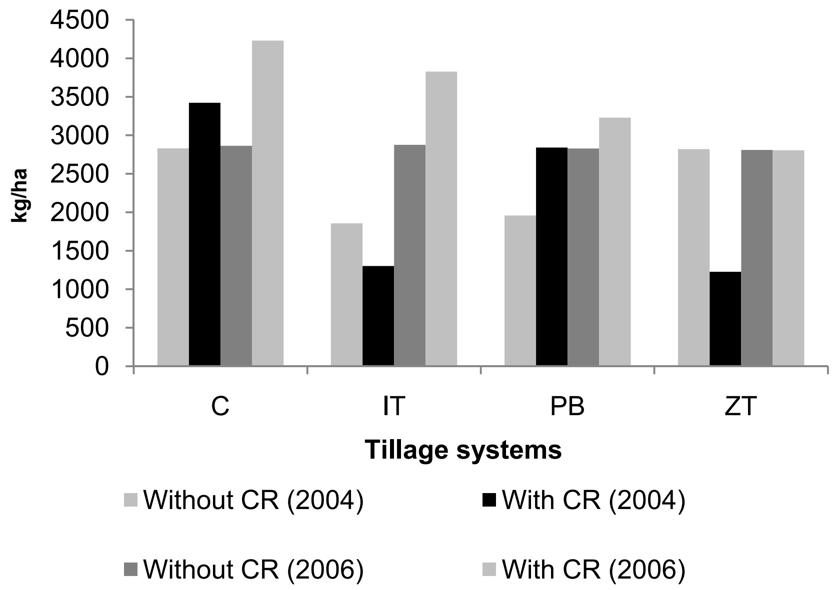


Figure 2.9 Raw cotton yield, 2004 and 2006

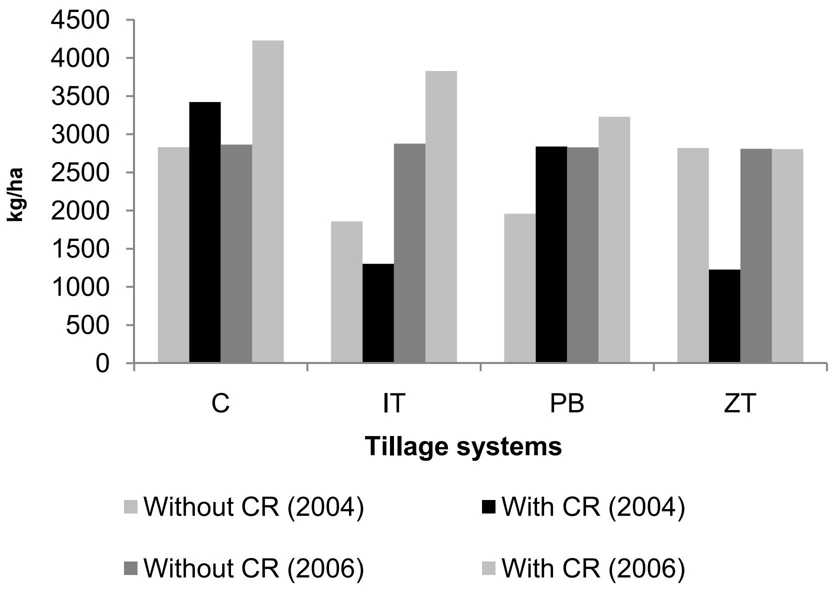


Figure 2.10 Raw cotton yield, 2004 and 2006

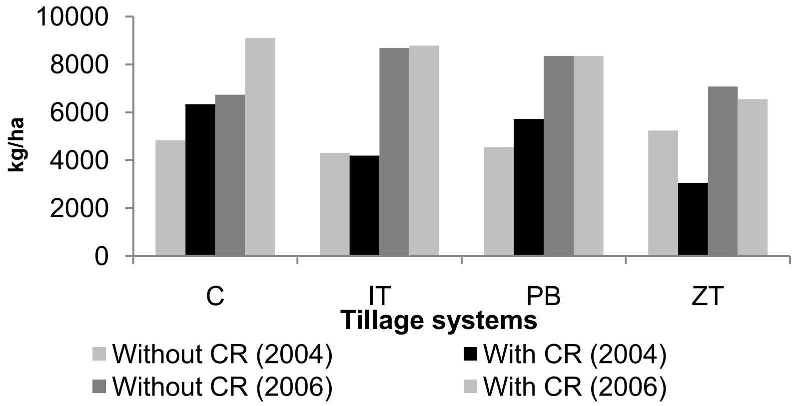


Figure 2.11 Total biomass, 2004 and 2006

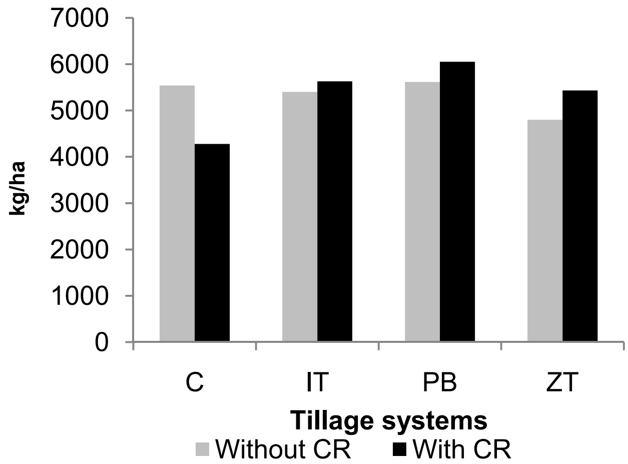


Figure 2.12 Grain yield, 2005

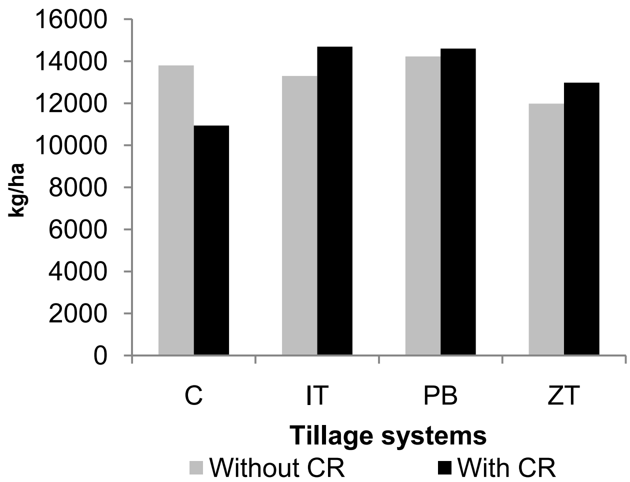


Figure 2.13 Total biomass, 2005

2.5 Discussion

Conservation agriculture practices including intermediate (IT), permanent beds (PB), and zero tillage (ZT) in 2004 appeared more favorable to cotton emergence (38-46%) compared to the control (CT). Turapov et al. (1986) reported that making of beds in early spring periods when the sun stands relatively low above the horizon improves access of solar radiation to the ground surface and as a result warms it up, thereby creating more favorable conditions for cotton emergence and growth. In the second cotton season in 2006, differences between treatments were not observed.

Similar to the first year of cotton research when winter wheat was sown on beds (IT and PB), values for emergence were higher than for CT (14-16%), especially in treatments with the crop residues. The high values for intermediate tillage and permanent beds compared with conventional and zero tillage were most likely because of the improved thermal regime and soil properties (Rawson and Macpherson 2000, Egamberdiev 2007, Turapov 1986). Moreover, soil studies conducted at the same location by Egamberdiev (2005) in the wheat sowing period in autumn showed increased humus, NPK and soil biology with conservation agriculture practices. Pulatov (2002) in similar irrigated conditions near Tashkent, Uzbekistan, also found an increased germination with conservation agriculture practices compared to conventional tillage. Numerous investigations in different parts of the world have shown beneficial effects of sowing on raised beds. In Australia, Crabtree and Henderson (1999) reported that high wheat yields in bed and furrows were due to an increased (average increased in wheat emergence of 16 %). Beneficial effects of raised beds on crop establishment were observed in irrigated conditions in Mexico and the Indo-Gangetic Plains (Sayre and Hobbs, 2004)

Cotton growth at an early stage in general was decreased with reduction of tillage intensity. Better results were observed for conventional and intermediate tillage systems, followed by permanent beds and finally the zero tillage system. In both years of investigation, this may have been due to increased nutrient access associated with improved root penetration. Dickey et al. (1992) reported that at deep tillage the compacted zones are eliminated and thus mineralization of nitrogen is improved. As a result, because of the improved root penetration and nutrient access, plant growth is advanced in the early phase.

In both cotton seasons, PB and ZT in the early phase of cotton growth was reduced. Growth on average in 2004 was 29% and 42%, and in 2006 it was 16% and 26% lower respectively, as compared to the CT. After irrigation in July-August, the growth stabilized in all tillage systems. The delayed cotton growth in PB and ZT was possibly due to the comparatively low values of the soil parameters. Previous soil studies conducted at the same location (Egamberdiev, 2007) showed low soil aggregation and higher bulk density in 0-30 cm depth on the PB and ZT plots, compared with the CT. Griffith et al. (1986) and Lal (1999) pointed out that in untilled soils, a high soil density could negatively effect rooting and thus crop growth. Sidhu and Duiker (2006) also found a reduced corn growth of 21% at the early stage of development in the compacted silt loam soil in the USA compared with control.

In the early vegetative phase, winter wheat growth was severely reduced with ZT. Plant height was on average 12% lower compared with the control (CT) and 23% compared with the IT. Pairwise comparison also revealed, except in IT, reduced growth in all tillage practices with crop residues. Such reduced growth on the residue plots, especially with ZT, probably was due to low soil temperature, nutrient immobilization and relatively higher soil bulk density in the untilled soil. Domitruk and Crabtree (1997) reported that untilled soils warm more slowly in spring and cool more slowly in autumn. Thompson and Troeh (1978) (cited in Wolf and Snyder, 2003) pointed out that root development is restricted with increase in soil bulk density, and at 1.5-1.6 g/cm^3 tends to be slowed and stops at 1.7-1.9 g/cm^3. In this study, soil bulk density and porosity in ZT at 0-30 cm was 1.55 g/cm^3 and 40.3%, respectively.

In both crop seasons, as a consequence of the delayed development of the cotton plants in the PB and ZT plots, the number of potential fruits was lower compared with the control, in 2004 by 34% (PB) and 32% (ZT), in 2006 by 15% (PB) and 18% (ZT). Although the fruit numbers increased in with CT and IT by about 50%, because of late formation more fruits had no time to be dehisced, which led eventually to a reduction in raw cotton yield. Therefore, a wide range of yields according to tillage system was obtained. A second factor that delayed the cotton growth, which in turn reduced cotton yield, was the delayed irrigation because of unavailability of irrigation water. Probably due to soil improvements over the previous three research years, in the ZT and PB plots in 2006, the quantity of the dehisced cotton fruits was 21 to 29%

higher compared with the previous cotton season. In addition, the yield results were not variable, as 2004 was the first experimental year. Nevertheless, the tillage impact was apparent, as the quantity of cotton fruits changed with reduction of tillage intensity throughout the cotton season (Figure 2.14), i.e., it was higher with CT and IT and lower with PB and ZT.

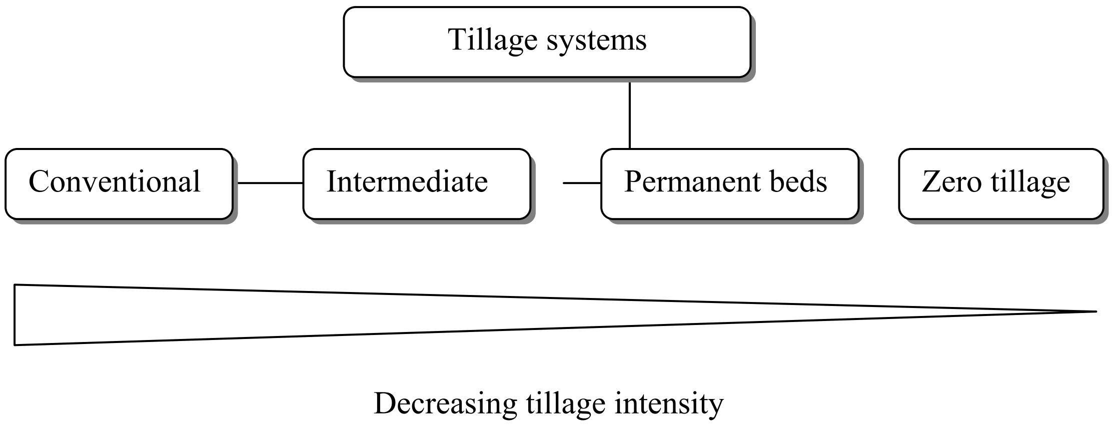


Figure 2.14 Tillage intensity in the experimental plots

In general, the crop yields under conservation agriculture practices tended to increase over the years compared with the control (CT). The raw cotton yield in 2004 was relatively lower than the control following the order IT (49%), PB (23%) and ZT (35%); one year after crop rotation in 2006 values followed the opposite order ZT (21%), PB (15%) and IT (5%). In winter wheat production, 2005, surprisingly, the yields were higher than the control (CT), i.e., 12% (IT), 19% (PB) and 4% (ZT). In addition, pairwise comparison of yields revealed the benefits of the crop residues, since all tillage practices with crop residues had increased yields. Similarly, all tillage practices led to yield increases in stem biomass. The increased yields under conservation agriculture practices were most likely because of improvements in soil properties over the three study years. Soil studies conducted at the same location by Egamberdiev (2007) showed improvements with regard to salinity and soil organic matter (Figures 2.14-2.21). In addition, the stepwise regression analysis and the maximum likelihood ratio test showed that soil organic matter is the main predictor for both crops, cotton and winter wheat yields. Long-term studies conducted in wheat-sunflower rotation by Madejon et al. (2007) also revealed increased yields in soil organic matter under conservation tillage systems. Numerous long-term investigations conducted under different soil-climatic conditions have revealed sustainable yield improvements under conservation agriculture. Boquet et al. (2004) reported that in long-term research, higher cotton yield results were observed in the fifth year, and consistent yield increases in the following years by 5-11% at optimum N under ZT compared with surface tillage in the Midsouth USA. In the Tennessee Valley, USA, in silt loam soil with irrigated cotton, Balkom et al. (2006) also found increased cotton yields of 13% in ZT compared with CT. A long-term study in the subtropical highlands of Mexico on wheat showed significantly high yields under ZT and PB (Govaerts et al., 2006). Irrigated wheat in the Sonora, Mexico, also showed increased yields under PB compared with CT (Sayre, 2005). Similarly improved yields in ZT and PB were observed in rice-wheat cropping systems in Bangladesh, India and Black Chernozem in the Canadian Prairies (Talukader et al., 2004, Rice-Wheat Consortium for the IGP highlights 2001-2003, Lafond et al., 2006).

