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Nitrogen management in irrigated cotton-based systems under conservation agriculture on salt-affected lands of Uzbekistan

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Dedicated to my late father

Khagu Prasad Wasti

ABSTRACT

Intensive soil tillage and mismanagement of irrigation water and fertilizers reduce soil organic matter and increase secondary soil salinization. These processes are increasing production costs, reducing soil fertility and threatening the sustainability of crop production systems in the irrigated drylands of Uzbekistan, Central Asia. These adverse effects can be counterbalanced by conservation agriculture (CA) practices combined with optimum nitrogen (N) management. This has been demonstrated in rainfed areas, but only sparse findings exist for irrigated crop production. Therefore, the effects of tillage, crop residue management and N rates were examined on growth, yield, water and N use efficiency (NUE), and the N balance of crops as well as the soil salinity dynamics in two cotton-based systems, (i) cotton/wheat/maize and (ii) cotton/cover-crop/cotton, in Khorezm, a region in northwest Uzbekistan. Also, on smaller sub-plots the effect of three different furrow irrigation techniques on the distribution and management of soil salinity on raised beds was studied. These techniques were every-furrow (EFI), alternating skip furrow (ASFI), and permanent skip furrow irrigation (PSFI).

The split-plot experiments with four replications were conducted from 2008-2009 in an area covering 3 ha. They included two tillage methods (permanent raised bed, BP; and conventional tillage, CT); two residue levels (retaining the maximum possible amount, RR; and removing residues according to farmers' practices, RH); and three N levels: no application (N-0); low-N (125 kg N ha^{-1} for cotton and 100 kg N ha^{-1} for wheat and maize); and high-N (250 kg N ha^{-1} for cotton, and 200 kg N ha^{-1} for wheat and maize). These treatments were evaluated on land previously cropped using conventional means (CT). The official N recommendation for the study region is 160-180, 180 and 150 kg N ha^{-1} for cotton, wheat and maize, respectively.

Raw cotton yield and its components were not affected by tillage methods in both cotton-based rotation systems in the first season after transformation from CT to CA practices. However, already one cropping cycle later, wheat and maize under BP produced, respectively, 12 and 42% higher grain yields than under CT. Under BP, water productivity increased in wheat by 27% and in maize by 84%, whilst 12% less water was applied during wheat and 23% during maize production compared to CT. Nitrogen applications significantly increased the growth and yield of all crops under both tillage practices. However, the response to N applied was higher under BP than CT. Increased boll density and boll weight in cotton, number of spikes m^{-2} and grains per spike in wheat, and cob density and number of grains per cob in maize predominantly caused higher yields. Total NUE in BP was higher by 42% in cotton, 12% in wheat, and 82% in maize crops compared to CT. With high N applications, the apparent positive N balance (N loss) in BP was lower by 71% in the cotton/wheat/maize system and by 53% in the cotton/cover-crop/cotton system than under CT.

Residue retention in BP increased grain yield of wheat and maize in the absence of N applications, but had an insignificant effect on crop yield at low-N and high-N application rates. Residue retention had no effect at all N levels under CT. In BP, it minimized the rate of soil salinity increase by 45% in the top 10 cm and by 18% in the top 90 cm soil profile compared to RH. The inclusion of a winter cover crop in the cotton-cotton rotation reduced the groundwater nitrate contamination considerably, and increased the NUE under both BP and CT.

Soil salinity on top of the beds increased significantly with EFI and ASFI compared to PSFI. The latter practice of salinity management provided the less saline area towards the irrigated furrow, as salts accumulated on the dry furrows. These accumulated salts can be leached, which reduced the salinity level in the center of the beds two-fold compared to EFI and ASFI.

For cotton, wheat and maize, grown in rotation, BP and residue retention with application of the recommended N for maize and ~15% less than recommended N for cotton and wheat were in many aspects superior to CT practices. Permanent bed cotton cultivation with a winter cover crop is a suitable alternative for cotton-cotton based systems in irrigated drylands of Uzbekistan. Should residues not be available, PSFI is a suitable alternative for salt management in raised bed planting in salt-affected irrigated lands.

Stickstoffmanagement im bewässerten Baumwollanbausystem mit konservierender Bodenbearbeitung (conservation agriculture) in versalzten Böden in Usbekistan

KURZFASSUNG

Intensive Bodenbearbeitung und inadäquates Management von Bewässerungswasser und Düngemitteln reduzieren organisches Material im Boden und führen zu zunehmender sekundärer Bodenversalzung. Diese Prozesse steigern die Produktionskosten, schmälern die Bodenfruchtbarkeit und bedrohen damit letztendlich die Nachhaltigkeit der Anbausysteme in den bewässerten Trockengebieten von Usbekistan. Konservierende Bodenbearbeitung (CA), die mit optimalen Stickstoff-(N)-gaben kombiniert wird, kann den obengenannten negativen Auswirkungen entgegenwirken. Dies ist in Gebieten mit Regenfeldbau demonstriert worden, es gibt aber kaum Daten für den Bewässerungsanbau. Daher untersucht diese Studie die Auswirkungen von Bodenbearbeitung, Ernterückständen und Stickstoffgaben auf Pflanzenwachstum und -erträge sowie Wasserproduktivität, Effizienz von Stickstoffanwendungen (NUE), Stickstoffbilanz der Anbaupflanzen sowie Bodenversalzungsdynamik in zwei Baumwollsystemen: (i) Baumwolle/Weizen/Mais und (ii) Baumwolle/Gründüngung/Baumwolle in der Region Khorezm im Nordwesten Usbekistans. Außerdem wurden auf kleineren Versuchsparzellen die Auswirkungen von drei verschiedenen Furchenbewässerungsmethoden auf Verteilung und das Management von Bodenversalzung auf erhöhtem Pflanzbett (BP) untersucht und zwar Bewässerung jeder Furche (EFI), alternierendes Auslassen jeweils einer Furche (ASFI), und permanentes Auslassen der zweiten Furche (PSFI).

Die split-plot Feldversuche wurden mit vier Wiederholungen 2008-2009 auf einer Fläche von 3 ha durchgeführt. Untersucht wurden zwei Bodenbearbeitungsmethoden (permanente Pflanzbetten, BP) und konventionelle Bodenbearbeitung, CT); zwei Mengen von Ernterückständen (Belassen der höchstmöglichen Menge, RR, und Entfernen der Rückstände wie durch die Bauern praktiziert, RH); und drei N-Mengen: keine N-Gabe (N-0), niedrige N-Gaben (125 kg N ha^{-1} für Baumwolle und 100 kg N ha^{-1} für Weizen und Mais); und hohe N-Gaben (250 kg N ha^{-1} für Baumwolle und 200 kg N ha^{-1} für Weizen und Mais). Die Versuche wurden auf Land durchgeführt, das zuvor konventionell bearbeitet wurde (CT). Offiziell werden für das Untersuchungsgebiet Gaben von 160-180, 180 bzw. 150 kg N ha^{-1} für Baumwolle, Weizen bzw. Mais empfohlen.

Die Bodenbearbeitungsmethode hatte keinen Einfluss auf den Rohbaumwollertrag oder seine Bestandteile in beiden Baumwollrotationssystemen in der ersten Anbauperiode nach der Umwandlung von CT zu CA. Jedoch bereits einen Anbauzyklus nach der Einführung von CA lagen der Weizen- bzw. Maisertrag unter BP 12% bzw. 42% höher als unter CT. Verglichen mit CT nahm unter BP die Wasserproduktivität bei Weizen um 27% und bei Mais um 84% zu, während 12% weniger Wasser bei der Weizen- und 23% bei der Maisproduktion verbraucht wurde. Die Stickstoffgaben führten zu einer signifikanten Zunahme des Pflanzenwachstums und Ertrags aller Anbaupflanzen in beiden Bodenbearbeitungsmethoden, jedoch war der Effekt des Stickstoffs höher unter BP als unter CT. Die erhöhte Dichte und Gewicht der Baumwollbäusche und Anzahl der Weizenähren m^{-2} bzw. -körner pro Ähre bei Weizen, und die Kolbendichte und Anzahl der Körner pro Kolbe bei Mais führten zu höheren

Erträgen. Bei BP war die Gesamt-NUE 42% höher bei Baumwolle, 12% bei Weizen und 82% bei Mais im Vergleich zu CT. Bei hohen Stickstoffgaben war die apparente positive N-Bilanz (N-Verlust) bei BP 71% niedriger im Baumwoll-/Weizen-/ Maissystem und 53% im System Baumwolle/Gründüngung /Baumwolle als bei CT.

Das Belassen der Ernterückstände führte bei BP zu einem erhöhten Körnerertrag bei Weizen und Mais bei N-0, aber der Effekt war nichtsignifikant bei niedrigen bzw. hohen N-Mengen. Bei CT wurde bei keiner der N-Mengen eine Wirkung beobachtet. Bei BP führten die Rückstände zu einer um 45% bzw. 18% geringeren Zunahme der Bodenversalzung in den oberen 10 bzw. 90 cm des Bodens im Vergleich zu RH. Eine Winter-Gründüngung in der Baumwolle-Baumwolle-Rotation führte zu einer bedeutenden Abnahme der Grundwasserbelastung durch Nitrate sowie zu einer erhöhten NUE sowohl bei BP als auch bei CT.

Die Bodenversalzung bei BP in den oberen Bodenschichten nahm bei EFI und ASFI signifikant zu im Vergleich zu PSFI. Letztere Methode ergab einen weniger versalzten Bereich in Richtung bewässerter Furche, weil sich das Salz in den permanent trockenen Furchen anreicherte. Diese erhöhten Salzmengen können ausgewaschen werden, wodurch die Versalzung in der Mitte zweier Pflanzbetten um ein Zweifaches reduziert wurde im Vergleich zu EFI und ASFI.

Bei in Rotation angebauten Baumwolle, Weizen und Mais war BP mit Ernterückständen zusammen mit der jeweils empfohlenen N-Menge und mit ~15% unter den jeweiligen Empfehlungen liegenden N-Mengen in vielen Aspekten den CT Methoden überlegen. Anbau von Baumwolle auf erhöhten, permanenten Pflanzbetten zusammen mit einer Wintergründungung ist eine geeignete Alternative für Baumwolle-Baumwolle-Systeme in den bewässerten Trockengebieten von Usbekistan. Sollten Ernterückstände nicht verfügbar sein, ist PSFI eine geeignetes alternatives Bodenversalzungsmanagement bei BP auf versalzten bewässerten Flächen.

ИСПОЛЬЗОВАНИЕ АЗОТНЫХ УДОБРЕНИЙ В СИСТЕМЕ ХЛОПКОВОГО СЕВООБОРОТА ПРИ ПРИМЕНЕНИИ РЕСУРСОСБЕРЕГАЮЩИХ ТЕХНОЛОГИЙ НА ЗАСОЛЕННЫХ ЗЕМЛЯХ УЗБЕКИСТАНА

АННОТАЦИЯ

Интенсивная вспашка и неэффективное использование оросительной воды и минеральных удобрений приводят к снижению содержания гумуса и увеличению вторичного засоления почвы. Эти процессы повышают производственные затраты, приводят к падению плодородия почвы, а также являются преградой для ведения устойчивого земледелия на орошаемых землях Узбекистана и Центральной Азии. Эти неблагоприятные эффекты можно предотвратить прилагая ресурсосберегающие и почвозащитные технологий и оптимальные нормы азотных (N) удобрений. В настоящем данная технология широко применяется в богарных условиях, однако ограниченная информация существует для орошаемого земледелия.

Исходя из этого, в условиях Хорезмской области Узбекистана нами была изучена эффективность вспашки, растительных остатков культур и норм азота на рост и продуктивность, эффективность использования воды и азотных удобрений, баланс азота и динамика засоления почв при двух хлопковых севооборотах: (1) хлопчатник-озимая пшеница/кукуруза в повторном севе и (2) хлопчатник-промежуточная культура-хлопчатник. В дополнительном эксперименте изучали влияния трёх методов полива на распределение почвенного засоления в гребнях: (1) полив в каждую борозду, (2) полив через борозду и (2) полив в выборочные борозды.

Полевые опыты были проведены в 2008-2009 гг. в четырех повторениях на площади 3 га методом разделенных делянок. Варианты опыта состояли из двух методов вспашки почвы (обычная вспашка (ОВ) и постоянные гребни (ПГ)) и двух уровней оставления растительных остатков на поле (сохрание растительных остатков всех культур, выращенных на поле и удаление растительных остатков по традиционному методу (практика фермеров). Изучались три нормы азотных удобрений: без внесения удобрений (N0), низкая норма N (125 кг/га под хлопчатник и по 100 кг/га под пшеницу и кукурузу) и высокая норма N (250 кг/га под хлопчатник и по 100 кг/га под пшеницу и кукурузу). До закладки опыта на участке возделывались культуры с применением обычных агротехнологий. Официальные рекомендации по применению N-удобрений в регионе составляют: 160-180 кг/га под хлопчатник, 180 кг/га под пшеницу и 150 кг/га под кукурузу.

В первый год изысканий, с переходом с обычной на почвозащитную технологию при обеих системах севооборота, методы вспашки не оказали влияния на урожай хлопка-сырца. Однако после первого цикла выращивания культур уже было отмечено, что урожай зерна пшеницы и кукурузы на варианте ПГ возрос на 12 и 42% соответственно по сравнению с ОВ. Эффективность оросительной воды на варианте ПГ увеличилась на 27% на пшеничном и на 84% на кукурузном полях. При этом, на выращивание пшеницы и кукурузы было затрачено соответственно на 12 и 23% меньше поливной воды по сравнению с вариантом ОВ.

Применение N-удобрений значительно повысило рост и урожайность всех культур на обеих системах вспашки. Однако эффективность N была выше на варианте ПГ, чем ОВ. Повышение урожайности культур привело к увеличению количества коробочек на одном растении, веса одной коробочки хлопчатника, количества колосьев на м^2 и зерна пшеницы, а также количества початков кукурузы и зёрен в нем. Коэффициент использования азота удобрений на варианте ПГ был выше на 42% на хлопчатнике, 12% на пшенице и 82% на кукурузе по сравнению с вариантом ОВ. При высоких нормах азотных удобрений очевидный позитивный баланс N (потери N) на варианте ПГ снизился на 71% в севообороте хлопчатник-пшеница/кукуруза и на 53% в

севообороте хлопчатник-промежуточная культура-хлопчатник по сравнению с вариантом ОВ.

На варианте ПГ без внесения азота сохранение растительных остатков способствовало повышению урожая зерна пшеницы и кукурузы. Однако при низкой и высокой нормах азота уровень растительных остатков не оказал влияние на урожайность этих культур. На варианте ПГ с полным сохранением растительных остатков на поле, в сравнении с удалением растительных остатков, скорость засоления почвы в 0-10 см слое почвы снизился на 45%, а в 0- 90 см слое на 18%. При обеих системах обработки почвы возделывание озимой промежуточной культуры привело к значительному сокращению уровня загрязнения грунтовых вод нитратами и повысило эффективность азотных удобрений. Уровень засоления почвы на поверхности гребней значительно повысился при поливе в каждую или через борозду, чем при поливе в выборочные борозды. В последнем случае площадь накопления солей была значительно меньше, так как концентрация солей происходила в неполиваемых бороздах. Эта соль может быть промыта, и тем самым уровень засоления почвы в данном случае снизится в два раза, чем при поливе в каждую или через борозду.

Возделывание хлопчатника, пшеницы и кукурузы в севообороте на постоянных гребнях с сохранением растительных остатков и использованием рекомендуемых норм азотных удобрений для кукурузы и снижение рекомендуемой нормы на ~15% для хлопчатника и пшеницы во многих аспектах превосходил технологию ОВ. Выращивание хлопчатника на постоянных гребнях с сохранением растительных остатков и последующей подзимней промежуточной культуры является приемлемой альтернативой монокультуре хлопчатника на орошаемых землях Узбекистана. Проведение поливов в выборочные борозды в случае удаления растительных остатков с поля может быть альтернативной технологией полива для контроля засоления почвы при возделывании культур на постоянных гребнях в орошаемых условиях.

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1 GENERAL INTRODUCTION

1.1 Problem setting

Irrigated agriculture plays a major role in the world's food security as it provides 40% of the global food production, although only from 17% of the total cultivated land (FAO 2000). The role of irrigation is expected to grow significantly in the near future. The FAO (2002) predicted that the irrigated area in developing countries needs to be expanded from 202 million ha in 1999 to 242 million ha in 2030 to meet the increasing food demand. The demand for irrigation will in particular increase in arid and semi-arid regions where more than 90% of agriculture depends on irrigation, due to predictions on the impact of climate change that will reduce irrigation water availability.