At the same time, some for short-term studies (up to 4 years) on zero tillage have revealed relatively lower crop yields. Schwab et al. (2002) reported that in cotton production in the Tennessee Valley, USA, 10% lower yields than for in-row subsoiling over four years. In the semi-arid region of Pakistan on a sandy clay loam Ishaq et al. (2001) found lower cotton yields, and in a 2-year research in the Mississippi Delta, USA (Pettigrew and Jones, 2001), an 11% lower cotton yield under zero tillage compared with conventional tillage practices was observed.

2.6 Conclusions

The results indicate that for the degraded loamy soil, cotton production with crop residues, the cotton yield was either significantly higher under conventional tillage than under the conservation tillage practices (3422 kg ha^{-1} vs. 1800 kg ha^{-1}) or not affected by the tillage systems. Winter wheat yield in 2005 was significantly higher under permanent beds and intermediate tillage with crop residues (6053 kg h^{-1} and 5631 kg h^{-1}); the conventional tillage with crop residues showed slower improvements (4278 kg ha^{-1}). Without crop residues, the lowest grain yield was for zero tillage (4800 kg ha^{-1}). The soil analyses show that soil organic matter influenced most the cotton and winter wheat yields. Permanent beds and zero tillage, both with and without crop residues, delayed plant development, especially in the early phases of plant development.

The short-term, 3-year investigations with cotton and winter wheat under zero tillage have revealed that the adoption period of this system may take longer compared with permanent beds. Therefore, in the adoption period, farmers may encounter delayed growth. As long-term investigations show (5-7 years), these problems reduce with improvement of soil quality (Gupta et al., 2006).

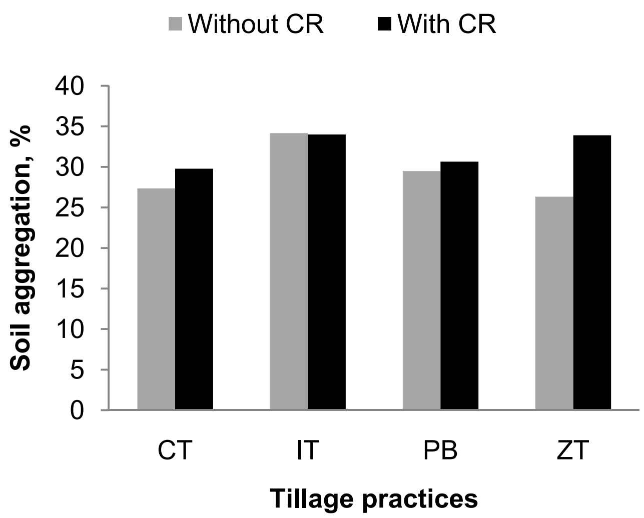


Figure 2.15 Soil aggregation, October 2004
(Egamberdiev, 2007)

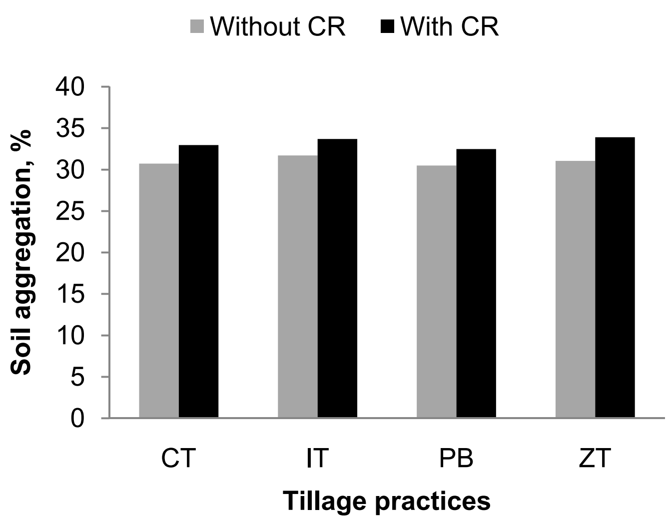


Figure 2.16 Soil aggregation, March 2005
(Egamberdiev, 2007)

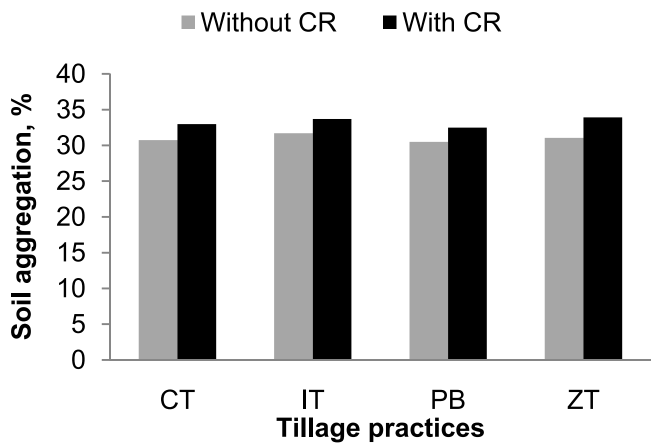


Figure 2.17 Soil aggregation, October 2005(Egamberdiev, 2007)

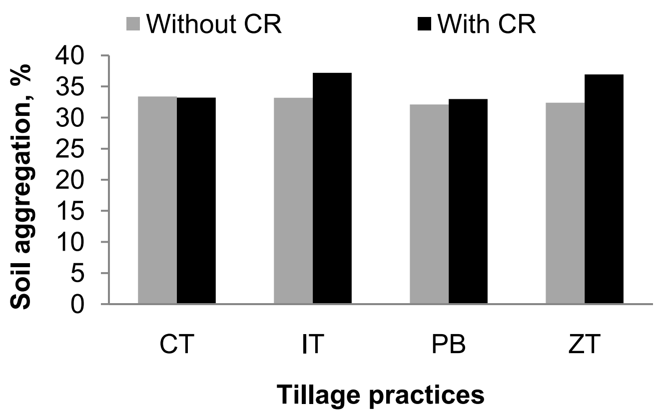


Figure 2.18 Soil aggregation, March, 2006

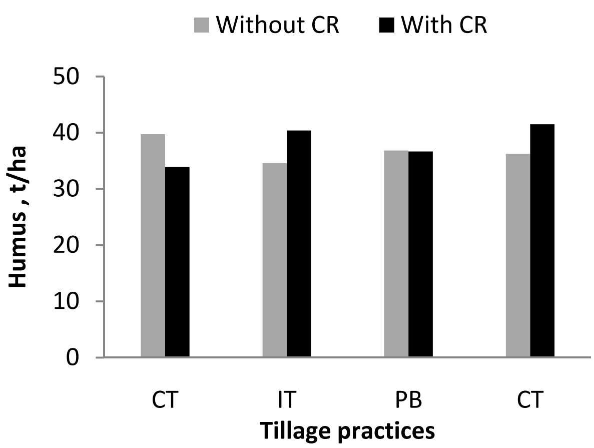


Figure 2.19 Soil humus content, July 2003 (Karimov, 2004)

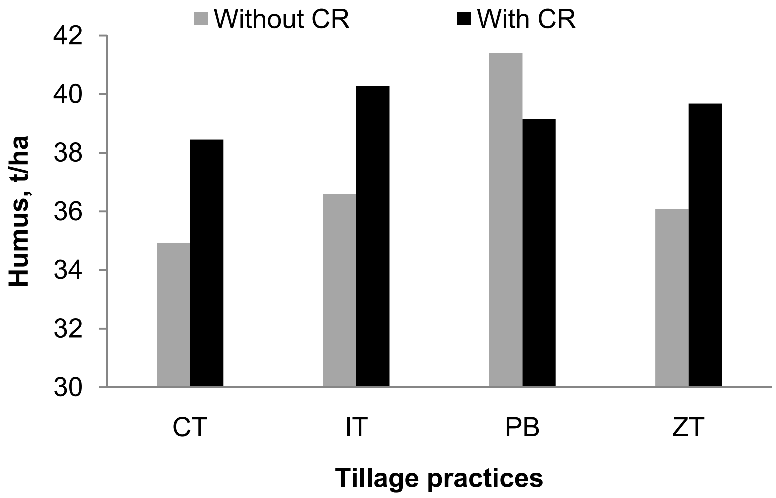


Figure 2.20 Soil humus content, March 2004, (Egamberdiev, 2007)

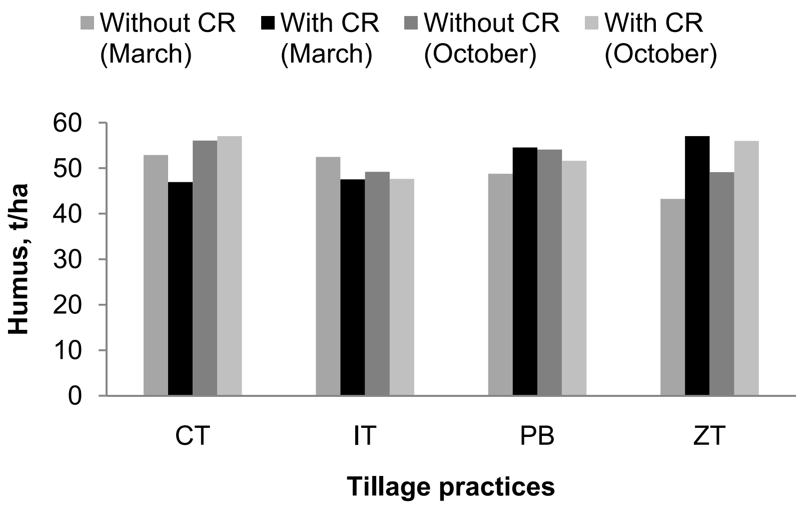


Figure 2.21 Soil humus content, 2006

Table 2.6 Cotton cultivation statistics, 2004

Tillage practice	Cotton emer-ce, (m^2)	Cotton height, cm				True leaves (per plant)	Fruiting branches (per plant)	Fruits (per plant)	Open fruits, (per plant)	Raw cotton kg ha^{-1}	Stem biomass, kg ha^{-1}	Total biomass, kg ha^{-1}	Harvest Index
		June	July	August	September								
Without crop residues													
Conventional	2^{b}	7^{ba}	18^{a}	54^{a}	87^{a}	3^{a}	9^{a}	18^{a}	3^{a}	2830^{a}	1997^{a}	4827^{a}	0.58^{a}
Intermediate	4^{ab}	8^{a}	19^{a}	64^{a}	71^{a}	2^{ab}	9^{a}	14^{ab}	3^{a}	1857^{a}	2431^{a}	4290^{a}	0.43^{ab}
Permanent beds	3^{ab}	8^{ba}	15^{a}	61^{a}	78^{a}	2^{ab}	10^{a}	11^{bc}	2^{a}	1958^{a}	2587^{a}	4544^{a}	0.40^{ab}
Zero tillage	5^{a}	8^{a}	12^{a}	50^{a}	80^{a}	2^{ab}	7^{a}	10^{bc}	2^{a}	2820^{a}	2422^{a}	5242^{a}	0.53^{ab}
With crop residues													
Conventional	3^{ab}	7^{ab}	18^{a}	62^{a}	63^{a}	2^{ab}	9^{a}	11^{bc}	3^{a}	3422^{a}	2917^{a}	6339^{a}	0.54^{ab}
Intermediate	4^{ab}	8^{ba}	21^{a}	68^{a}	84^{a}	2^{ab}	11^{a}	7^{c}	2^{a}	1302^{b}	2891^{a}	4193^{ab}	0.31^{b}
Permanent beds	4^{ab}	7^{ab}	15^{a}	62^{a}	86^{a}	4^{ab}	8^{a}	8^{c}	5^{a}	2840^{ab}	2882^{a}	5722^{a}	0.47^{ab}
Zero tillage	3^{ab}	5^{b}	9^{a}	50^{a}	77^{a}	1^{b}	7^{a}	9^{bc}	3^{a}	1227^{b}	1832^{a}	3059^{a}	0.39^{ab}
ANOVA											Probability<F(alpha)		
Crop residues	0.92	0.04	0.92	0.69	0.7	0.3	0.56	0.01	0.5	0.6	0.12	0.6	0.2
Tillage practices	0.03	0.05	0.12	0.63	0.15	0.05	0.2	0.004	0.2	0.02	0.15	0.65	0.02
Interaction (tillage prc*crop res	0.04	0.07	0.8	0.9	0.03	0.26	0.9	0.04	0.2	0.04	0.07	0.05	0.27

Means with the same letter are not significantly different as indicated by the Bonferroni post hoc test

Table 2.7 Cotton cultivation statistics, 2006

Tillage practice	Cotton height, cm				True leaves (per plant)	Fruiting branches (per plant)	Fruits, (per plant)	Open fruits (per plant)	Raw cotton, kg ha^{-1}	Stem biomass, kg ha^{-1}	Total biomass, kg ha^{-1}	Harvest index
	June	July	August	September								
Without crop residues												
Conventional	13^{a}	51^{a}	78^{a}	79^{a}	4^{a}	11^{a}	8^{a}	5^{ab}	2864^{a}	3872^{a}	6736^{a}	0.42^{a}
Intermediate	13^{a}	50^{a}	81^{a}	85^{a}	4^{a}	10^{a}	7^{a}	5^{ab}	2876^{a}	5813^{a}	8690^{a}	0.33^{a}
Permanent beds	11^{a}	39^{ab}	72^{a}	72^{a}	4^{a}	12^{a}	6^{a}	4^{ab}	2828^{a}	3976^{a}	6804^{a}	0.42^{a}
Zero tillage	11^{a}	35^{b}	77^{a}	79^{a}	5^{a}	9^{a}	7^{a}	3^{b}	2809^{a}	4411^{a}	7220^{a}	0.38^{a}
With crop residues												
Conventional	13^{a}	42^{a}	67^{a}	71^{a}	4^{a}	13^{a}	7^{a}	6^{a}	4230^{a}	4873^{a}	9103^{a}	0.46^{a}
Intermediate	14^{a}	52^{a}	75^{a}	80^{a}	5^{a}	14^{a}	6^{a}	5^{a}	3828^{a}	4961^{a}	8789^{a}	0.44^{a}
Permanent beds	11^{a}	39^{ab}	76^{a}	81^{a}	4^{a}	13^{a}	7^{a}	5^{ab}	3230^{a}	5126^{a}	8356^{a}	0.39^{a}
Zero tillage	10^{a}	34^{b}	74^{a}	74^{a}	3^{a}	11^{a}	5^{a}	4^{ab}	2805^{a}	3746^{a}	6551^{a}	0.43^{a}
ANOVA Probability<F(alpha)												
Crop residues	0.7	0.6	0.18	0.42	0.35	0.01	0.16	0.02	0.03	0.7	0.05	0.15
Tillage practices	0.01	0.001	0.55	0.25	0.89	0.12	0.22	0.03	0.28	0.11	0.03	0.65
Interaction (tillage*crop res)	0.86	0.31	0.46	0.20	0.34	0.48	0.4	0.75	0.5	0.13	0.09	0.9

Means with the same letter are not significantly different as indicated by the Bonferroni post hoc test