The high population growth rate, degradation of agricultural lands and scarcity of fresh water have raised doubt about the future suitability of the dominant agricultural practices for irrigated drylands. In face of the environmental and economic challenges, there is an urgent need to reconsider the existing classical agricultural systems and to adapt agricultural systems that can help to prevent soil quality and soil fertility degradation, and hence increase productivity. Uzbekistan is one of the countries most seriously affected by land degradation and desertification in the world, as is evidenced by the 85% of the land that now suffers from various levels of secondary salinization (Dintzburger et al. 2003; Figure 1.1). It is further reported that approximately 20 000 ha of irrigated land in Uzbekistan are lost to salinity and invariably abandoned every year (Toderich et al. 2009). Irrigated agriculture is one of the main pillars of Uzbekistan’s economy, e.g. this sector contributes to 22% of the country’s GDP and employs 44% of its labor force (CIA Factbook 2010).

In Uzbekistan, cotton (*Gossypium hirsutum* L.) is the predominant crop in the agriculture system. It has played a major role in the country’s economic development since the Soviet Union era (1926-1991). With an annual raw cotton production of 3.7 million t in 2008 (FAOSTAT 2010), Uzbekistan is the world’s sixth largest cotton producer and third largest cotton exporter (Bremen Cotton Report 2010) and accounts for 13-18% of the national GDP (Wehrheim and Martius 2008).

After Uzbekistan’s independence in 1991, winter wheat (*Triticum aestivum* L.) in Uzbekistan has gained importance and has become the second strategic crop for satisfying domestic food needs (Guadagni et al. 2005). The area under wheat was only around 0.62 million ha in 1992, mainly in the rainfed areas, but expanded rapidly to 1.4 million ha in 1997 and has remained almost constant (FAOSTAT 2010), covering 31% of the irrigated regions of Uzbekistan (FAO 2002). Maize (*Zea mays* L.) is the third major cereal crop after wheat and rice in Uzbekistan. It is cultivated annually on about 35,000 ha and yields on average 6.6 t ha^{-1} (FAOSTAT 2010). It is mostly used as feed but also for human consumption (Christmann et al. 2009). Cotton-based systems are the major crop rotation systems in Uzbekistan (Conrad et al. 2010).

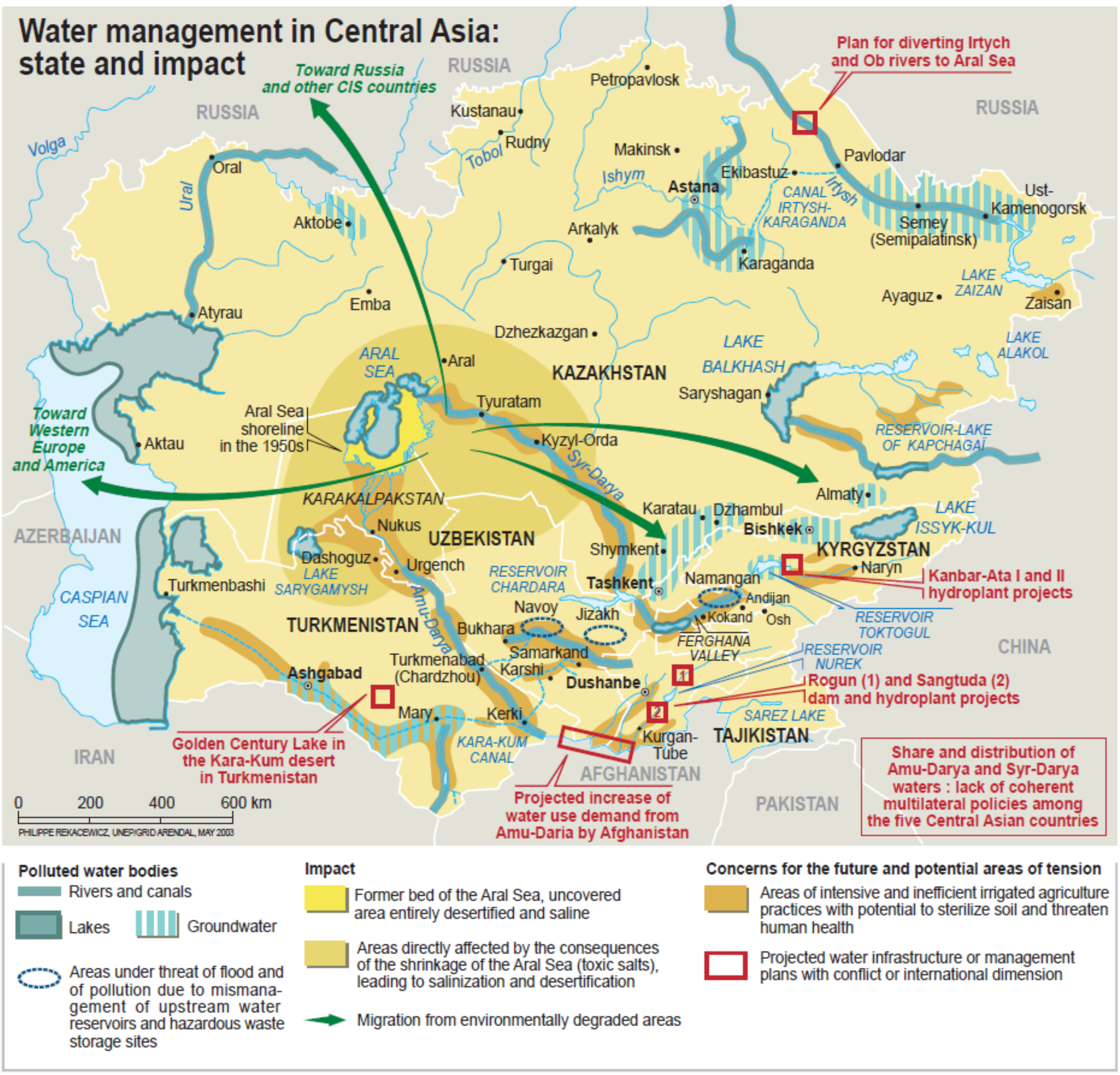


Figure 1.1 Water management in Central Asia: state and impact. (Source: P. Rekacewicz UNEP/GRID-Arendal; http://maps.grida.no/)

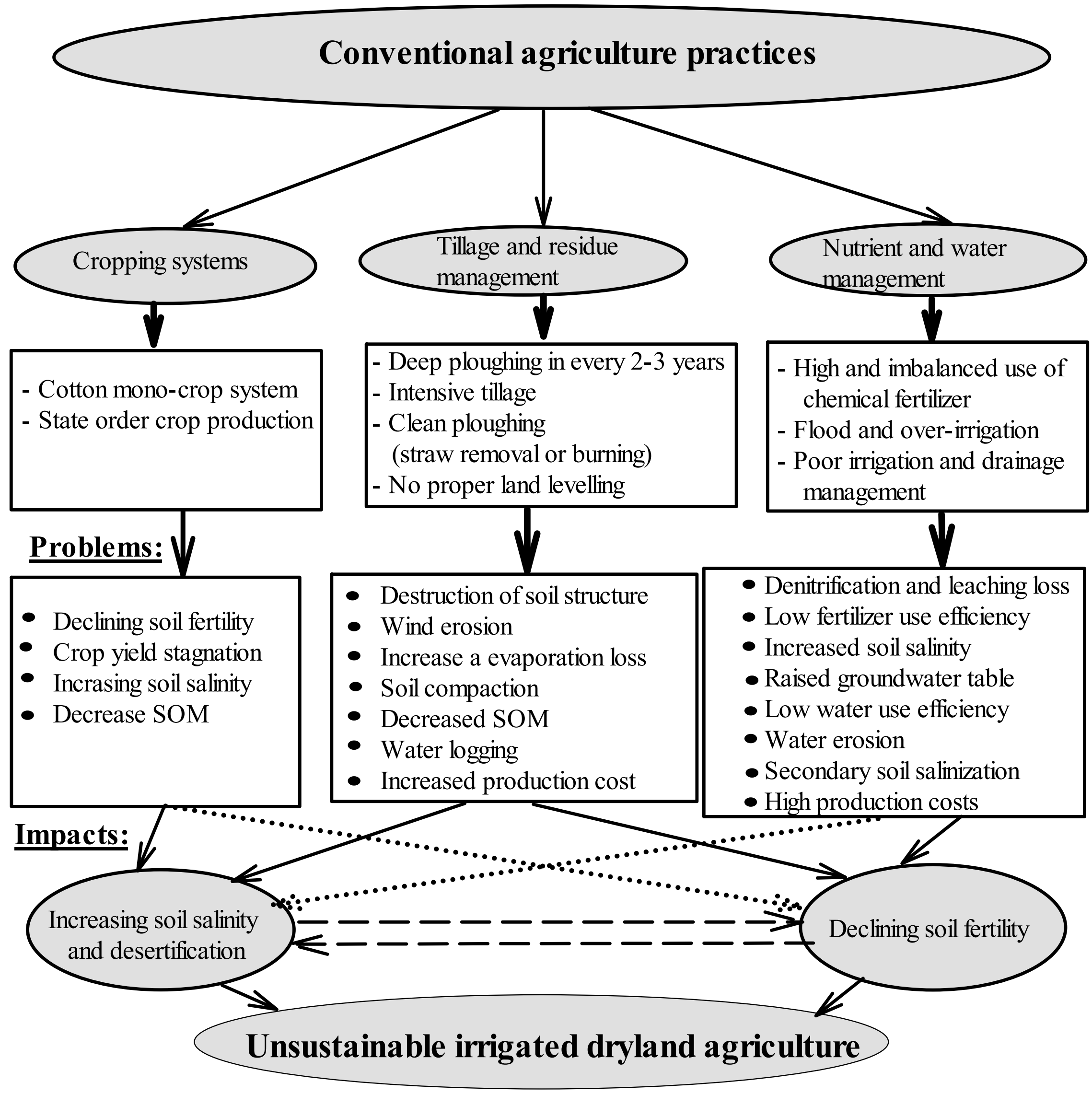


Figure 1.2 Problems associated with conventional agriculture systems in irrigated drylands in Uzbekistan. SOM=soil organic matter

Crop production under conventional agriculture practices in the irrigated drylands in Uzbekistan is influenced by various factors (Figure 1.2). Decades of intensive soil tillage, constant removal of crop residues, extensive use of chemical inputs and over-irrigation have contributed to declining soil fertility and increasing secondary soil salinization, leading to land degradation and desertification of irrigated areas. Due to intensive soil tillage and cotton mono-cropping, the soil organic matter in the region is rather low, i.e., 0.33 to 0.6% (Kienzler 2010). Furthermore, due to destruction of soil structure through excessive soil tillage and residue removal, the soil in the region is highly susceptible to wind erosion. An excessive use of irrigation water raises groundwater tables and this has increased secondary soil salinization and a deterioration of the soil quality (Figure 1.1). During the vegetation period, about 67% of the fields in Uzbekistan have groundwater levels above the threshold values that induce secondary salinization (Ibrakhimov et al. 2007).

Previous findings confirmed that nitrogen (N) use efficiency in the conventional production systems in Uzbekistan is rather low (Kienzler 2010). High temperatures and intensive irrigation and soil tillage under conventional practices enhance the mineralization of soil N (Vlek et al. 1989), which leads to N losses through denitrification (Scheer et al. 2008) and leaching (Kienzler 2010). The high N losses are not only a source of environmental pollution, they also increase production costs. All these factors threaten the sustainability of crop production in Uzbekistan.

1.2 The potential and challenges of conservation agriculture in irrigated drylands

Land degradation and land use are highly linked to each other. As explained above, intensive soil tillage, decreasing soil organic matter, increasing secondary soil salinization and mismanagement of irrigation water and fertilizers are presently increasing production costs, reducing soil fertility and threatening the sustainability of the crop production systems in the irrigated drylands of Uzbekistan, Central Asia. There is urgent need to take preventive steps to overcome the current conventional agricultural approach to make agriculture in irrigated drylands sustainable.

Conservation agriculture (CA) that aims at reduced tillage, proper crop rotation, and retention of optimal levels of crop residues (Sayre and Hobbes 2004) can minimize the adverse effect of conventional agriculture practices. During the 1970s, conservation tillage and soil mulching were proposed to counterbalance and combat soil erosion. During the 1980s, sub-soiling and deep ploughing were proposed to alleviate soil compaction. Since the 1990s, soil quality and CA practices like reduced or no tillage and crop residue retention have received considerable attention (Wang 2006). Different forms of CA practices are now applied on more than 100 million ha worldwide (Derpsch and Friedrich 2009). CA practices are becoming increasingly attractive also in countries where conventional agriculture has to cope with serious problems due to land degradation and increasingly unreliable climatic conditions.

Among the wide range of CA practices worldwide, permanent raised bed planting is gaining importance for many row-spaced crops. The reported benefits associated with permanent raised beds include, (1) better irrigation management (Sayre and Hobbes 2004; Hassen et al. 2005), which saves 25-30% of irrigation water with increased water productivity, (2) improved nutrient availability (Govaerts et al. 2005) through proper placement of fertilizer, (3) reduced soil salinity (Bakker et al. 2010) by reducing evaporation loss of water and leaching salts from the furrows, which also prevents water logging, (4) energy and labor savings, thus reducing production costs (Gupta et al. 2009), and (5) equivalent or higher yields compared to those from conventional tillage practices (Sayre and Hobbes 2004; Govaerts et al. 2005; Hassen et al. 2005). Crop residue retention increases the soil organic matter content (Govaerts et al. 2005; Egamberdiev 2007), decreases soil salinity, reduces soil evaporation loss and thus increases water use efficiency (Huang et al. 2001; Deng et al. 2003). The combination of conservation tillage (permanent beds), residue retention and proper N management has been shown to be an alternative option for sustainable crop production systems under rainfed as well as irrigated systems (Limon-Ortega et al. 2000; Sayre and Hobbes 2004; Govaerts et al. 2005; Wang et al. 2007).

Despite these apparent advantages, CA research has only recently been introduced in Uzbekistan. Consequently, the effects of N application, reduced tillage, residue management, and crop rotation on crop performance, production, water productivity and its effect on soil salinity under the specific conditions of the irrigation system and practices in Uzbekistan are still poorly understood (Gupta et al. 2009).

Due to the numerous interacting factors, crop yield is not always higher with CA than with conventional practices, and certainly not so at the onset of the transition period from conventional to CA. A frequently cited concern regarding CA is the decreasing availability of plant-available N due to its immobilization by crop residues (Rice and Smith 1984; Franzluebbers et al. 1995; Doran et al. 1998). However, it is not clear to what extent this may occur or not when implementing CA practices in irrigated lands. Furthermore, crop residue retention competes often with farmers' practices in Uzbekistan for using this resource as livestock feed, which limits the field application of crop residue. Thus, proper N application and management with optimal levels of residue retention together with conservation tillage needs to be developed specifically for the cropping systems in Uzbekistan. A better understanding of crop growth, yield and water productivity of major crops under CA, and greater knowledge of the short- and long-term impacts of CA practices on the nutrient balance, soil salinity and sustainable crop production is necessary in irrigated drylands.

The Khorezm region, south of the Aral Sea in Uzbekistan, was selected in the current study as an area representative for the degradable areas in the region The German-Uzbek project of the Center for Development Research (ZEF) of the University of Bonn, Germany (www.khorezm.uni-bonn.de), has been working in the region since the year 2001. Khorezm is a suitable pilot area for developing concepts for ecological and economic sustainable land use in the Aral Sea Basin (ZEF 2001). It is hoped that the findings of the present study will be effective not only in the intervention region but also in other areas of irrigated drylands suffering from similar problems.

1.3 Research objectives

Considering the presently unsustainable conventional crop production systems in the irrigated drylands of Uzbekistan, the aim of this study was to compare crop growth, yield and water productivity of major crops under conservation and conventional agriculture practices with different N rates and its effect on soil salinity and N use efficiency in cotton-based cropping systems to define a sustainable crop production system for the irrigated drylands of Uzbekistan. The outcomes of this study are, therefore, expected to support the development of sustainable agriculture practices in irrigated drylands that can help to increase crop productivity, and minimize the negative effects associated with existing conventional agriculture practices.