Table 2.8 Winter wheat cultivation, 2005

Tillage practice	WW population, m^2	Height, cm			Yield, kg ha^{-1}			Harvest Index
		March	April	May	Grain yield	Stem biomass	Total biomass	
Without crop residues								
Conventional	49^{a}	13^{a}	70^{ab}	82^{ab}	5542^{ab}	8260^{a}	13802^{ab}	0.40^{a}
Intermediate	45^{a}	15^{a}	71^{ab}	83^{ab}	5403^{ab}	7894^{a}	13298^{ab}	0.41^{a}
Permanent beds	43^{a}	15^{a}	77^{a}	84^{ab}	5617^{ab}	8613^{a}	14230^{ab}	0.40^{a}
Zero tillage	31^{a}	13^{a}	68^{ab}	76^{b}	4800^{ab}	7182^{a}	11982^{ab}	0.40^{a}
With crop residues								
Conventional	34^{a}	12^{a}	62^{b}	76^{b}	4278^{b}	6659^{a}	10937^{b}	0.38^{a}
Intermediate	52^{a}	14^{a}	80^{a}	90^{a}	5631^{ab}	9058^{a}	14688^{a}	0.39^{a}
Permanent beds	51^{a}	13^{a}	62^{ab}	90^{a}	6053^{a}	8543^{a}	14596^{a}	0.41^{a}
Zero tillage	35^{a}	12^{a}	48^{ab}	82^{ab}	5432^{ab}	7543^{a}	12975^{ab}	0.42^{a}
ANOVA Probability<F(alpha)								
Crop residues	0.23	0.18	0.32	0.17	0.88	0.84	0.57	0.68
Tillage practices	0.05	0.35	0.01	0.03	0.02	0.28	0.03	0.6
Interaction (tillage*crop res)	0.66	0.88	0.15	0.32	0.09	0.52	0.35	0.86

Means with the same letter are not significantly different as indicated by the Bonferroni post hoc tes

3 EFFECTS OF CROP RESIDUES ON IRRIGATED COTTON AND WINTER WHEAT PRODUCTION

3.1 Introduction

If surface crop residues are retained after harvest, they have beneficial effects on soil properties and crops, which have been shown by numerous field investigations. Keeping the crop residues in both rainfed and irrigated agriculture reduces soil losses, protects the soil from water and wind erosion, and adds soil organic matter (SOM) to the soil (Derpsch 1999, Hagen 1996). Preserving the SOM or humus is essential to maintaining soil fertility (Martius et al. 2001). A permanent soil cover with a thick layer of crop residue is a key factor in zero tillage (Derpsch, 2001) and represents the second pillar of conservation agriculture (the first being the reduction of soil disturbance; cf. Chapter 2). For example, an adequate mulch cover, including also green manure and used in combination with adequate rotations, has been a major factor in the success of zero tillage systems in Latin America, because it positively affects soil moisture and soil temperature and improves chemical, physical and biological soil fertility in this region (de Machado & Silva 2001). FAO (1999) estimated that more than 100 million tonnes of cereal residues are being produced annually in developing countries. However, large amounts of the crop residues are either burnt or used as forage for livestock, and only the smaller part generally remains on fields, which, in the long run, means constant nutrient mining with sometimes disastrous consequences for the soils (Craswell et al. 2004).

Better management of these residues also improves crop yields by improving soil water holding capacity (Singh et al., unknown). Moisture conservation is particularly important in irrigated systems, as these generally only receive a small amount of precipitation. In regions such as Khorezm this can be achieved by a combination of capturing and retaining snowfall and rainfall on the fields, proper irrigation water management, and measures to reduce evaporation (Stoskopf 1981). The mulch and standing stubble preserved under conservation agriculture systems reduces evaporation and may increase water retention; thus soil moisture content is generally higher under reduced till versus conventional tillage systems (Carefoot et al 1990, Lafond et al. 1992, cited in Malhi et al. 2001).

Investigations by Sarkar et al. (2007) under rainfed systems showed that soil surfaces with organic mulch can form a barrier against evaporation and even may improve the microclimate under the crops. Consequently, soil moisture depletion occurs at a slower rate under organic mulches than under bare soil conditions. Thomas et al. (1996) reported that some factors in wheat production with zero tillage can be limiting in both rainfed and irrigated areas. They investigated the impact of these factors on soil water storage under different tillage systems, each with and without nitrogen fertilizer and crop rotation. Available soil water was greater using zero till under both conditions; however, soil nitrate-nitrogen was insignificantly higher using mechanical tillage under irrigated conditions. Water use efficiency was higher in rainfed than in irrigated areas. Water use efficiency under a chickpea-wheat rotation was found to be higher under irrigated than under rainfed conditions.

Depending on the thickness of the layer of crop residues on the soil surface, the soil temperature varies. A low soil temperature is not always favorable for plants. It can be positive when crops are sown in summer, e.g., cover crops; usually these crops are planted after winter crops. In order to achieve a good crop population in autumn, relatively stable soil temperatures are required. In severe winters, crop residues may stabilize the soil temperature, and shoots under the residues may be protected from freezing. Sarkar et al. (2006) reported that in a rainfed lowland system in eastern India, the morning soil temperature at 0.0-0.2 m depth was 0.1-0.8 °C higher under conventional tillage than under zero tillage. In the afternoon, at 14:00 h, the difference was 0.1-0.4 °C, and the seed yield of yellow sarson (Brassica napus L. var. glauca) was 25% higher than under conventional tillage.

Soil moisture can also be a factor in reducing N volatilization under zero tillage systems. Losses of N will increase if the N is applied in both moist and dry soils (Scheer et al. 2008.). In order to reduce volatilization losses after fertilizer application, significant rainfall or irrigation are needed (Malhi et al. 2001). The study by Thomas et al. (1996) cited above showed that soil nitrate-nitrogen was higher using mechanical tillage in irrigated conditions compared to rainfed land with wheat and with a chickpea-wheat rotation; however, for wheat alone this was not significant.

The germination of crops, unlike their further development, is affected by various factors including soil type, its quality, and the soil moisture availability as well as seed quality, whereas as the affect of the applied tillage system usually is less strong (Pulatov et al., 2002). The influence of crop residues on wheat germination also has been reported and needs to be differentiated according residue type and amount, which in fact influence the soil temperature regime (Jessop and Stewart, 1983). Crop residues have also improved soil structure and erosion control (Black, 1973, Hayes and Kimberling, 1978, cited in Jessop and Stewart, 1983), and thus improved the agro-ecologic conditions of the crops.

A wealth of literature underlines the impact of conservation agriculture practices and crop residue management on crop yield in rainfed areas under various soil-climatic conditions. But conservation agriculture experiments on irrigated crop production have not yet been studied as comprehensively. Investigations that have so far been conducted under irrigated conditions suggest that appropriate crop residue management and crop rotation can improve soil properties, reduce salinity and increase crop yield. For example, Pulatov (2002) reported that experiments in Uzbekistan with zero tillage and winter wheat conducted in irrigated areas revealed yields comparable to conventional practices. Interestingly, the assessment of development parameters has shown that the number of germinated plants is significantly higher under conservation agriculture than under traditional tillage. Govaerts et al. (2005) reported that the yield differences of wheat under rainfed conditions in Mexico during the first four years of zero tillage with crop rotation and full residue retention were significant. Lowest yields were obtained without crop residues – nearly 37% less compared to full residue retention. In the same management system, maize yields were 51% higher than with continuous maize production and residue removal. Based on trials with wheat and maize, it can be assumed that small-scale farmers in the highland regions of Mexico can expect yield improvements from 25 to 30% after 12 years of zero tillage with appropriate rotations and residues. Li et al. (2007) investigated the impacts of wheel traffic on runoff, soil water and crop production under rainfed conditions over a period of six years on heavy clay vertosols (vertisoils) in Australia. They found that controlling traffic, besides reducing runoff and increasing plant available water capacity, combined with zero tillage increased mean grain yield by 14.5%, compared with wheeled stubble mulch treatments. Investigations conducted on a gray luvisol (Boralf) soil in Canada (Malhi et al. 2006) showed that the combined effects of zero tillage and straw treatments on the yield of crops such as barley, pea and wheat over three years were insignificant. The crop yield in the fourth year of the experiment was 20% higher with zero tillage compared to conventional tillage methods.

The purpose of this research was to study the effect of crop residues on irrigated cotton and winter wheat production under the conditions of Khorezm, Uzbekistan, where soils are degraded, and the crop residues are normally removed from fields for other purposes.

3.2 Materials and methods

3.2.1 Study site

Studies were carried out in 2004, 2005, and 2006 at the Research Farm (41°36'N, 60°31'E) of the Urgench State University near Khiva, Khorezm region, Uzbekistan (Figure 3.6). The research farm has a mean annual temperature of -8°C in winter and +32°C in summer and an average annual precipitation of 100 mm, about 70% of which occurs in winter and spring. The area is irrigated by canals (Akramkhanov, 2005). Khorezm has an average growing period of 180 days. Soil of the research farm is predominantly loamy and of poor quality, e.g., high salinity (Egamberdiev, 2007). Another major limitation is the frequent lack of irrigation water. The main crops grown in the area are cotton (*Gossypium hirsutum* L.), wheat (*Triticum aestivum* L.) and rice (*Oryza sativa* L.).

3.2.2 Experimental design

The irrigated experiment started in 2003 with some modification in 2004. The experimental design was completely randomized with 4 replications. A total of 4 tillage practices (Table 3.1) with and without crop residues on the 32 plots were established. The size of individual plots was 75.0 m x 11.3 m. On these plots, the effects of tillage practices, crop residues and their interaction were investigated. The crops used in the rotation was cotton (*Gossypium hirsutum* L. cv. Khorezm 127) and winter wheat (*Triticum aestivum* L. cv. Mars).

Cotton seeds were sown at 60 kg ha^{-1} in 90-cm spaced rows and winter wheat in 4 rows in between the cotton at 180 kg ha^{-1}. Both crops were fertilized with 200 kg nitrogen ha^{-1} (nmmonium nitrate 34% N), 140 kg phosphate ha^{-1} (ammonium phosphate

11% N and 46% P2O5) and 100 kg potassium ha^{-1} (potassium chloride 60% K2O). The crop rotation was cotton-winter wheat-cotton.

To assess the effects at various vegetative phases of the crops, phenological and yield measurements were conducted according to UZCRI (1981), Bell and Fischer (1994), Rawson and Macpherson (2000).

Table 3.1 Layout of experimental plots, where: CT = Conventional tillage, IT = Intermediate tillage, PB = Permanent beds, ZT = Zero tillage, + = Crop residues were left on the soil after harvest, - =Crop residues were removed from the soil after harvest

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
+	+	-	-	+	-	-	+	+	+	-	-	-	+	-	+
CT	PB	IT	PB	IT	ZT	CT	PB	IT	ZT	PB	ZT	IT	CT	CT	ZT

17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
+	-	+	-	+	+	-	-	+	+	-	-	+	-	+	-
PB	PB	IT	ZT	IT	ZT	CT	ZT	PB	CT	IT	PB	CT	IT	ZT	CT

Table 3.2 Measurements on cotton plots

Parameter	Time	Applied method
Plant population	June	Counted the number of emerged cotton plants in 1 m of row in 3 randomly selected areas
Cotton height (cm)	June, July, August, September	Measured height of 100 randomly selected cotton plants from the first leaf to the top with ruler
True leaves	June	Counted true leaves above cotyledons on the selected plants
Fruiting branching	August, September	Counted number of fruiting branches per plant on the selected plants
Fruits	August, September	Counted number of fruits on the selected plants
Dehisced fruits	August, September	Counted dehisced fruits on the selected plants
Cotton yield (kg ha^{-1})	September	Harvested cotton on 3 randomly selected subplots (1 m^2)

Table 3.3 Measurements on winter wheat plots

Parameter	Time	Applied method
Wheat population	November	Counted the number of emerged plants on 4 randomly selected areas on each research plot (1 m^2 each) 20 days after seeding .
Plant height (cm)	March, April, May	Height of 48 plants was measured in the selected areas. In each of the above 4 areas 3 plants were randomly selected. Height was measured to the top of the spike, not including the awns.
Wheat biomass (kg ha^{-1})	June	In 3 randomly selected areas in each plot, plant matter was harvested at ground level. Fresh weight was determined and wheat bundles were then oven-dried at 75^0C, and weighed.
Grain yield (kg ha^{-1})	June	After threshing of harvested wheat, grains were weighed.

3.2.3 Statistical analyses

Field data were analyzed separately for cotton and winter wheat. Mean values of each crop parameter at various vegetative phases over 3 years (2004-2006) were statistically analyzed (SAS Institute, 2003) for analysis of variance (ANOVA) at the 0.1 probability level.

Table 3.4 Brief description of cotton variety Khorezm 127

Parameter	Value
Vegetation period, (days)	130
Yield (kg ha^{-1})	4000
Fiber length (mm)	34
Thousand seeds weight (g)	124
Recommended cotton plants in 1 ha, (thousand)	70-80
Fruiting branches	13-14

Table 3.5 Brief description of winter wheat variety Mars

Parameter	Value
Vegetation period (days)	220-230
Yield (kg ha^{-1})	up to 10000
Thousand kernel weight (g)	38-40

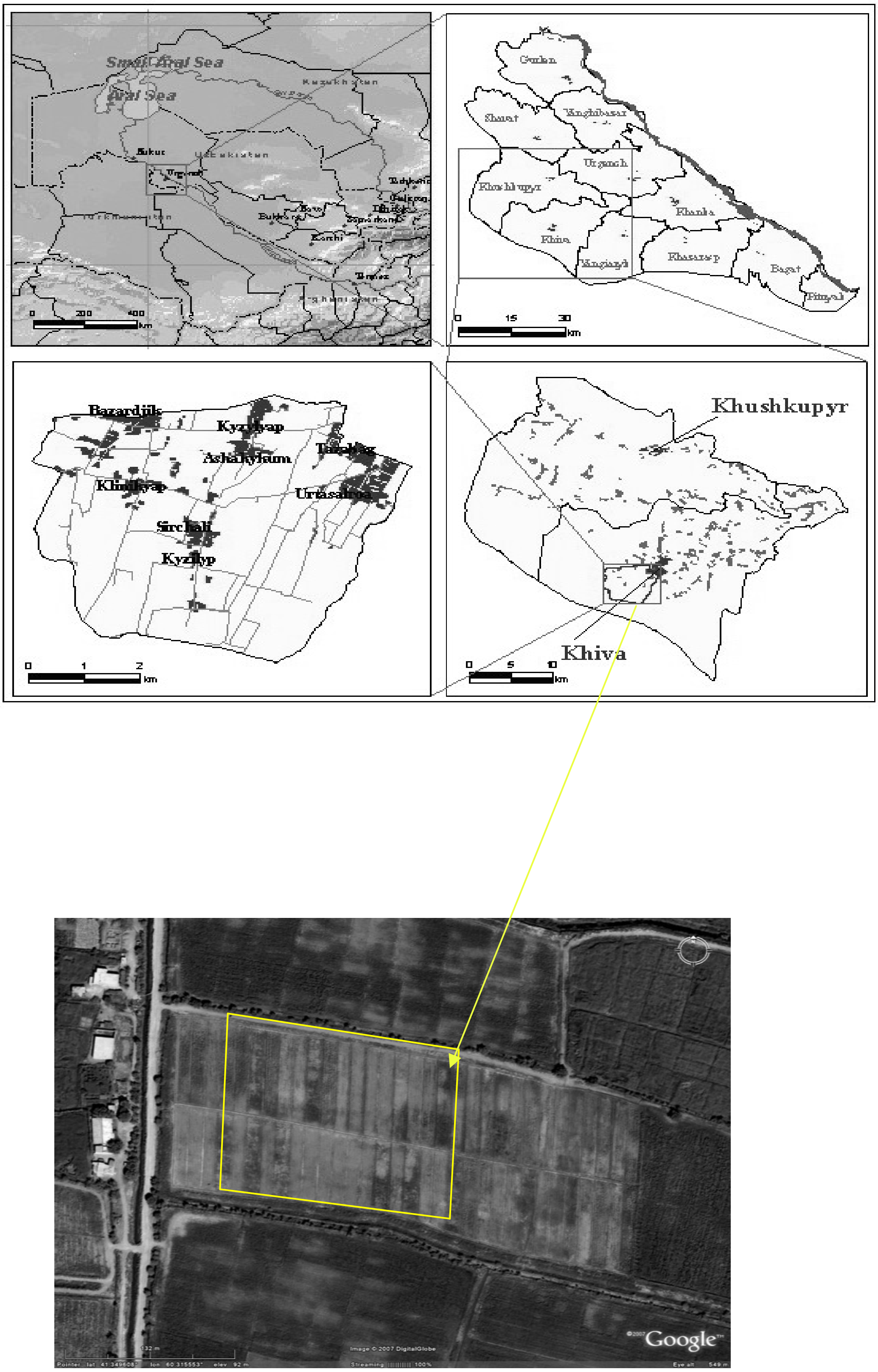


Figure 3.1 Experimental field (yellow frame)

3.3 Results

The effect of the surface crop residue on cotton and winter wheat emergence in all 3 years of investigations was insignificant. Similar results were obtained for crop growth (Tables 2.6, 2.7, 2.8). In general, the height of the cotton plants in both years was lower where crop residues were retained, while the height of the winter wheat plants at final full height development was on average 4% higher with residue retention versus residue removal.