The specific objectives were to:

1. Analyze cotton growth and yield and determine N use efficiency and N balance under conservation tillage with a terminated wheat cover crop and selected N fertilizer application rates;
2. Analyze growth, crop yield, and water productivity of cotton, wheat and maize in rotation under conservation agriculture practices with different N fertilizer application rates;

3. Compare N uptake, efficiency and balance of applied N in a cotton/wheat/maize rotation systems under conservation and conventional practices with different N rates;
4. Compare soil salinity dynamics under conventional and conservation agriculture practices;
5. Investigate the effect of different furrow irrigation techniques on salt distribution, crop performance and salt leaching under raised bed systems.

1.4 Outline of the thesis

The thesis consists of seven chapters, including this general introduction (Chapter 1), which is followed by providing details of the study region (Chapter 2).

In Chapter 3, the effect of CA practices and N rates on cotton growth, yield and yield components, N use efficiency and apparent N balance in a cotton/cover-crop/cotton rotation is analyzed. The effect of a winter cover crop on groundwater NO_3-N contamination is also described.

Chapter 4 compares the effects of conservation and conventional agriculture practices with different N fertilizer rates on growth, yield and water productivity of cotton, wheat, and maize in rotation.

Chapter 5 describes the effect of different tillage methods, residue and N rates on N uptake and use efficiency and apparent N balance and system N use efficiency in cotton, wheat and maize in rotation.

Chapter 6 deals with salt dynamics under conservation and conventional agriculture practices in cotton/wheat/maize rotation systems, and also the effect of different irrigation techniques on salt dynamics and leaching efficiency in bed planting.

In the general discussion in Chapter 7, conservation agriculture practices with different N levels with respect to crop yield, water productivity, N use efficiency, apparent N balance, and soil salinity dynamics are assessed in two cotton-based systems. Furthermore, the main conclusions and recommendations are presented.

2 STUDY REGION

2.1 Geographical and demographical setting

This study was conducted in 2008-2009 in the Khorezm region of Uzbekistan within the framework of the German-Uzbek ZEF/UNESCO Khorezm project. The Khorezm region is located in northwest Uzbekistan at 60.05°- 61.39°N latitude and 41.13°-42.02°E longitude. Elevation ranges 90-138 m above sea level.

The region covers an area of about 6200 km^2 and is bordered by the Amu Darya River to the northeast, the Karakum desert to the south, the Kyzylkum desert to the east, the Republic of Turkmenistan to the southwest, and the Autonomous Republic of Karakalpakstan to the north (Figure 2.1). In 2007, the region had a population of 1.51 million, and about 80% of this population lived in rural areas (Bekchanov et al. 2010), with incomes largely depending on irrigated agriculture.

The Khorezm region is one of the most intensively cultivated areas in Uzbekistan, and has 270,000 - 300,000 ha under irrigated agriculture (Conrad 2007). All irrigation water in the region comes from the Amu Darya River. In view of its downstream location on the Amu Darya, Khorezm is especially vulnerable to water shortage and droughts. Furthermore, the extensive and inefficient irrigation in Khorezm has drastically increased secondary soil salinization and degradation of the irrigated land, which is threatening the sustainability of the ecological and socio-economic situation in the region.

The field experiments were conducted at the research site of the ZEF/UNESCO project in Urgench district (60°40´44``N and 41°32`12``E) of Khorezm region (Figure 2.1).

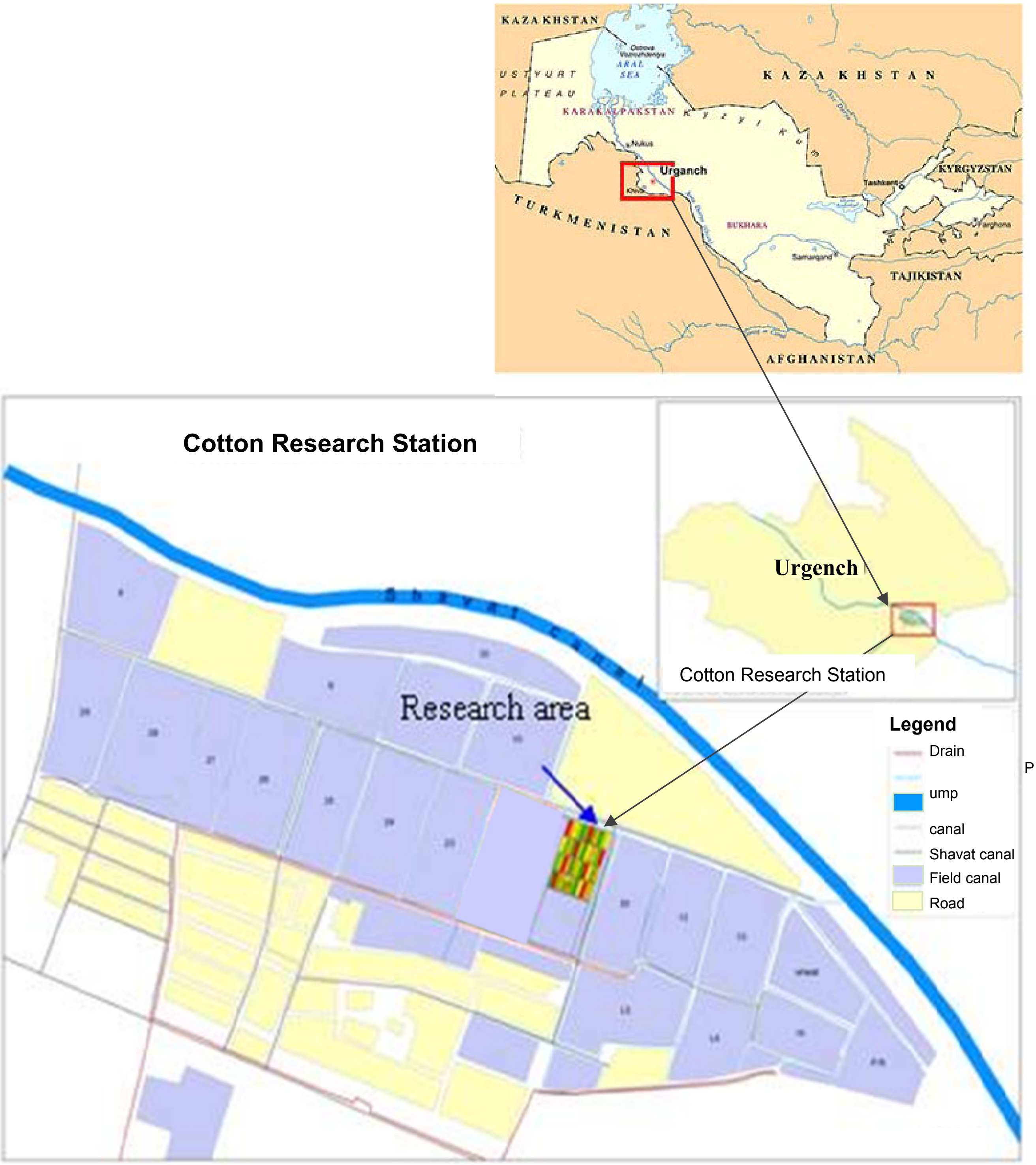


Figure 2.1 Khorezm region in the northwest of Uzbekistan and location of the study farm (for further details see figure 4.1)

2.2 Climate

The climate of the Khorezm region is, according to the Köppen-Geiger Climate Classification System, a typical continental, cold arid desert climate with long, hot and dry summers and short, very cold dry winters (Kottek et al. 2006). Potential evapotranspiration (1200 mm year^{-1}) always greatly exceeds precipitation. Higher precipitation generally occurs in April and November (Forkutsa 2006). The meteorological station in Urgench reported a mean annual temperature of 13.4 °C with a minimum in January/February (-7 °C) and a maximum in June/July (40 °C) for the last 37 years. Mean annual rainfall in the same period amounted to 94.6 mm (Figure 2.2). The average yearly frost-free period is 205 days (Khamzina 2006).

The climatic conditions favor the growing of annual, warm-season crop such as cotton and maize, since these crop favor frost-free regions with high temperature, high solar radiation and little precipitation (Chaudhary and Guitchonouts 2003; Kienzler 2010), and also winter wheat, which can survive under low temperature during winter (Fowler et al. 1999). Crop production under the continental climatic conditions, however, is possible only with assured irrigation. However, a declining availability of irrigation water in the region, where the average probability of obtaining the sufficient irrigation water declined by 16% since the past two decades (Müller 2006), necessitates the development of a crop production technology that can increase the water use efficiency.

The region is characterized by a north-easterly wind during the main crop-growing season (from April until October) with an average wind velocity of 1.4 to 5.5 ms^{-1} with maximum velocities reaching 7-10 ms^{-1} (Forkutsa 2006). Wind erosion on the tilled and uncovered soil is high under such a climatic condition. The introduction of conservation tillage and mulching techniques may thus help to conserve soil nutrients and preserve/re-introduce soil life, and prevent further soil loss to wind erosion.

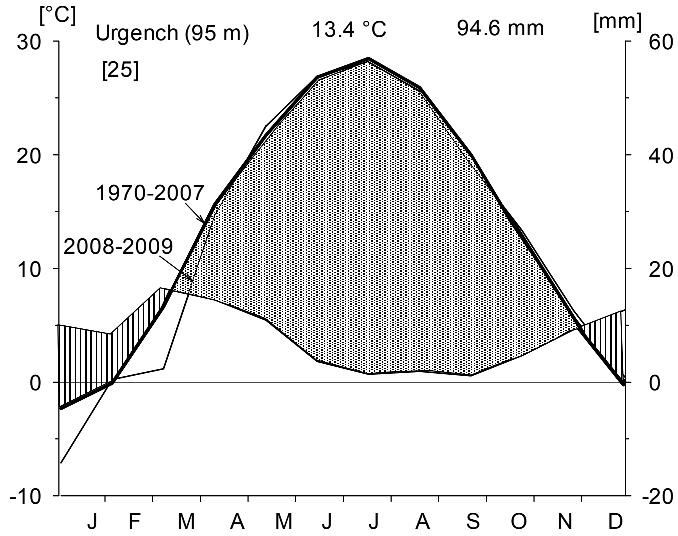


Figure 2.2 Mean monthly air temperature and monthly precipitation for Urgench, Khorezm, Uzbikistan, according to Walter and Leith (1967)

2.3 Soil

According to the FAO classification, Khorezmian soils can be classified into three major types (FAO 2003): (i) calcaric gleysoils, i.e., meadow soils in the irrigated areas characterized by a shallow groundwater table often with elevated groundwater salinity and secondary salinization in the upper soil, (ii) calcaric fluvisoils, i.e., meadow soils commonly found mainly along the Amu Darya River in the eastern part of Khorezm, and (iii) yermic regosols, soils that are formed from alluvial rock debris deposits outside the irrigated areas and also from the dunes of the Kara Kum desert mainly in the south of Khorezm (Figure 2.3). However, the FAO classification is rather broad and does not include the detailed characteristics of the Russian/Uzbek classification. According to the latter classification, the major soil type of the region is an irrigated alluvial meadow, which covers 60% of the area. The other common soils in Khorezm are boggy-meadow (covering 16%), takyr-meadow (15%), boggy (5%), grey-brown and takyr (2%) (Rasulov 1989 cited by Kienzler 2010). The soil textures are light, medium and heavy loams (Rizayev 2004 cited by Scheer 2008).

The inherent fertility of all Khorezmian soil types is rather low, thus cultivation of agricultural crops requires the input of fertilizers. The organic matter content in the

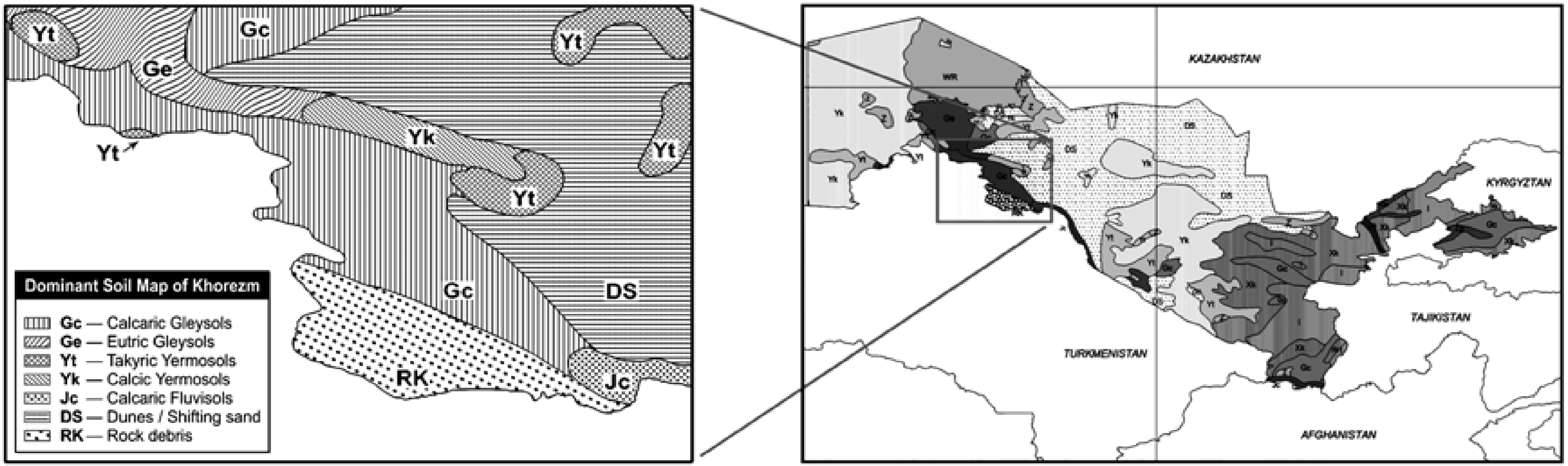


Figure 2.3 Predominant soils of Khorezm (from FAO 2003)

Khorezmian soils ranges from 0.33 to 0.6%. In the experimental field the soil organic matter (SOM) content was rather low with 0.4-0.5% in top 30 cm soil depth (Table 2.1). The low SOM contents in the study region is due to high temperatures and intensive irrigation and soil tillage practices, which enhance fast decomposition in the plow layer (Vlek et al. 1981) and continuous cotton mono-crop (Sainju et al. 2006). Hence with annual crop residue retention as is advocated under CA, it should be able to increase SOM at least for a short period.

Nitrogen is considered the most limiting nutrient in the Khorezmian soil (Ibragimov 2007). The total organic N (N_{org}) content usually comprises around 90-95% of the soil total N content in the plowing layer of agriculture soils, and is closely associated with the SOM (Vlek et al. 1981). For Khorezm, N_{org}-content in the soils has been reported to vary from 0.012-0.073% in 0-30 cm depth (Kienzler 2010). In the experimental field the total N content was 0.04 to 0.05% in top 30 cm soil depth (Table 2.1).

The total soil P (0.10-0.21%) and K (1.0-2.2%) concentrations are relatively high in the 0-30 cm layer. The concentration of the plant-available form of P (P_2O_5) is generally moderate (15-93 mg P_2O_5 kg^{-1}) in the Khorezmian soils (Djumaniyazov 2006; Kienzler 2010). The exchangeable form of K (K_2O) in the soil reportedly ranged from low (84 mg K kg^{-1}) to high (470 mg K kg^{-1}), greatly depending on preceding crops and fertilizer management (Djumaniyazov 2004; Kienzler 2010). In the experimental field the available phosphorus (22-28 mg kg^{-1}) and exchangeable potash (89-99 mg kg^{-1}) were in the moderate range (Table 2.1). Therefore these two nutrients did not receive priority in this study.

Table 2.1 Initial soil properties of the experimental site in 2008.