At the flowering phase, the number of sympodial (fruiting) branches in 2004 was not significantly different for the treatments (P>0.56), while in 2006, the difference was significant (P>0.009). With crop residue plots, the number of branches was higher. At the same time, the number of fruits on these branches in 2004 differed significantly (P>0.007), and the plots without crop residues had higher fruit numbers; however, in 2006, the results did not differ significantly (P>0.2). Nevertheless, there were more fruits on the mulched plots (Table 2.7). At the end of the vegetative phase which corresponds with the ripening of the early cotton fruits, the number of dehisced fruits in 2004 did not differ significantly for treatments, while in 2006 the treatments with crop residue retention had significantly more dehisced cotton fruits (P>0.5, P>0.02). However, in both years, plots with residues had higher numbers of dehisced fruits.

The effect of crop residues on raw cotton yield in 2004 was insignificant (P>0.6), while in 2006, yields were significantly higher (P>0.03). Although the yields of stem biomass were higher, the differences in both cotton seasons were not significant (P>0.12, P>0.7). Similar to the results of the raw cotton yield, the difference in total cotton biomass was significantly higher in 2006 (P>0.65, P>0.05) for the residue plots.
In 2005, winter wheat growth and yield parameters were not effected by crop residues. The effect of the residues on grain yield, stem biomass and total biomass was not significant (P>0.9, P>0.8, P>0.6) (Table 2.8).

3.4 Discussion

The relatively low germination of cotton seeds on the plots with residues was probably due to the lower soil temperature and not to the lower air temperature, since it has been observed that crop residues on a soil surface can reduce the spring soil warming and hence adversely influence seed germination (Jessop and Stewart 1983). Usually, cotton is sown in the Khorezm region from the beginning of April until the beginning of May, much depending on the weather. The recommended soil temperature is 14-15°C to obtain a good cotton stand, and below 14°C the germination is greatly retarded (Handbook of Agriculture, 1999). Yet, in the cotton planted in 2006 following winter wheat, the density of the cotton seedlings in both residue treatments was higher than recommended, and thinning was conducted, since highest yields are obtained with an optimal density. For the cultivar used in the Khorezm region, this is estimated at 70000 plants ha^{-1} (optimal plant density with shallow ground water 70000-90000 plants ha^{-1}, Khamidov (1984)). With a plant density surpassing this optimal level, both cotton development and yield decreased (Berdnarz et al., 2006, Munk, 2001).

Moreover, during the first growth phases, in both cotton seasons, the crop residues adversely affected growth. This could also be attributed to the low, sub-optimal soil temperature as recorded elsewhere (Moncrief, 1993), This was caused by the reduced albedo due to the crop residues, which reflected the sun energy, and consequently the soil temperature warmed up more slowly with residue retention (McVay, 2003).

Despite this well known phenomenon, farmers in the Khorezm region do not monitor the soil temperature, and mainly rely on their experience and the presence of irrigation water for seeding cotton. Moreover for obtaining optimum yields, the duration of the cultivator used is around 130 days, which means that to complete the entire growth cycle cotton usually is seeded in early April, irrespective of the recommended soil temperature of 14°C (Masharipov, 1999).

Although the benefit of crop residues for winter wheat germination and growth was found to be insignificant, higher growth and germination rates were observed (2% and 4%). This was because of the reduced salinity on the plots with residues (Figure 3.2). Derpsch (1999) and Landler (2004) reported that a decrease in soil salinity was caused by the reduced evaporation on the residue plots, which improved crop establishment on these fields. The relatively high germination of winter wheat on mulched plots may also have been due to a slower cooling of the soil as compared to the bare soil (Hatfield and Prueger, 1996). On the other hand, crop residues adversely affected wheat development in the early growth stages, perhaps due to the low temperature and thus low nitrogen immobilization (Jessop and Steward 1983).

Since detailed measurements of soil temperatures were beyond the scope of this study, no final conclusions can be drawn. However, the surface crop residues positively effected cotton development as evidenced in the differences in fruiting branches and open fruits. Fruiting branches in 2004 were 1.5% higher and 25% in 2006. The number of closed fruits was 33% and 10% lower, respectively. These low values were probably due to the delayed growth of cotton plants in the early phases. At the same time, the quantity of the open fruits was higher by 20% and 22%, respectively.

Crop residues depressed the raw cotton yield in 2004 by 7%. Contrarily, after wheat rotation, in 2006 yield was 24% higher compared to without residues.

The influence of crop residues on growth and yield only became visible in the second cotton season (i.e., third year of investigation), which confirms the previous findings for other soil-climate conditions. Bruce et al. (1995) as well as Schomberg et al. (2003) reported that reduced tillage and crop residue applications increased soil organic matter and water-stable aggregates at the soil surface, which in turn improved the infiltration rate. In addition, Triplett et al. (1996) and Schomberg et al. (2003) observed cotton yield increments only from the third year onwards of their five-year investigations.

Previous research, therefore, has confirmed that the shift from conventional tillage to conservation practices usually involves a delay of several years before the accumulation of the gradual positive changes in the soil is apparent. The studies mostly underlined the positive impact of mulching with crop residues on soil biology, and the decreased soil water evaporation and increased water storage (Hatfield and Prueger, 1996) or reduced water losses in cotton cultivation (Luscano and Baumhardt 1994). This was confirmed by the separately conducted, in-depth soil studies by Egamberdiev (2007) during this study, which underscore the beneficial impact of crop residues on various soil physical and biological properties (Figures 3.2, 3.3). Although the presence of crop residues seemed to have (insignificantly) depressed raw cotton yield in the first year 2004, in contrast, the stem (11.5%) and total biomass (2%) obtained were already higher, albeit insignificant. Moreover, the insignificant biomass gain of cotton plants in 2004 was obviously due to the delayed development and to the fact that growth was impeded by the insufficient supply of irrigation water throughout the season. In the second cotton season 2006, probably due to the accumulated effects of the residues during the three previous years, stem and total biomass gain was 3.5% and 6.3% higher, respectively, on the plots with crop residues.

Previous work at the same location in 2003 on winter wheat under crop residues (Karimov, 2004) showed a significant increase in grain yield on residue plots (2397 kg ha^{-1}) compared to bare soil conditions (1435 kg ha^{-1}), although the yields were both still below average. However, in the first year of experiments the residues were very beneficial to the winter wheat. In the following winter wheat season 2005, i.e., after the crop rotation with cotton, the differences in grain yields between mulched and bare plots did not differ (5340 kg ha^{-1} vs. 5348 kg ha^{-1}). Although the yield gain was two times higher compared to the season 2003, in 2005 the effect of the tillage methods was more significant than that of crop residue retention or interactions (Tursunov et al., forthcoming). The comparatively high yields of the first years were probably because of the relatively high amount of residues at the sowing time in autumn and spring (Tursunov et al. 2005). Since the residue impact is connected with its amount, a change in soil temperature, evaporation, water storage, soil organic improvement, soil erosion reduction and biological activities in the soil depends on the residue thickness (Hatfield and Prueger, 1994; Lascano and Baumhard, 1996; Schomberg et al., 2003; Hagen, 1996; Steiner and Schomberg, 1995). This basically defines the factors of the reduced influence of the crop residues in the crop season 2005, when winter wheat was sown into the standing cotton and the amount of crop residues was lower than in the previous winter wheat season. The stem and total biomass also were not affected by the crop residues. According to FAO (2000), the optimum amount of crop residues in wheat production is 4 t ha^{-1}. A thicker layer can make sowing difficult and reduce germination, and thus could lead to yield reduction. Four-year investigations conducted by Sayre (2002) also revealed a correlation between the surface crop residue amount and wheat yield, i.e., with reduction of residues, the yield of wheat decreased.

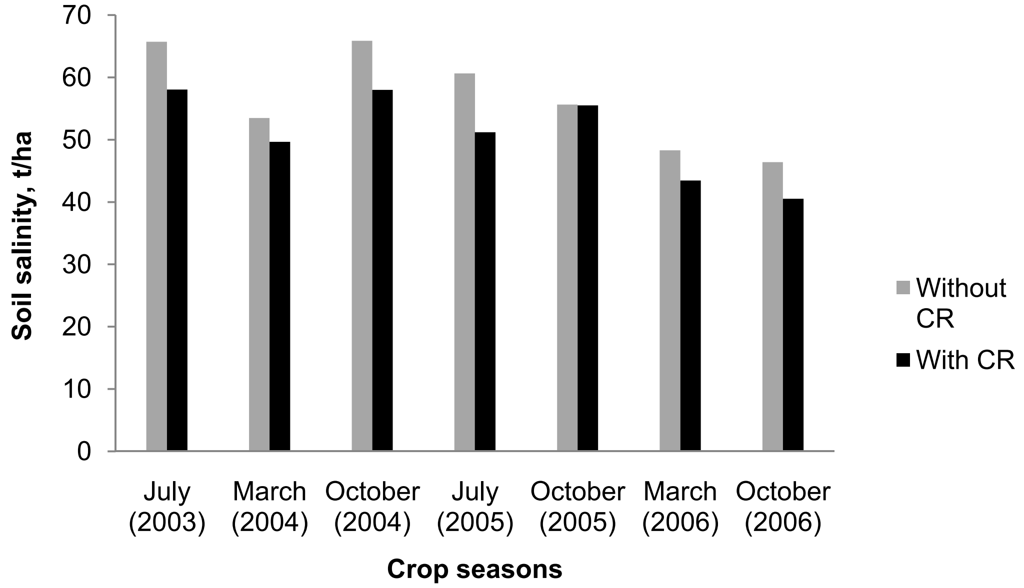


Figure 3.2 Soil salinity changes over the study years 2003-2006

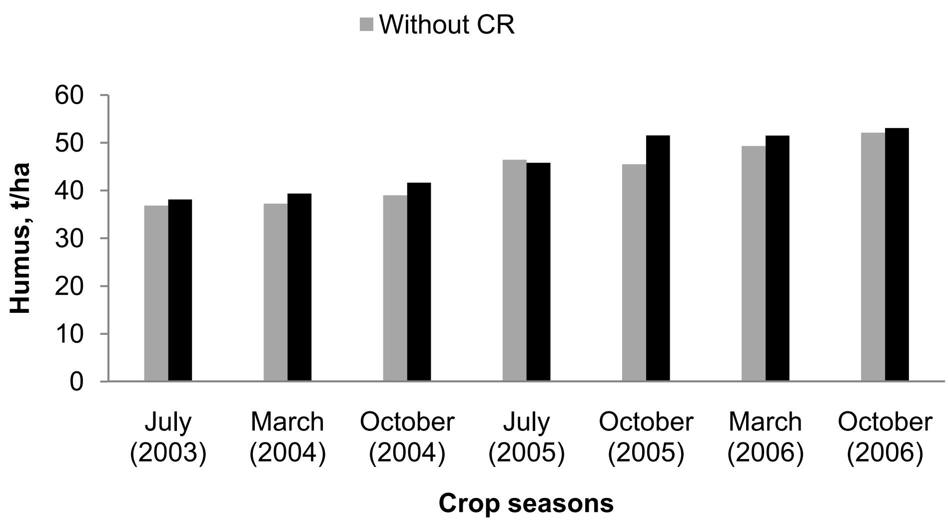


Figure 3.3 Soil humus improvement over the study years 2003-2006

3.5 Conclusions

The results indicate that surface crop residues can have a significant influence on crop production and soil properties. With the retention of the crop residues, the yield of cotton and winter wheat gradually increased. In the first cotton season, the raw yield was lower, but stem and total biomass were higher, and in the second year all yield parameters were higher with retained crop residues. The yield of winter wheat that was sown into the standing cotton plants was at the level of the yield in the treatments where residues had been removed. However, the yields of crops under crop residue management became higher over the years. The increased yields may be related to the reduced soil salinity and the improved soil aggregation and humus content, since over the years the soil properties significantly improved.

4 ADOPTION AND DEVELOPMENT OF A SEEDER FOR SOIL CONSERVATION AGRICULTURE FOR IRRIGATED FARMING

4.1 Introduction

One of the chief requirements for the introduction of soil conservation agriculture is a seeder suitable for the planting of crops in untilled and mulched soil and in the presence of stubbles and/or a cover crop, which are needed to protect the environment and soil properties. The agricultural seeders for cotton and winter wheat that were available in Uzbekistan at the onset of the study were suitable only for sowing on tilled soils, although in recent years, planting of winter wheat into standing cotton rows has been widely applied. For sowing winter wheat, farmers use either a cotton cultivator and/or a fertilizer spreader to distribute the wheat seed into the standing cotton crop and to sow the seeds. This equipment is not suitable for wheat sowing, but other options do not exist.

Due to the lack of an appropriate seeder for sowing cereals in the standing cotton plants, several field operations are necessary before sowing. In Uzbekistan, farmers must conduct up to 5 field operations in order to sow winter wheat into the standing cotton. First, the soil is loosened, and then the seeds are spread. After that, the seeds are buried. Finally, the cotton stems are cut at ground level and removed from the fields.

To seed the crops with appropriate seeders according to the planned farming practices, i.e., conventional, minimal or zero tillage, various international companies have produced different types of seeders. For instance, seeders produced by John Deere or Case are very diverse, as they are designed for seeding and planting in both tilled and untilled soils with crop residues. Some seeders are very sophisticated and expensive. In Uzbekistan and thus also Khorezm, for the majority farmers these seeders are inaccessible due to the limited resources of the farmers.