Depth (cm)	Bulk density (g cm^{-3})	Soil pH	NH_4-N (mg kg^{-1})	NO_3-N (mg kg^{-1})	Total N (%)	Organic carbon (%)	Available phosphorus (mg kg^{-1})	Exchange-able potash (mg kg^{-1})
0-10	1.35	5.57	5.4	5.3	0.05	0.36	27.9	98.5
10-20	1.41	5.56	6.5	4.4	0.05	0.30	25.9	95.0
20-30	1.42	5.57	6.3	5.2	0.04	0.26	21.9	89.3
30-60	1.52	5.69	6.3	4.0	0.03	0.23	19.2	81.4
60-90	1.57	5.78	5.2	3.9	0.03	0.19	17.6	76.8

Note: SOM = 1.56 x organic carbon

Inefficient and excessive use of irrigation water on the agricultural lands in the region over several decades has led to highly saline soils (Ibragimov 2007). The fluctuation of the groundwater table in the region is mostly driven by irrigation and leaching activities (Ibrakhimov et al. 2004). During the growing period, i.e., March to August, the average groundwater table rises up to 1.2 m and drops to about 1.8 m in October. The average salinity of the groundwater ranges between 1.68 g l^{-1} in October and 1.81 g l^{-1} in April (Ibrakhimov et al. 2004). The higher groundwater levels enhance soil salinization by annually adding 3.5-14 t ha^{-1} of salts depending on the salinity level of the groundwater (Ibrakhimov et al. 2007). According to official government data (1999-2001), the entire irrigated area in the Khorezm region suffers from secondary soil salinization, and about 81% of the area has water-logging problems (Abdullaev 2003).

Thus, prior to crop planting, i.e., in early spring, 20-25% of the water given later for irrigation is applied to leach the salts from fields (Conrad et al. 2011). Although perhaps effective, the leaching with the huge amounts of water raises the groundwater tables further and hence increases the risk of increasing secondary salinisation (Akramkhanov et al. 2010). In the absence of an efficient drainage system, this is common in most areas. The risk of re-salinization in the root zone increases (Forkusa et al. 2009). Under saline and high groundwater table conditions, agriculture practices such as CA, which reduces irrigation water use and minimizes soil salinity, is expected help to sustain the agriculture systems.

2.4 Land use

Agriculture has been practiced in Khorezm region for thousands of years, mainly with millet, wheat, barley, water melons, and gourds (Forkutsa 2006). After the development of large irrigation and drainage systems from the mid 20th century onwards, agriculture began to bloom with the diversion of massive amounts of water from the river valleys to the surrounding areas mainly for cotton production. From that period onwards, the quality of the river water has deteriorated due to the discharge from the upstream collector-drainage systems to the river (Vinogradov and Langford 2001; Forkutsa 2006).

During the Soviet era, cotton became the priority crop, and about 70% of the irrigated land was used for cotton in 1970, but this declined to 56% in 1990 (before independence). The cotton area has further declined since independence due to the introduction of wheat as a second priority crop (Wehrheim and Martius 2008). Currently, about 265,000 ha of land are used for irrigated agricultural production in Khorezm (Bekchanov et al. 2010). Cotton, wheat, rice, and fodder maize are the dominant crops in the region (Wehrheim and Martius 2008), where cotton uses 42% of the irrigated area followed by winter wheat (20%), rice (7%), while fodder (10%), fruits and vegetables (10%) and garden crops occupy the remaining irrigated area in 2007 (Figure 2.3). Thus, for introducing sustainable agricultural practices which are advocated with CA, most gains can be made when addressing with priority the cotton and wheat based rotations.

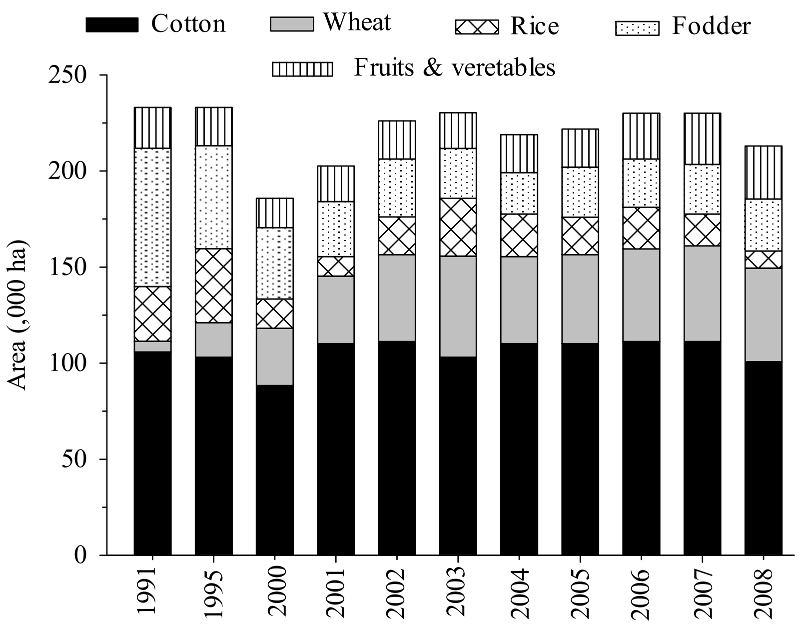


Figure 2.4 Area under different crops in Khorezm region (1991-2008) according to the regional department of statistics.

According to "bonity" classification, which indicates the quality of irrigated land (Figure 2.5) about 40% the total irrigated land in the Khorezm region is very good and capable of producing 81-100% of the potential cotton yield, about 26% is good indicating to be capable of producing 61-80% of the potential cotton yield, 19% is of moderate quality and capable of producing 41-60% of the potential cotton yield, and 15% is poor and capable of producing 40% of the potential cotton yield.

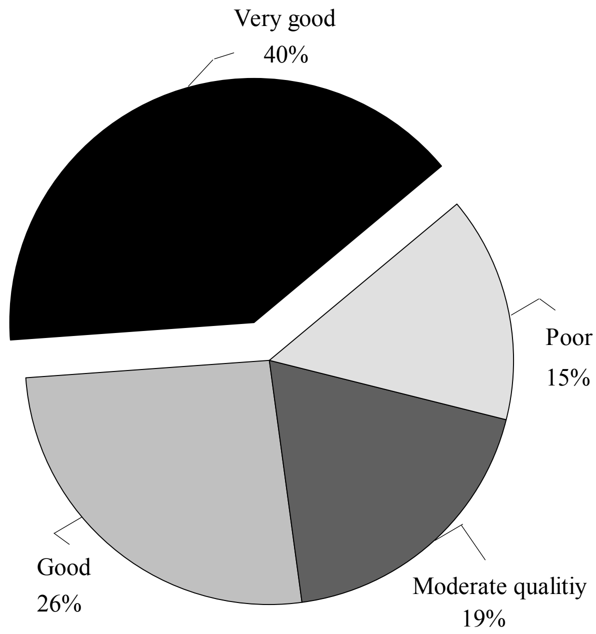


Figure 2.5 Quality of land bonitation ("bonitet") suitable for irrigation (% irrigated land) in the Khorezm region (FAO 2003).

In Uzbekistan, agricultural production is mainly state controlled. Three main farm types have been formed in different steps after independence from the Soviet Union (Scheer 2008): (1) shirkats - the agriculture cooperatives were formed as a transitory successor of former *kolhozes* and s*ovkhozes*, (2) *dehqon* farms - household farms, i.e., subsistence-oriented household plots that represent an important contribution to household food security, and (3) *fermer* enterprises - a new type of farm that has emerged during the past five years established on the basis of long-term leases with a commercial orientation (Wehrheim and Martius 2008). Conservation agriculture practices are mostly relevant in dehqon farms and fermer enterprises, which have a major contribution to food security.

3 IMPACT OF TILLAGE AND NITROGEN FERTILIZATION ON PERFORMANCE AND NITROGEN USE EFFICIENCY OF COTTON IN A COTTON/COVER-CROP/COTTON SYSTEM

3.1 Introduction

Cotton (*Gossypium hirsutum* L.) is grown annually on more than 1.45 million ha in the irrigated drylands of Uzbekistan (FAOSTAT 2010). Since the Soviet Union era (1924-1991) cotton production has played a major role in the country's economic development and this has remained after the country's independence in 1991. Uzbekistan is the sixth largest producer and third most important exporter of cotton fiber in the world (Bremen Cotton Report 2010). Cotton accounts for 13-18% of the national GDP (Wehrheim and Martius 2008).