In Uzbekistan, many types of seeders are industrially produced. These seeders are mainly designed for sowing crops on tilled soils. Seeders for untilled soils are not commercially produced. The lack of seeders capable of sowing seeds on untilled soils makes the sowing of cereals difficult. Examples of commercially produced and the most widely used seeders are presented in the following.

4.1.1 Cotton seeders

In the Khorezm region, the basic crops are cotton and winter wheat. The agricultural industry is mainly focused on the need to satisfactorily sow these major crops. Cotton seeding has been practiced for a long time; hence the machinery is quite well developed. The following types of seeders are used:

1. **Model СЧХ-4Б**

Model СЧХ-4Б (Figure 4.1): designed for cotton seeding on tilled and levelled fields.

Coverage
2.4-3.6 m (60-90 cm)
Productivity
1,44-2,6 ha/hour
Working speed
6-7 km/hour
Weight of seeder
580 kg

Figure 4.1.Cotton seeder СЧХ-4БSource: http://www.uzbekselmash.uz/index.php?page=25

This seeder allows sowing both linted[1] and de-linted[2] cotton seeds. It is also designed for sowing on a partially levelled soil surface, since it has a flexible mounting system for the seed openers that allows them to follow the soil surface by moving up and down. The necessary depth for seeding is adjusted by changing the depth regulator. The seed rate can be adjusted by changing the position of a regulator. The main disadvantages of this seeder are that it (i) is designed for sowing on tilled soils, (ii) has an imprecise seed rate regulation system, and (iii) cannot apply fertilizers simultaneously with seeds.

2. **Model СМХ-4-04-0**

Another widely used seeder is the model СМХ-4-04-01 (Figure 4.2). This seeder is designed not only for sowing de-linted cotton seeds, but also for sowing other crops, such as sorghum, corn, soy-beans, and sugar beet.

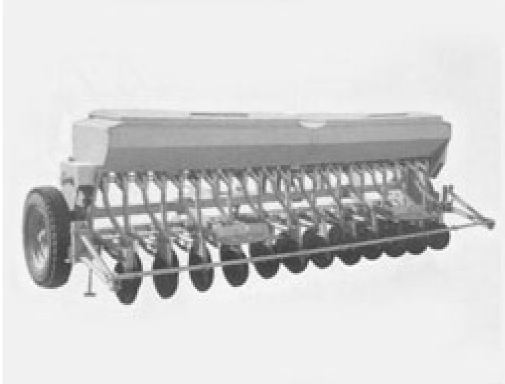
Coverage	2,4-3.6 m (60-90 cm)
Output	2,8 ha/hour
Working speed	6-8 km/hour
Weight of the planter	635 kg

Figure 4.2 Seeder CMX-4-04-01
Source: http://www.uzbekselmash.uz/index.php?page=25

This seeder is commercially produced. Despite the multiple functions, the seeder has several constraints: (i) it cannot handle linted[1] cotton seeds, which in the Khorezm region is the main type of seed used; and (ii) the comparatively high cost of de-linted[2] cotton seeds. Other constraints of this seeder are similar to those of the model СЧХ-4Б described above.

4.1.2 Seeders for cereals

The large-scale sowing of winter wheat started in Uzbekistan in 1996 as a result of the government's strategy to gain independence from wheat imports (Djanibekov, 2008). Usually, winter wheat is sown into standing cotton stems. Due to the lack of appropriate seeders, farmers have modified existing equipment such as seeders that are not originally for sowing wheat seeds. On tilled soils, farmers mainly use model DEM (ДЕМ) – 3.6 (Figure 4.3).



- Coverage
  3.6 m
- Output
  4 ha/hour
- Working speed
  8-10 km/hour
- Weight of the planter
  750 kg

Figure 4.3 Seeder DEM – 3.6
Source: http://www.uzbekselmash.uz/index.php?page=25

This commercially produced seeder is intended for sowing wheat, barley and other cereals. Use of this seeder requires preparation of fields for sowing, i.e. cleaning of field from residues, plowing, levelling, and harrowing. The main advantages of this seeder are: (i) it allows seeding various cereals, (ii) it provides relatively good depth control, (iii) it has good responsiveness to uneven fields, and (iv) it has a relatively high sowing capacity. The main disadvantages are: (i) as already mentioned, use of this seeder requires carrying out of several field activities that lead to both economic and ecological losses; (ii) there is no reservoir for fertilizer, and consequently the seeder cannot apply fertilizer concurrently with seeds; and (iii) it has only one type of opener (disc opener) and there are no replacements on the market, which reduces flexibility.

Since winter wheat sowing is mainly conducted after cotton harvesting in October and November, sowing into the standing cotton with this seeder is limited.

4.2 Seeder shortcomings

The lack of suitable wheat seeders for sowing wheat into standing cotton plants has forced farmers to adapt implements not intended for sowing grains in the autumn period. The sowing of winter wheat also requires numerous field activities that are both ecologically and economically undesirable. Given that soil conservation activities within irrigated areas have been practiced in different countries, there was no need for designing a completely new seeder. Instead after the examination of crop planting practices in the Khorezm region, a more universal seeder, developed in India, was acquired within the framework of this project (Figure 4.4). This seeder is capable of sowing both grains (wheat, maize, rye) and cotton seeds. In addition, it can sow on no-tilled soil with crop residue. Several types of implements, such as knife openers, double-end shovels, disk, star wheels, and ridgers can be added depending on the requirements. Additionally, this seeder allows application of fertilizer concurrent with sowing. For this, two reservoirs, one for seeds and another for fertilizers are installed on the seeder. Each tank has its own delivery system. Further details on the seeder design are described in Yadav et al. (2002).

Figure 4.4 Indian seeder

However, this seeder has several disadvantages. Although designed for cotton seeding, it needs de-linted seeds, which are expensive and not common in the Khorezm region. Most existing cotton seeders are designed for the use of both linted and de-linted cotton seeds, but mainly linted seeds are used. Further testing of this seeder with cotton showed that the sowing depth was not kept, since the solid frame of the seeder was not sufficiently flexible to follow the irregularities of the soil surface to maintain a uniform seeding depth. This was particularly true on the more heavy soil textures, which during cotton seeding are often hard, and also when there is layer of crop residues. The recommend seeding depth in Khorezm is 5 cm (Khamidov, 1984). Cotton in particular is very sensitive to seeding depth, as the placement of seeds below the recommended sowing depth strongly reduces germination and hence results in irregular plant establishment (Handbook of Agriculture, 1999). In case seeds remain above the recommended depth, soil moisture for germination can be insufficient, and the expected quantity of cotton seeds will not germinate (Mirakhmedov, 1989). Finally, also the quality of the materials used in the construction of the Indian seeder was insufficient for larger work areas. The seeder was easily damaged, which slowed down the seeding process due to frequent repairs and re-adjustments.

4.3 Seeder development

As mentioned above, the use of the existing seeders requires several pre-sowing field operations. However, increasing the number of field activities concurrently increases costs and expenses and hence decreases the farmer's income (Foster, 2002; Hanks and Martin, 2007). In addition, studies worldwide have shown that soil tilling can lead to soil degradation, compaction and consequently to yield reduction (FAO, 2008). To reduce the negative impact of field operations on the soil quality and to improve crop yield, new technologies need to be developed that are more universal and suitable for daily farming activities. Moreover, recent household studies in the Khorezm region showed that equipment use and rental is one of their largest expenses (Rudenko, 2008).

As mentioned above, one of the basic requirements for any seeder is keeping the prefixed sowing depth. Adherence to the recommended planting depth is especially important in the Khorezm region, since the climate is sharply continental. Increasing sowing depth slows crop emergence (Abrecht, 1989). Overwetting of deeply placed seeds leads to seed decomposing or, due to the thick soil layer, the seeds will not develop further (Rawson and Macpherson (2000).

According to Radford (1986), the optimum sowing depth for wheat establishment is 5 cm. For Khorezm it is also recommended to sow cotton at this depth, while for winter wheat optimum sowing depth is 3-5 cm (Handbook of Agriculture, 1999; Mirakhmedov, 1989.). To be able to sow accurately and place the crop seeds at the necessary depths, a depth control system must be installed on the seeder.

Several studies have shown that the fitting of press wheels to seeder increases crop germination. Investigations conducted by Radford (1986) have shown that sowing wheat with a press wheel increases crop establishment. At the same time, it is necessary to know the position of the press wheel at which the crop establishment is optimum. Otherwise, incorrect regulation could lead to decreasing crop emergence, as shown by Montemayor (1995) for cotton, which is related to soil compaction by the press wheels. Field research to determine the effect of press wheels on barley establishment compared with a chain harrow conducted by Radford and Wildermuth (1987) revealed that depending on sowing depth, application of press wheels increased crop emergence, i.e., at depth 4.5 cm from 74 to 88%, and at 5.5 cm from 55 to 89%.

Suitability of seeders for farming also depends on the fixed openers. Seeders with a well designed seed and fertilizer delivery system, but without appropriate openers can be an impediment to a wide application. Openers are key implements of the sowing machines (Gould et al., (1996), Green, 1999). There are many types of openers. They differ by types, furrow openers, disc type, knife-openers, inverted T openers and star wheels. The above-mentioned openers can be used for sowing of cultivars on both tilled and untilled soils, i.e., they are universal openers. According to Chaudhuri (2001), under zero tillage conditions the best performance can be obtained with chisel and inverted-T furrow openers. Nearly all openers used by the farmers in the Khorezm region are designed for sowing on tilled soils. In order to sow cotton seeds, the opener set with depth control and covering knives is used. To avoid the many field operations necessary for sowing winter cereals into the standing cotton stems when farmers do not have seeders with openers, in our experiments with winter wheat, the knife and disc openers were used. In general, a suitable opener can be mounted according to tillage practice; it can be a knife-opener, different types of disc openers or star wheels. Seeders with a high clearance and appropriate opener for sowing winter cereals into the standing cotton stems before the final hand harvest considerably reduced the farmers' difficulties.

Prior to the project, the Tashkent Institute of Irrigation and Melioration had developed some prototypes of universal seeders (Figure 4.6 and Figure 4.7). One of these universal planters was developed on the basis of an existing cotton cultivator

(Figure 4.5) (Культиватор-растение питатель хлопковый КХУ-4Б), which is designed for soil loosening and entering of mineral fertilizers into the soil. The given unit is widespread among farmers and industrially produced. In addition, this unit is not sophisticated and is very convenient to use.

Cotton cultivator-crop feeder CCU – 4B (КХУ-4Б)

- Type
  tractor mounted
- Output, ha
  1.12 – 2.21
- Coverage, m
  2.4, 2.8, 3.6
- Tillage depth, cm
  3 - 20
- Working speed, km/h
  5 – 6

Figure 4.5. Cotton cultivator (КХУ-4Б) Source: http://eng.bir.uz/technologies/catalogue/obj1140411874/obj1140419229/obj1140421775

In order to develop a new seeder that satisfied the needs of the farmers, the following aspects were considered: The universal seeder should be a) easy to use, b) easily adjustable, c) multipurpose, d) capable of sowing on rather rough soil, i.e., depth of sowing should not vary when soil surface is rough (unlevelled), e) implements can be easily replaced, f) it should be possible to apply fertilizers simultaneously with seeds, g) the seeder would be capable of making furrows and loosening soil, h) in case of replacement of openers or other operative parts, the necessary implements should be widely available, i) it should be capable of sowing the seeds on both tilled and untilled soils, j) it should be capable of sowing the crop seeds into crop residues remaining on the soil surface, and k) it should provide uniform placement of seeds.

In order to achieve the intended purposes, the seed box was completely modified (Figure 4.6). A new seed and fertilizer delivery system was developed. For a sustainable supply of seeds (2) and fertilizers (1) two boxes were installed on the frame of the seeder. On the bottom of the seed and fertilizer boxes, two different distributing mechanisms are placed. Altering the position of mechanism (8) changes the width of slots through which seeds enter the delivery system, i.e., the position of the mechanism is adjusted depending on the seed type. In order to fix the seed rate, depending on type of seeds, the position of the device is changed (9). In the delivery system the seeds move in pipes to the openers. In order to provide a uniform seed and fertilizer supply, the driving system was improved.

To regulate seed depth, the depth controller was modified (3). Also, soil packing systems (5, 6) were installed.

Figure 4.6 Seeder developed for sowing cotton

All modifications were tested in real field conditions, with both cotton and winter wheat. Field tests revealed a number of advantages of the Indian seeder when compared to local seeders. First, this seeder is capable of sowing the wheat seeds into the standing cotton stems, as it has high clearance. Second, it is possible to mount different openers, such as disk, double-disk, knife type and others. Third, it has better depth control, and is also capable of sowing the seeds into untilled soils with crop residues. In case of cotton, both linted and de-linted cotton seeds can be sown. In addition, this seeder can be used for application of fertilizers and for soil loosening (cultivator-loosener).

At the same time, the field tests revealed some engineering limitations. First, the system needs to be improved such that crop seed and fertilizer rates are fixed. The current system is difficult to calibrate, which takes unnecessary time. Second, there are some difficulties when sowing seeds on beds, especially when wheat seeds are concerned. The seeder does not sow uniform, i.e., the distance between the lines of seeds is not maintained. For cotton sowing, the soil packing device also needs to be improved.

Figure 4.7 Seeder developed for sowing cereals

(Figure 4.6, arrows 5 and 6), which at present is not flexible enough. In addition, appropriate openers need to be developed that which can sow crop seeds through a thick layer of crop residues. At the same time, assessment of the limitations that were encountered revealed that, except for openers, improvements can be achieved by relatively small efforts and in a short time, as many components of this seeder are commercially produced and readily available.

As mentioned above, this seeder allows the mounting of different types of soil openers. However, only a few types of soil openers are industrially produced. In order to increase the potential of the seeder for conservation tillage practices, new soil openers need to be developed. These are aspects that will be addressed in the next project phase.

4.4 Conclusions

In order to conserve and improve the soil properties and at the same time increase the income of farmers in the Khorezm region where soils are degraded and farmers' resources are limited, multipurpose and less expensive seeders are necessary. Especially at present, when the number of farmers has increased due to the privatization of collective farmers, many farmers are facing difficulties related to agricultural machines, particularly regarding appropriate seeders. The seeder developed in the framework of the project addresses all the shortcomings of the previous systems and requires lower investments. In addition, the relative affordability to farmers could facilitate the introduction of conservation farming systems, as this newly developed seeder easily can be applied to both tilled and untilled soils, and less labour is required. The land on which sowing is conducted is also exposed to less compaction. Thus, application of this seeder will improve the farmers' profits and livelihoods, and at the same time will lead to more ecologically sustainable land use.

5 FINANCIAL ANALYSIS OF CONSERVATION AGRICULTURE PRACTICES

5.1 Introduction

For several decades, arable land in Uzbekistan, Central Asia, has been deteriorating due to erosion, soil salinity and unsustainable management practices. Moreover, water scarcity and the concurrently shallow, saline groundwater tables are perceived by farmers as major bottlenecks (Ibrakhimov, 2004, Akramkhanov, 2005, Egamberdiev, 2007). Improved agricultural systems must be developed based on sustainable agricultural practices, which increase land productivity and improve resource use efficiency. To this end, one promising avenue is the use of conservation agriculture practices, which according to the definition of the FAO (2008), aim "...to reduce soil degradation through several practices that minimize the alteration of soil compaction and structure and any effects upon natural biodiversity".

Globally, the area under conservation practices has increased in the last years, with zero tillage farming practices now covering up to 98 million hectares worldwide (FAO 2006). Zero tillage is one of the conservation agriculture practices, where the seeds are sown on the undisturbed soil surface (Derpsch, 2001). However, studies have underlined that there could be a time lag between the application of conservation agriculture practices and the achievement of the desirable effects. Moreover, immediately after the conversion from conventional to conservation agriculture, farmers often face lower yields (FAO, 2008). In the worst case reported, it had taken 5-7 years to re-establish the (initial) yield levels (Gupta et al., 2006). This initial yield gap will directly lead to income loss of the farmers. Thus, for conservation agriculture practices to be adopted by farmers, there should be additional, direct incentives together with the benefits to the environment. Such incentives, for example, could be reduced costs stemming from the reduction of field activities (mechanization and labour). Since conservation agriculture often goes along with cost saving, this is attractive for farmers in developing countries, where prices are not stable and tend to increase fast (Murodov, 2002; Baffes, 2004; Shashi Kumar, 2007). Findings around the globe show that among the many factors, farmers strongly consider the financial returns when choosing between farming (tillage) practices and when deciding for or against shifting from conventional to conservation agriculture (Siziba et al, 2007).

Economic analyses of conservation agriculture practices have used a range of approaches, such as partial budgets, benefit cost analysis, gross margin analysis, and in general underscored that conservation agriculture practices are indeed profitable and result in increased benefit cost ratio and higher return to farmers (Foster, 2002; Hanks and Martin, 2007; Singh and Kumar, year unknown). This in part explains the rapid expansion of the new technologies. Therefore, an economic analysis of benefits and costs associated with the conservation agriculture practices that have technically shown to be promising becomes imperative before any recommendations to farmers are made. This assumes that farmers behave rationally, i.e., that they seek for either higher economic return or lower costs. This is in particular true for irrigated agriculture, since most experiences with conservation agricultural practices predominantly originate from rainfed cropping systems.

An economic analysis of four tillage practices (conventional, intermediate, permanent beds and zero tillage) studied in the context of a project on sustainable management of land resources in the Aral Sea Basin (Vlek et al. 2003, ZEF 2003) was conducted. The tillage practices were combined with and without crop residue retention, in a cotton-winter wheat crop rotation under irrigation (for more details see Chapter 2 and 3). These experiments were implemented on-farm, though researcher managed, on an operational scale during the three successive years of study. This allows a comparison of the different activities based on a gross margin analysis. The analysis could be elaborated further for more clear long-term results with incorporation of indicators of soil organic matter and soil quality parameters important for yield levels and consequently farmers' benefits.

5.2 Materials and methods

The experiment started in 2004 with cotton. The experimental design consisted of a complete randomized design with 4 replications. A total of 4 tillage practices (Table 5.1) with and without crop residues was established on 32 plots (see also Chapter 2 and 3).

Table 5.1 Experimental design of tillage practices. + is plots with crop residues, - is plots without residues.

Conventional (C+); (C-)	Cotton: Autumn ploughing, spring seedbed preparation, sowing on flat field Winter wheat: Autumn seedbed preparation, sowing on flat field into standing cotton
Intermediate treatments (IT+); (IT-)	Cotton: Autumn ploughing, spring seedbed preparation; new beds with irrigation furrows between the beds, cotton sown on the beds. Winter wheat: Autumn sowing on existing raised bed, 4 rows of wheat on each bed into standing cotton, i.e., 2 rows on each side of each row of cotton
Permanent beds (PB+); (PB-)	Cotton: Sowing cotton on unploughed, existing permanent bed. Winter wheat: Sowing of winter wheat on permanent beds, 4 rows of wheat on each existing permanent beds into standing cotton, i.e., 2 rows on each side of the row of cotton
Zero tillage (ZT+); (ZT-)	Cotton: Sowing of cotton on unploughed land on flat soil Winter wheat: Sowing winter wheat on unploughed land 4 rows of wheat into standing cotton, i.e., 2 rows on each side of each row of cotton

The gross margin analysis (GMA) was applied to assess the economic potential of each of these conservation tillage practices in terms of gross margin (GM) on a per hectare basis (which represents returns on land) and the rate of return on investments (RR). In addition, dominance and sensitivity analyses were carried out to determine those practices with the highest potential in order to compare the risk profiles of these farming practices.

5.2.1 Gross margin analysis and rate of return

Gross margin has been accepted in agricultural economics as the unit of analysis for evaluating the economic performance of farming activities (FAO, 2001). Generally, gross margins provide a simple way of comparing the profitability of activities and are easily understood by farmers, since products and costs are directly affected by activities such as conservation tillage. Gross margin (GM) is defined here as GM = GR - TVC; where GR equals the gross revenue (income) from selling agricultural outputs, and TVC equals the total variable costs. This is done separately for each treatment studied.

The GR was estimated based on the empirically measured yields and output prices obtained from the regional division of the Ministry for Agriculture and Water Resources Management in Khorezm (OblVodKhoz). Yield data are given in Chapter 2 and 3.

The TVC included the costs for machinery and fuel, seeds, fertilizers, labor, herbicides, and irrigation water. Special attention was paid to machinery and fuel costs due to their highest share in total costs and to their potential to be decreased under conservation agriculture. These costs were calculated based on the applied amounts of inputs and the prices for the study years obtained from the regional division of the Ministry for Macroeconomics and Statistics in Khorezm (OblStat) and the Machine-Tractor Park (Khiva MTP).

The economic efficiency of the different treatments was estimated with the associated rate of return (RR), which shows the amount of profit (gross margin) received per each invested monetary unit. This was calculated as RR = GM / TVC.

5.2.2 Dominance analysis

Assuming that farmers seek for maximization of their production levels and for increasing efficiency, the production in relation to costs becomes of paramount importance. To predict whether it is worthwhile for a farmer to engage and invest in a particular activity (here, conservation tillage practice), a dominance analysis was conducted in addition to gross margin and rate of return assessment. This analysis compares the total variable costs with the respective gross margins and helps to choose the option with the best potential. Practices with high TVC and low GM will be dominated by those with higher GM, and consequently will be excluded from further economic analysis. For improving the visualization of these analyses, GM was plotted against the corresponding TVC. The dominating practices then appear below the established GM curve (cf. Figures 5.1-5.4).

5.2.3 Sensitivity analysis

To provide a more detailed financial analysis of conservation tillage practices, especially for those with insignificant differences in economic performance, and in order to account for the possible production risks, sensitivity analyses were conducted. Therefore, rather than just looking at absolute values of GM and RR, the range of GM and RR of the individual practices were expanded to include the respective standard error (SE):

$$\text{GM - 1SE} \sim \text{GM + 1SE}$$
$$\text{RR - 1SE} \sim \text{GM + 1SE}$$

5.3 Results

The GM analyses (Table 5.2) revealed that throughout the experimentation period (for each year separately and in three years cumulatively) the conventional treatments with cotton and wheat both with and without crop residues (C+, C-) had only moderate to low gross margins and relatively low rates of return, averaging UZS 280,000 UZS ha^{-1} and a 0.68 rate of return for C+, and UZS 370,000 ha^{-1} and a 0.87 rate of return for C-. Although this trend was not yet clear for the first year of the experiment, when gross margins and rates of return for conventional treatments with cotton showed better economic performance (Table 5.2) than permanent bed trials and zero tillage with residues, the effects became more evident from the second year onwards. However, from an economic point of view, none of the conservation agriculture treatments were significantly better.

In the first year, for example, the zero tillage treatment without crop residue (ZT-) had the highest GM and RR, but also the highest standard error for both indicators, thus indicating the highest probability of production risk (Table 5.2). This treatment was followed by the intermediate treatments with and without crop residues (IT+, IT-), which had attractive GM and the second highest RR. However, if any decision had to be based upon the amount of TVC, then the permanent beds with and without crop residues (PB+, PB-) were the best option.

Dominance analysis (Figure 5.1) showed similar but somewhat different figures. Here, the intermediate treatments (IT+, IT-) along with the conventional treatments (C+, C-) were clearly dominated by the other two conservation agriculture treatments (ZT+, ZT-, PB+, PB-). The highest gross margins were obtained with ZT-. While TVC of ZT- were almost comparable to PB+ (252 and 246 thousand UZS per ha), the gross margin under ZT- was 1.5 times higher.

The GM analysis of conservation tillage practices with winter wheat in 2005 showed the highest GM and RR for the permanent beds trials (PB+, PB-), followed by the intermediate treatments (IT+, IT-) (Table 5.2, Figure 5.2). According to the dominance analysis, the conventional treatments in 2005 were clearly dominated by conservation agriculture treatments (Figure 5.2). In this year, the analysis also showed that the GM under PB+ was superior to ZT-, and that conservation tillage practices with crop residues (PB+, IT+, ZT+) had a better potential than the same treatments without crop residues (Figure 5.2). The costs of all conventional treatments in 2005 were on average, 1.3 times higher (UZS 479,000 ha^{-1}) than the average costs of all conservation agriculture practices (UZS 364,000 ha^{-1}).

Table 5.2. Financial analysis of conservation agriculture treatments. SE = standard error. Mechanization and fuel costs are a sub-set of total variable costs TVC. RR = rate of return. In 2006 the average exchange rate was about UZS 1,200 per USD

	Conservation tillage practice	**Gross margin**		**RR on investment**		**TVC**	**Mechanization and fuel costs**
		Mean	**SE**	**Mean**	**SE**		
		Thousand UZS / ha		coefficient		Thousand UZS / ha	Thousand UZS / ha
Cotton 2004	**PB+**	269	65	1.09	0.26	246	29
	PB-	239	89	1.00	0.37	239	31
	C+	335	147	1.19	0.52	280	94
	C-	371	158	1.31	0.56	283	96
	IT+	389	115	1.39	0.41	280	87
	IT-	369	140	1.35	0.51	274	89
	ZT+	133	80	0.61	0.37	217	21
	ZT-	406	171	1.61	0.68	252	23
Wheat 2005	**PB+**	514	60	1.44	0.17	358	57
	PB-	527	130	1.43	0.35	370	69
	C+	143	253	0.30	0.54	473	172
	C-	396	231	0.81	0.48	485	185
	IT+	453	36	1.27	0.10	358	57
	IT-	492	94	1.33	0.25	370	69
	ZT+	424	55	1.19	0.15	358	57
	ZT-	396	123	1.07	0.33	370	69
Cotton 2006	**PB+**	360	129	0.65	0.23	554	50
	PB-	392	174	0.71	0.31	554	59
	C+	362	132	0.54	0.20	665	188
	C-	343	158	0.51	0.23	676	212
	IT+	447	119	0.64	0.17	700	188
	IT-	410	146	0.62	0.22	659	197
	ZT+	372	89	0.70	0.17	533	31
	ZT-	374	127	0.71	0.24	528	42

Table 5.2. continued

	Conservation tillage practice	Gross margin Mean	Gross margin SE	RR on investment Mean	RR on investment SE	TVC	Mechanization and fuel costs
		Thousand UZS / ha		coefficient		Thousand UZS / ha	Thousand UZS / ha
Total in 3 years	**PB+**	1,142	254	0.99	0.22	1159	137
	PB-	1,158	393	1.00	0.34	1163	160
	C+	840	532	0.59	0.38	1419	455
	C-	1,110	547	0.77	0.38	1444	492
	IT+	1,288	271	0.96	0.20	1338	333
	IT-	1,271	380	0.98	0.29	1303	356
	ZT+	929	225	0.84	0.20	1108	109
	ZT-	1,177	656	1.02	0.57	1150	134
Average of 3 years	**PB+**	381	85	1.06	0.22	386	46
	PB-	386	131	1.04	0.35	388	53
	C+	280	177	0.68	0.42	473	152
	C-	370	182	0.88	0.42	481	164
	IT+	429	90	1.10	0.23	446	111
	IT-	424	127	1.10	0.33	434	119
	ZT+	310	75	0.83	0.23	369	36
	ZT-	392	140	1.13	0.42	383	45

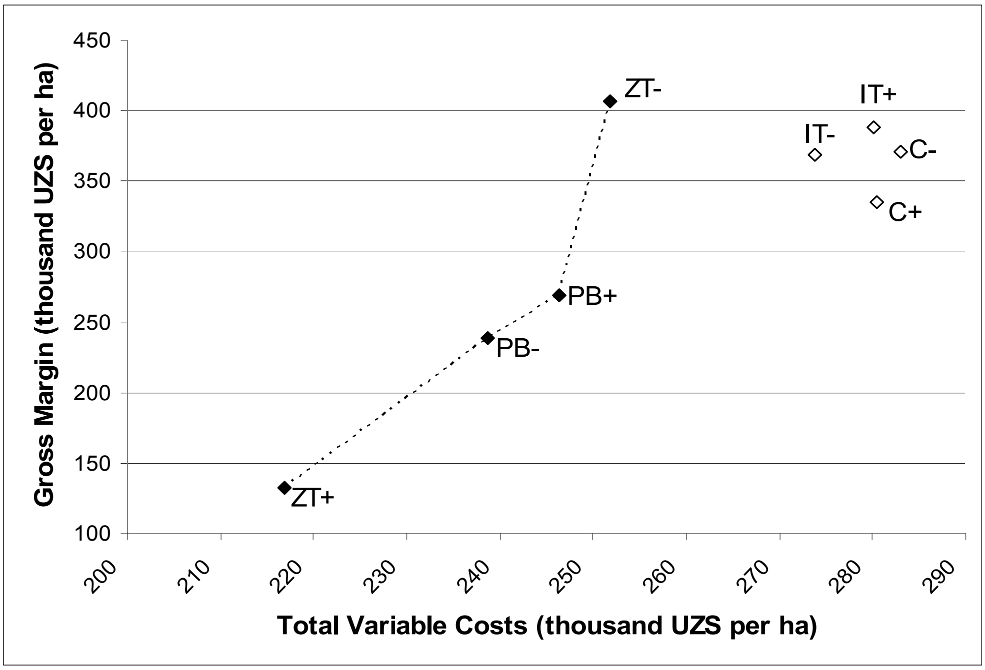


Figure 5.2**.** Gross margin curve for wheat conservation tillage practices in 2005. Black dots: dominating practices. The connecting line is made for improved visualization only.

In 2006, the conventional treatments (C+, C-) again had low GM and lowest RR compared to conservation agriculture treatments (Table 5.2). Intermediate treatments with and without crop residues (IT+, IT-) had highest GM but also highest TVC, thus resulting in only the third best rate of return (Table 5.2). Zero tillage practices (ZT+, ZT-) in 2006 became most promising as evidenced by the low TVC and highest RR. While this year, the IT and the conventional system had similar high costs (660 -700 thousand UZS per ha), the IT system was clearly superior with regard to GM (Figure 5.3). Dominating treatments in 2006 were basically all conservation agriculture treatments without crop residues (ZT-, PB-, IT-, and IT+). The costs of the conventional system (average 671 thousand UZS per hectare) were 1.2 times higher than those of both ZT and PB (with or without crop residues) with (on average, UZS 671,000 ha^{-1}).

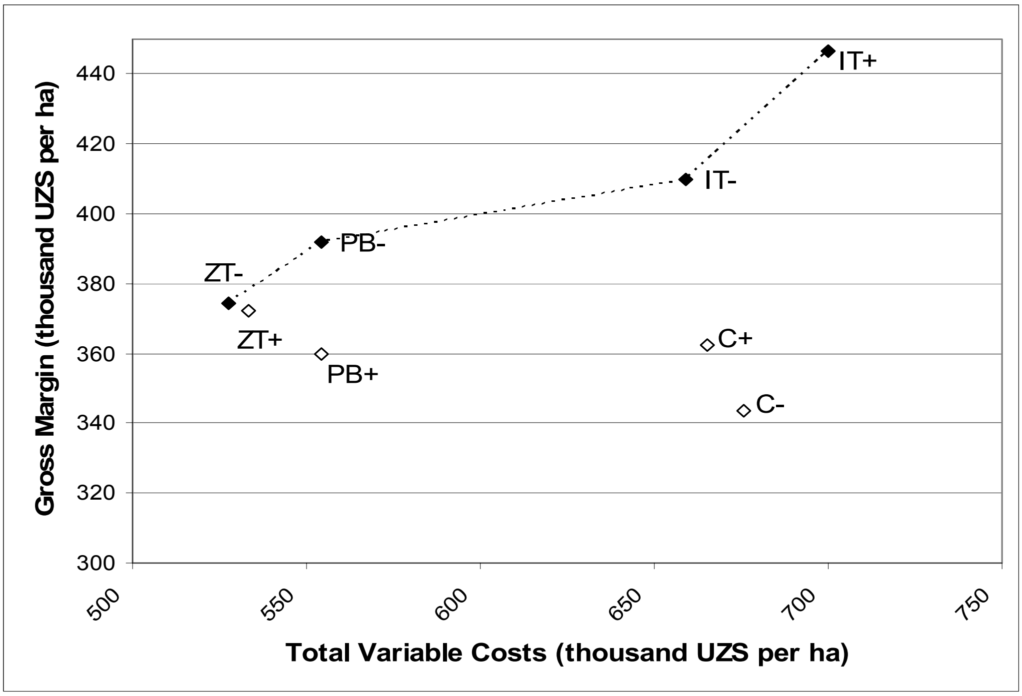


Figure 5.3. Gross margin curve for cotton conservation tillage practices in 2006. Black dots: dominating practices. The connecting line is made for improved visualization only.

Analysis of the accumulated results over the period 2004-2006 showed that in general the conventional practices (CT+ and CT-) were less attractive compared to the different conservation agriculture practices. Conventional practices showed lower GM and rate of return and at the same time had higher production costs based on both cumulative and average figures (Table 5.2).

However, in the course of these years no clear trend became visible with respect to which of the conservation agriculture practices was most promising. Cumulative GM analysis of the conservation treatments over 2004-2006 indicated the possibility of receiving the highest GM from the same land plot under the cotton-wheat-cotton rotation with intermediate treatment practices (IT+, IT-). The second highest GM could be achieved from ZT practices without crop residue (ZT-), however under highest standard error and thus highest production risk. Permanent bed trials (PB+, PB-) presented the third best option with high GM and, in fact, highest RR (Table 5.2). The dominance analysis revealed the clear dominance of the conservation practices over the conventional treatments because of the higher TVC and lower GM in the latter. Permanent bed practices with and without crop residues were also formally dominated by the other two conservation agriculture treatments (Figure 5.4), but in fact differed very little from ZT-

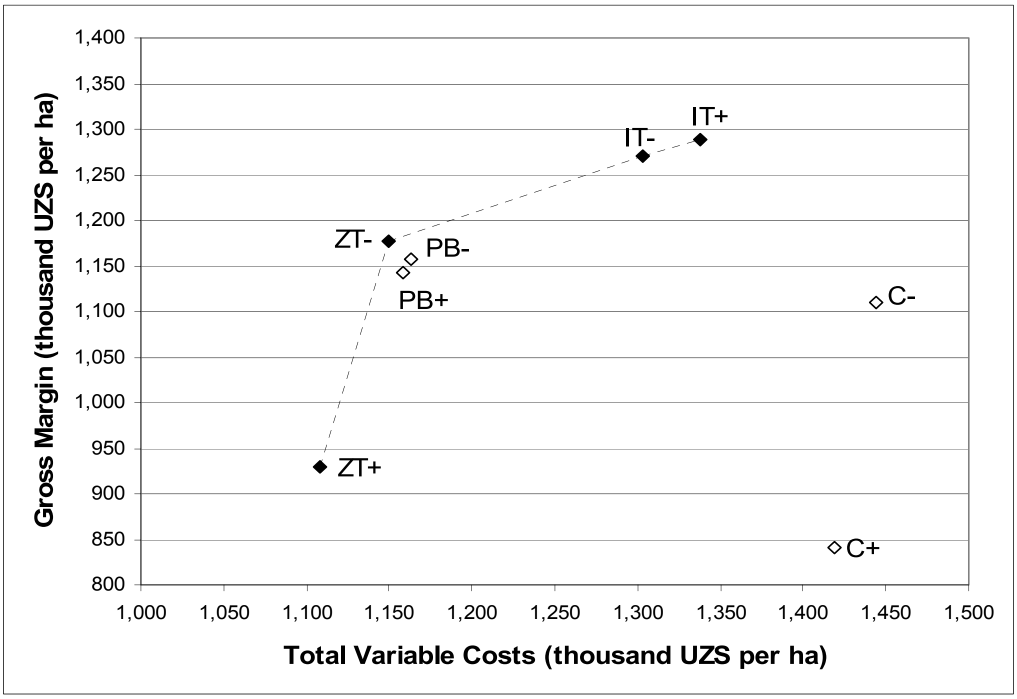


Figure 5.4. Cumulative Gross Margin curve for the different conservation tillage practices for three years cotton-wheat-cotton rotation. Black dots: dominating practices. The connecting line is made for improved visualization only.

Machinery use and fuel costs are presently the highest expenses for farmers in Uzbekistan (Rudenko and Lamers, 2006). Therefore, they have been singled out in Table 5.2. In the first year of the experiment, when cotton was grown, the share of machinery and fuel costs contributed up to 34% to the TVC in conventional practices, while in zero tillage and permanent beds it was only 9% and 13%, respectively. During the winter wheat cultivation in the following year, machinery and fuel costs stood at 38% under conventional practice and 19% under zero tillage and permanent beds. The share of machinery and fuel costs under the intermediate treatments appeared close to conventional treatments with cotton and to the permanent beds with winter wheat. Cumulative and average figures for machinery and fuel costs follow the general trend and were highest in conventional treatments and lowest for zero tillage and permanent beds.

5.4 Discussion and conclusions

Conservation agriculture practices have been expanding steadily all over the world. The rapid distribution of conservation tillage practices was largely due to the farmers' recognition of the advantages of conservation agriculture, such as a significant reduction in field management operations, resulting in reduced labour and machinery costs, as well as the soil improvement and potential yield increase in the long run (FAO, 2008). Consequently, the valuation of conservation agriculture practices worldwide indicates that the highest returns and the lowest relative risk were obtained from no-till (conservation agriculture) practices (Hanks and Martin, 2007). Smolik and Dobbs (1991) showed in a review spanning five years of studies on alternative agricultural systems, that the highest average net income over costs (excluding management costs) was achieved from conservation agriculture practices. Other studies (e.g., by Williams, 1988) showed that conservation agriculture practices such as conservation tillage, zero tillage, and ridge-till were more profitable than the conventional agricultural practices in these areas. Cost effectiveness analysis of wheat cultivation under conventional and zero tillage conducted in Punjab, India (Singh and Singh, 2003), showed a 3-fold reduction in costs (2497 vs. 762 Rs/ha). Economic analysis of cotton experiments carried out under five tillage practices during five years in the Mississippi Delta, USA

(Hanks and Martin, 2007), also revealed the lowest cost in zero tillage as compared to conventional tillage (90 vs. 34 USD/ha).

However, the bulk of the evidence originates from rainfed cropping systems, since no-till practices so far have hardly been considered for irrigated land. In this study, for the first time the ecological and financial benefits of conservation agriculture have been analysed in the arid regions of Central Asia; in particular for the cultivation of cotton and winter wheat which, covering 77% of all irrigated land (MAWR, 2004), are the dominant crops in Central Asia. The detailed production analyses showed that the yields did not differ significantly across all treatments for both conventional and conservation tillage (Chapter 2 and 3). This is encouraging, as the different conservation practices did not show the typical initial yield gaps experienced with conservation agriculture world-wide. Therefore, on the one hand, conservation agriculture practices would bring benefits to the environment, and to the soil in particular, via an accumulation of soil organic matter, improved soil nutrient exchange capacity and reduction of soil salinity (Egamberdiev, 2007), while on the other hand, and due to the absence of the initial yield gap, the introduction of conservation agricultural practices would not be detrimental to the farm household income.

A closer look at the cost structure within the financial analyses revealed that conventional practices, both with and without crop residues, require more and more intensive field activities than conservation practices, resulting in higher costs. In our experiments, these costs were 1.2-1.5 times higher. This explains the lower gross margins and lower rates of return from the conventional systems (starting from 2005). Therefore, if farmers would move to applying the tested conservation practices, they would benefit from the reduction in some of the variable costs right from the start. The savings will be in particular in costs for machinery use and fuel; these are presently the highest expenses for farmers in Uzbekistan (Rudenko and Lamers, 2006). Here, the potential for saving on production costs is considerable, ranging from 45 to 116 USD per ha.

Another aspect is important for the decision between conventional and conservation practices. In addition to higher costs, the conventional treatments also had higher production risks as shown by the higher standard errors of GM and RR (Table 5.2). This is particularly important, since previous research in Khorezm concluded that farmers here are quite risk adverse, due to several factors. These include widespread poverty (roughly 28% of the rural population live below the poverty line of one USD per day), a high rural unemployment rate (Mueller, 2006), and the general lack of farm capital that can cushion the losses in years of low production (Rudenko and Lamers, 2006). Rural poverty can also partly explain the low experimentation rates without external support, where farmers in the study region generally show little interest in experiments with cropping systems, and stick to the proven, conventional approach. Another reason for this may lie in the fact that the land is still the property of the state, which controls agricultural activities, including land treatment and failure to follow the assigned agricultural practices may lead to the land being taken away from the farmers.

Since the present findings suggest that (short-term) yield gaps are not to be expected, that cost saving may be immediate, and that production risks are even reduced when changing from conventional to conservation practices, recommendations should be based in the first place on profitability and income stability arguments, rather than on the usually cited aspects of long-term economic benefits, ecological sustainability and ecosystem services (e.g., fertilizer use reduction when 'ecological services' kick in from improved soil fertility).

Which system to choose may be left to the farmer. The dominance analyses showed the generally higher potential of conservation over conventional practices throughout the entire experimentation period; however, no consistent and clear evidence in favour of any one of the specific conservation agriculture treatments was found. However, aspects of soil fertility and water economy (Egamberdiev, 2007) have not been considered here, and may help narrowing the choice down.

One of the pillars of conservation agriculture is retaining (part of the) crop residues (Derpsch, 2001). Although the financial analyses did not clearly show any short-term difference between retaining crop residues and removing them (in particular for cotton), from a technical point of view and in the long run, practicing conservation agriculture requires the retention of crop residues to achieve the positive effects on soil quality (FAO, 2008). The use of crop residues as an integrated part of conservation agriculture should be emphasised during the introductory period, to increase farmers' awareness about these benefits, since a more holistic view might not be intuitive to them, and this may not seem attractive and convincing when looking at the immediate farm production alone.

Recent research findings in the Khorezm region have confirmed the growing dependence of rural households on animal husbandry (Djanibekov, 2006; Mueller, 2006). Bobojonov and Lamers (2008) argued that this is likely to increase, given the steadily growing demand for livestock commodities for which Khorezm has a clear comparative advantage. However, feed supply in Khorezm is presently insufficient, both in quantity and quality (Kan et al., in press), and farmers rely heavily on crop residues for feeding their livestock, although the residues are of low quality (Khamzina et al., 2006). Therefore, there is a clear competition between crop residue being used as fodder, and being left on the fields for conservation. Therefore, fodder crops should be introduced at a larger scale than presently practiced. Alternatives are presently being developed, e.g., the potential of using foliage of suitable trees for animal feed (Lamers and Khamzina, forthcoming), the introduction of a higher share of alfalfa, grown as a third crop, and others. These measures need to go hand-in-hand with the introduction of conservation agriculture.

Finally, practicing conservation agriculture, often said to require a mind-shift (Sayre, unpubl. 2008), needs a learning and adaptation phase. Farmers who gain more practice in the new technologies will further decrease the variability (standard errors) of both GMs and RRs under conservation agriculture. With thus lower production risks, conservation agriculture practices may become more and more convincing and attractive to farmers. This also calls for a role of extension services and adult education approaches in the training and education of farmers which should in the end reduce soil salinity, increase household income and benefit the ecology in Khorezm in particular, and irrigated agriculture in the Central Asia region as a whole. The technologies presented here can be adapted, with little changes, in similar agroecological conditions (irrigated lands under semi-arid conditions) in Uzbekistan, Kazakhstan, and Turkmenistan, and even in the wider region including, for example, the Caucasus.

6 GENERAL DISCUSSION AND CONCLUSIONS

Numerous studies have shown that soil properties and crop production can be improved by conservation agriculture practices. Studies also showed that such practices predominantly are mainly applied in rainfed agriculture; the crop area under irrigated agriculture with conservation agriculture practices has increased in recent years. Studies, conducted in the Khorezm region, Uzbekistan, where crop production relies on extensive use of water, machinery and fertilizers, have also shown the benefits of conservation agriculture on irrigated land. The objective of this study was to elaborate the effects of tillage practices and crop residues on crop production, and the financial benefits, and to develop suitable seeders for local conditions.

6.1 Tillage practices and crop residue management

Many studies have shown that reduced tillage practices and crop residue management (keeping crop residues and mulch on the soil surface) both lead to improved, more efficient use of soil, water and financial resources. In this study, all three conservation agriculture practices – intermediate tillage, permanent beds and zero tillage – resulted in improved soil properties compared with the control (Figures 2.14-2.21). For instance, the humus content was most improved in the second cotton season (third year of study, 2006) under permanent beds and zero tillage, especially when the crop residues were kept on the soil surface (Figures 2.18-2.21). Although the importance of N, P, K contents, salinity and others is unquestionable, the detailed studies of soil measurements showed that soil organic matter (SOM) was the most significant factor in crop production as compared to the others, i.e., SOM was the main predictor for the cultivated crops. The positive effect of conservation tillage systems on soil has also been evidenced by many other field investigations. The experiments conducted in Iran by Shirani et al. (2002) showed that reduced tillage with manure application can increase the content of SOM. Moreover, an increased rate of manure application can substantially increase the organic matter in the soil. Reicosky (2002) reported that tillage or soil preparation is an integral part of traditional agricultural production, and that tillage is also a principal agent resulting in soil perturbation and subsequent modification of the soil structure with soil degradation. Intensive tillage causes soil degradation through carbon loss and tillage-induced greenhouse gas emissions that impact productive capacity and environmental quality. Studies have shown that high initial carbon dioxide (CO_2) fluxes are more closely related to the depth of soil disturbance and low CO_2 and water fluxes are associated with low soil disturbance. Sisti et al. (2004) examined soil carbon and nitrogen stocks in long-term experiments in Oxisol soil, Passo Fundo and Rio Grande do Sur, Brazil, with three types of crop rotations (wheat (*Triticum aestivum*) – soybean (*Glycine max*), wheat – soybean – vetch (*Vicia villosa*) – maize (*Zea mays*), and wheat – soybean – oat (*Avena sativa*)). They found that carbon concentration in the top 5 cm of soil was considerably higher in all three rotations managed with zero tillage than in those with conventional tillage. The values of total nitrogen concentration were similar to those of carbon concentrations.

In addition, research has revealed that reduced tillage is beneficial to soil fauna. Previous studies at our study site showed the beneficial effects on soil biology, e.g., earthworms, which had higher densities under conservation tillage systems (Egamberdiev, 2007). Investigations conducted by McGarry et al. (2000) in the subtropics of Australia with zero tillage have revealed that earthworm channels and termite galleries are major contributors to measured increases in hydraulic conductivity and infiltration in zero tillage systems. Sharma et al. (2004) reported that the effect of tillage on termite incidence in rice in the Indian plains was not significant, whereas tillage options did impact termite incidence in wheat production over two years of experiments.

As mentioned before, compact soils have a high bulk density. The analyses of results obtained in long-term experiments with different tillage practices and rotations in semi-arid Spain also showed that the highest bulk density was measured under zero tillage compared to minimal and conventional crop cultivation (Hernanz et al. 2002). Also, Derpsch (2001) reported that soil compaction can be a serious problem. Therefore, to avoid compaction, maximum levels of crop residues should be retained, green manure applied, cover crops grown and crop rotation practiced. Crop roots, biological activities and earthworms and insects loosen the soil. In addition, good soil cover helps to maintain a higher moisture content on the soil surface, which results in better penetration of the cutting elements of the seeding equipment.

Irrigation water can also be saved by conservation tillage practices. Studies on water consumption in our conservation agriculture experiments - intermediate and permanent beds - have shown a reduction in water consumption by up to 25% (Tursunov, 2006). Consequently, soil improvements and effective use of water resources over the study years led to better cotton and winter wheat yields. Many studies have shown the dependence of water consumption on the used tillage system. Field investigations conducted in rice-wheat systems in South Asia revealed up to 50% water savings in bed planting systems (Lal et al., 2004). Under permanent bed planting in India with a rice-wheat system, water use was reduced by 30% (Singh et al., 2006). Conservation tillage systems led to water savings up to 46% as compared to conventional tillage in cotton, corn and peanut production in Georgia, USA (Hawkins et al., 2007).

Although the development of both cotton and winter wheat at early vegetative phases was delayed in conservation tillage systems in this study, especially with the crop residues, the typically expected initial yield gap was insignificant in cotton ($P<0.28$, 2006); in winter wheat the grain yield in these tillage systems was even significantly higher as compared to conventional tillage ($P<0.02$, 2005). A number of studies have shown the positive effects of conservation tillage systems on crop yields. Govaerts et al. (2005) and Balkcom et al. (2006) reported higher yields with conservation tillage compared to conventional tillage for wheat and cotton in Mexico and Tennessee Valley, USA. A 3-year field study conducted by Gangwar et al. (2006) in the Indo-Gangetic plains with three tillage types (conventional, zero tillage, reduced/strip) on wheat grown after rice showed that the best wheat yield was obtained under reduced tillage (5.1 t ha^{-1}), followed closely by zero tillage (4.75 t ha^{-1}) compared to conventional tillage (4.6 t ha^{-1}). They stated that the reason for the high yield under reduced tillage was good soil aeration, better germination, better water penetration, less weed infestation, and increased nutrition as compared to the other systems. Singh et al. (2001) reported that the highest yield for a rice-wheat cropping system was obtained under zero tillage in rainfed conditions in India; the yield was 1.7-1.9 t h^{-1} higher than for direct-seeded unpuddled rice. The analyses of long-term experiments in semi-arid Spain on crop production (Hernanz et al. 2002), in which three tillage practices with two types of rotation were tested, showed that the long-term average yield of cereals is greater under zero tillage.

The availability of crop residues on the soil surface improves the soil properties, in the cold periods it protects crops from being frozen, and decreases soil moisture losses (Veseth, 1988, McVay, 2003). Investigations by Sarkar et al. (2007) in rainfed systems showed that with organic mulch on the soil surfaces can form a barrier against evaporation and that the mulch can alter the microclimate. Consequently, soil moisture depletion occurs at a slower rate under organic mulches than under bare soil conditions. This utility of the residues depends on the amount that is retained on the soil surface. However, a thick layer of residues creates difficulties at sowing of crops. In this case, it is necessary to have special openers that can cut through residues. A thick layer of residues may cause problems for crop germination and development in early phases, due to slow warming of the soil (Rawson and Macpherson, 2000, Troeh and Thompson, 2005). Thus, the optimal amount of crop residues for more effective crop production should be found through active crop residue management.

In the degraded soils of Khorezm, retention of crop residues after harvest could be an option for soil improvement. However, leaving the residues on the soil is often difficult, especially in Khorezm conditions, since the residues are also used as fodder (wheat straw) and as fuel (cotton stems). In order to satisfy the farmers' demand for residues and at the same time improve soil properties, it is necessary to determine the minimum amount of residues at which the retained residue still is beneficial. According to FAO (2000) and Rawson and Macpherson (2000), the optimum amount is 4 t ha^{-1}. The component trial with different crop residue amounts in this study showed that keeping the residues at a level of 4-5 t ha^{-1} for Khorezm conditions is optimal, since exceeding that level led to significant reduction in crop germination and had an adverse affect on crop development (Tursunov et al., forthcoming), while reducing the level did not lead to the expected benefits. In addition, sowing of crop seeds with seeders is difficult when the layer of residues is thick. However, the availability of proper seeders helps in overcoming these difficulties. These difficulties are more relevant for those crops that after harvest leave a significant amount of residues, e.g., cereals (up to 9000 kg ha^{-1} in our experiment with winter wheat).

Thus, in order to achieve the balanced use of cereal residues on such degraded crop lands, a partial removal of the residues from the fields could be an option.

6.2 Development of the seeder suitable for local condition

It is often overlooked that the use of appropriate machinery is one of the cornerstones of successful implementation of conservation agriculture practices (Sayre, unpubl. communication). The existing conventional farming system in Khorezm relies on intensive pre- and post-sowing field operations, causing increased expenses and hence reduction in the farmers' income and deterioration of soil ecology (degradation and compaction) and also leads to reduced crop yields. Many investigations have shown the advantages of conservation tillage systems in crop production. However, the retained crop residues after harvest may make seeding the next crop difficult. In order to reduce the tillage intensity and its negative impacts, and to overcome crop residue constraints, appropriate seeders need to be used. There are many studies on the adoption and development of seeders for conservation agriculture. For instance, in Australia and the Indo-Gangetic Plains, a growth in the production of different seeders suitable for conservation agriculture and the development of different types of implements has been observed in the past years (Gupta and Rickman 2002, Sayre 2000). Torbert et al. (2007) developed the forward residue mover that pushes the residues away and prevents entanglement in the row-cleaner mechanism.

In the framework of the present study, a new seeder was developed that is capable of sowing seeds into tilled and untilled soils. Previously to that, another seeder was imported from India and tested under local conditions, but it was seen to have some shortcomings. This Indian seeder can sow cereals and cotton seeds and at the same time apply fertilizers. However, it has a number of shortcomings, which limit its application. The main disadvantage of the given seeder is that it cannot sow linted cotton seeds, which are common in this region. Also, it cannot maintain a uniform sowing due to the solid frame, and is not flexible enough. In order to achieve uniform sowing, the land has to be levelled, preferably through laser levelling. Such levelling is still not affordable for the majority of farmers in Khorezm. Furthermore, the seeder has a low clearance that makes it difficult to sow cereals into the standing cotton stems, which is a common practice in region.

As no seeder suitable for sowing crops into tilled and untilled soils with the crop residues in the region was available, a universal seeder capable of sowing seeds under such conditions was developed.

The newly developed seeder satisfies all requirements. The ability of this seeder to sow both de-linted and linted cotton seeds and cereals into untilled soil significantly saves resources and time. In addition, it is easy to use, adjustable, multipurpose, can be used for soil loosening and allows sowing seeds on unlevelled soil. Different openers can be easily mounted and replaced, and are widely available in the local market. Its high clearance makes it possible to sow the cereal seeds into the standing cotton. Moreover, for commercial production of this seeder no need great investment is necessary, as many necessary implements are widely available in the local market and are commercially produced.

6.3 Economics of conservation agriculture practices

Many publications on the application of conservation agriculture practices showed that the cropping area under such practices is expanding, as the involved farmers have realized the potential for reducing expenses connected to crop production. Field activities under conservation practices are much less as compared with conventional tillage, hence the reduced machinery and labor costs. Consequently, these practices have higher rate of returns and low production risks. According to KASSA (2006), the use of conservation tillage systems is increasing because “the short-term benefits they generally provide to farmers through the cost reduction for labor, machinery and fuel are likely to be sufficient to further boost their dissemination …” Research conducted in Southern Illinois also showed lower machinery requirements and costs with zero tillage (Phillips et al., 1997).

Crop production in the degraded soils of Khorezm under conventional farming requires more intensive field activities, which in turn lead to increase in costs. Application of conservation agriculture practices can be an alternative for reducing these costs (up to 1.5 times). As a result, a high gross margin and rate of return can be obtained. In the current agriculture of Uzbekistan, machinery use and fuel are the highest costs in crop production. Their share varies from 34-38%, depending on the cultivated crop. If conservation agriculture practices are introduced, this economic indicator drops to 10-12%, i.e., a threefold reduction of the given expenses can be achieved. A large decrease in labor and machinery costs was found in conservation tillage in the Lake Erie Basin (Forster, 2002). According to FAO (2001), the use of conservation tillage allows savings in time, labor and fuel costs from 30-40% compared to conventional tillage.

Another aspect of the economics of conservation agriculture is keeping the residues on the soil surface after harvest. In Khorezm, due to the high dependence on livestock for crop residues as fodder, the demand for residues has increased. Cotton stalks wheat and rice straw, for example, are sold on the local market, and farmers get a small benefit from selling them. Therefore, after harvesting, the residues are frequently removed from fields for further use. There are many suggestions on how retention of residues can be achieved. Here, the most feasible options could be expansion of lands under fodder crops and partial removal the residues from fields. This would help to reduce the farmers' dependence on residues, and they could then leave much more crop residues on the field and the same time improves their income.

6.4 Conclusions

A study of the effects of conservation tillage systems in the degraded soils of Khorezm, Uzbekistan (Aral Sea Basin) on cotton and winter wheat production was undertaken and analyses reveal that:

- The effect of tillage systems on cotton yield in 2004 was significant ($P<.02$) with crop residues, where conventional tillage had the highest yield (3422 kg ha^{-1} vs. 1800 kg ha^{-1} (conservation tillage). Without crop residues, no tillage effects were observed. Despite high cotton yields in 2006 as compared to the previous cotton season, these were not significantly different between tillage systems ($P<0.28$). Nevertheless, the highest yield was for the conventional system with crop residues (4230 kg ha^{-1}) and the lowest for zero tillage with crop residues (2805 kg ha^{-1}). Studies on winter wheat showed significantly increased yields on intermediate and permanent beds with crop residues (5631 kg h^{-1} and 6053 kg h^{-1}, respectively), as compared to the conventional tillage with crop residues (4278 kg ha^{-1}).
- At early vegetative phases, in both cotton seasons, zero tillage with crop residues showed slower plant development, as the height of cotton under these tillage systems was lower than that under conventional tillage with crop residues. The

winter wheat growth also delayed at the early vegetative phase (in March) in zero tillage with crop residues, as compared to the conventional tillage with crop residues (48 cm vs. 62 cm).

- The crop residues led to significantly increased cotton branches ($P<0.01$) and dehisced fruits ($P<0.02$) in 2006.
- Winter wheat growth was significantly higher under intermediate tillage and permanent beds with crop residues than under conventional tillage with crop residues (90 cm vs. 76 cm, 2005).
- The studied conservation tillage systems show potential for improvement of the degraded agricultural lands. Over the three study years, soil salinity under zero tillage with crop residues and permanent beds with crop residues decreased 46% and 38%, humus content increased for 40% and 44%, respectively, at 30 cm depth.
- In the 3-year study soil salinity decreased under crop residues (58 t ha^{-1}, 51 t ha^{-1} and 41 t ha^{-1} respectively), soil aggregation improved (29%, 32% and 34%) and humus content increased (42 t ha^{-1}, 45 t ha^{-1} and 53 t ha^{-1}) in 30 cm depth in 2004, 2005 and 2006, respectively.
- Unavailability of adequate seeders for conservation agriculture required the development of a new seeder. A seeder imported from India was, in general, suitable for sowing cotton and winter wheat seeds into tilled and untilled soils in the Khorezm conditions. But, in order to use the given seeder in full capacity it had to be modified, as 1) it was unable to sow linted cotton, 2) low clearance limited sowing of seeds into the standing cotton, 3) depth control was poor, and 4) uneven soil lowered sowing quality.
- The new seeder developed in the framework of the project is able to sow both linted and de-linted cotton seeds and cereals, has a high clearance, allows mounting of different openers, can be used for making furrows and soil loosening, together with sowing fertilizer can be applied, and depth control is improved.
- Financial analyses revealed the profitability of cotton and winter wheat production under conservation agriculture practices. Cumulative gross margin analyses showed better gross margins and rate of returns for both cotton and

winter wheat with intermediate tillage, permanent beds and zero tillage as compared with conventional tillage. With crop residues, the highest GM with a relatively low standard error was obtained under intermediate tillage and permanent beds ((UZS 1,288,000±271,000 (USD 1074±225) and 1,142,000±254,000 (USD 952±212)), and was lowest for conventional tillage (UZS 840,000±532 (USD 700±443)), i.e., PB and IT had a 40% higher GM compared to the conventional tillage. Without crop residues, these values insignificantly differed. The results show the clear advantage of conservation agriculture practices over conventional tillage because of lower total variable costs and higher gross margins.

- Conservation tillage systems require reduced machinery use and fuel. Under these tillage systems up to UZS 128,000 (USD 107) per ha can be saved.

In general, it can be seen that the application of conservation agriculture practices in degraded soils under irrigated agriculture in Central Asia can improve soil quality and increase cotton and winter wheat yields.

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