More than 90 years of cotton mono-crop cultivation with excessive tillage and use of fertilizers and irrigation water to fulfill the state-order cotton production in Uzbekistan have led to soil and environmental degradation. Conventional practices in the region typically involve intensive land preparation for each crop with up to 4-5 machinery passes, deep tillage to reduce the sub-soil compaction, flood irrigation with insufficient drainage, and excessive use of fertilizers. The wasteful use of the resources creates environmental pollution, for instance through N_2O emissions (Scheer et al. 2008) and NO_3 leaching (Kienzler 2010); it increases production costs (Tursunov 2009), raises secondary soil salinization through rising groundwater levels (Forkutsa et al. 2009), and causes deterioration of soil quality (Lal et al. 2007). Due to crop residue removal and excessive soil tillage, evaporation loss of water is high in the region, results in increases the surface soil salinity. Also soils in the region are in particular highly susceptible to wind erosion in spring, which in turn reduces the organic matter content in the soil. Under such conditions, conservation agriculture (CA) technologies which reduce soil disturbance and retain crop residues can minimize soil evaporation and soil erosion losses, increase soil carbon sequestration, increase the nutrient use efficiency, and reduce energy requirements for crop establishment compared with conventional tillage (Sayre and Hobbs 2004; Lal et al. 2007). Among CA practices, permanent raised bed is gaining importance, and has been introduced in Asia and arid western USA (Sayre 2004). Permanent raised bed is credited with numerous advantages, such as better irrigation management by reducing the deep percolation, plant establishment by providing favorable root development environment (Sayre and Hobbs 2004) and opportunities for inter-bed cultivation for weed control. It gives comparatively better yields and an efficient use of input resources, i.e., water, fertilizers and herbicides, and also can help reducing production costs compared to conventional tillage (Mehta and Bandyopadhyay 2004).

The effects of tillage on cotton growth and yield have been variable. Some studies have shown that cotton yield was similar to or greater in CA than in conventional tillage (Daniel et al. 1999; Nyakatawa et al. 2000). Others have reported lower cotton yield in CA (Ishaq et al. 2001; Pettigrew and Jones 2001; Schwab et al. 2002). Moreover, others have reported that increased cotton yields with CA were observed only after several years (Triplett et al. 1996). Higher soil moisture resulting from the accumulation of surface residue in CA has been reported to increase cotton seed germination, root growth, and yield compared with conventional tillage (Bordovsky et al. 1994; Nyakatawa and Reddy 2000; Nyakatawa et al. 2000) while poor root penetration and difficulties in getting adequate crop stands and weed control have been caused to reduce cotton yields in CA (Schertz and Kemper 1994; Triplett et al. 1996). However, decreased production cost with increased environmental benefits of reduced soil erosion and N leaching and increased C sequestration suggests that CA will improve soil quality and sustain crop production (Smart and Bradford 1999; Paxton et al. 2001; Tursunov 2009).

Nitrogen (N) is the key limiting nutrient for cotton production on irrigated dryland. Nitrogen management practices under conventional cotton cultivation practices in Uzbekistan are highly inefficient, but can be substantially improved through better fertilizer management, i.e., better scheduling of fertilizer and irrigation application time (Kienzler 2010). Even with judicious N applications, the warm and moist soil conditions can favor the buildup of inorganic N in the soil profile presumably through organic matter mineralization and the decomposition of decaying roots and other plant residues while N uptake does not occur (Vlek et al. 1981; Weinert et al. 2002). In Uzbekistan, cotton is planted in April and harvested in September. Crop N uptake reduces during later crop growth stages and uptake could not occur after leaf defoliation, which is a common practice to induce boll opening and ease harvesting. In the absence of a living crop, the buildup of residual soil N during later crop growth stage being leached out when salt leaching is practiced during early-spring. Late summer-sown cover crops can sequester N and store it over the winter, when soil pools of NO_3 are prone to leaching (Huntington et al. 1985; and Shipley et al. 1992; Weinert et al. 2002). A winter cereal cover crop can accumulate up to 150 kg N ha^{-1} (Shennan 1992; Ditsch et al. 1993), with rooting systems reaching down to 80 cm (Frye et al. 1985), and –if retained in the field- can supply N for the following summer crop (Sainju et al. 2007). Furthermore, earlier research shows that inclusion of cover crops in mono-crop cotton systems increases the soil organic carbon (Sainju et al. 2005). Due to the sparse and stiff cotton residues, the introduction of a winter cover crop in a mono-crop cotton system increased the carbon inputs and soil organic carbon compared with a bare fallow (Sainju et al. 2006).

Nitrogen response to cotton yield may vary with tillage method (Sainju et al. 2006). In 5 yrs of field study in Midsouth USA, Boquet et al. (2004) reported that without N application cotton yields were lower in CA than in conventional tillage, but with optimum N application, yields were higher in CA. Similarly, on irrigated Vertisols of Australia, Constable et al. (1992) observed that the optimum N dose was lower for the CA than the conventional tillage. In 3 years of study, Bronson et al. (2001), however, reported that to produce the economically optimum lint yield, 19 to 38 kg ha^{-1} additional N was needed with CA compared to conventional tillage.

Cultivation practices based on CA principles have only recently been introduced in the irrigated areas of Central Asia. Hence, the impact of CA on soil properties, crop yields, and N management are insufficiently characterized in these environments. The few experiments previously conducted in the region have shown the potential of CA in cotton production, while the impact of different tillage methods on yields has been analyzed (Tursunov 2009). Furthermore, recent studies in irrigated drylands addressed N fertilizer response in mono-crop cotton in conventional systems (Kienzler 2010; Norton and Silvertooth 2007; and Mahmood et al. 2008). However, the interaction between tillage and N fertilization effect on cotton production had not been investigated in irrigated drylands of Uzbekistan. This study analyzes cotton growth and yield, and determines N use efficiency and the N balance under conservation and conventional tillage with various level of N fertilizer application.

3.2 Materials and methods

3.2.1 Description of the experimental site

Experiments were conducted during 2008 and 2009 in Khorezm, in western Uzbekistan (60°40´44``N and 41°32`12``E, 100 m a.s.l.). The experimental field had been mono-cropped with cotton under heavily mechanized production conditions for more than 20 years. Annual fertilizer applications had been in the order of 200:140:100 kg NPK ha^{-1}. Following field preparations that included deep ploughing, laser-leveling and salt leaching in February/March 2008, cotton was sown as the first transition crop in May 2008 and harvested in October 2008. After this, the impact of the treatments of tillage and N level on the rotation of cover crop (October 2008-April 2009) and cotton (April-October, 2009) was effectively studied.

The soil in the experimental area is an irrigated alluvial meadow, with sandy loam to loamy soil, low in organic matter (0.3-0.6%) and saline (salinity ranging from 2-16 dS m^{-1}). The groundwater table is shallow (0.5-2 m). The climate is arid, with long, hot and dry summers and short, very cold winters. Average precipitation is less than 100 mm $year^{-1}$. Potential evapotranspiration (1200 mm $year^{-1}$) always greatly exceeds precipitation. The mean annual temperature is 13.6 °C (Figure 2.2).

3.2.2 Experimental design and treatments

A two-factor, split-plot experiment with four replications was designed to explore the influence of two tillage methods (bed planting, BP and conventional tillage, CT) as the main factor and three N levels (no application (N-0), less than recommended (N-125) and more than recommended (N-250)) as the subplot treatments. The officially recommended N application rate for cotton is 160-180 kg ha^{-1} (MAWR 2000). The subplot (12 m x 6 m size) treatments were completely randomized. In this study the term bed planting is used for permanent raised bed, as the beds were freshly prepared in 2008, but was maintained as permanent afterwards.

Table 3.1 Field activities in bed planting and conventional tillage in cotton under cotton/cover-crop/cotton rotation system.

Cotton	Bed planting	Conventional tillage	Time
2008	Salt leaching		February
	Deep ploughing, laser leveling		March
	Bed making	Flat leveling	April
	Cotton sowing on bed	Cotton sowing on flat	May 6
	Furrow cultivation followed by band application of N fertilizer	Inter-row cultivation followed by band application of N fertilizer and furrow opened for irrigation	June
	Band application of N fertilizer	Inter-row cultivation followed by band application of N and furrow opened for irrigation	July
	Broadcast seeding of wheat (for cover crop) on standing cotton after 2nd picking		October
2009	Glyphosate applied to terminate the cover crop		First week of April
	Cotton sowing on bed without cultivation	Cotton sowing on flat after three times soil tillage and rough leveling	April 25
	Phosphorus and potassium fertilizers were drilled during planting	Phosphorus and potassium fertilizers were broadcast applied during field preparation	
	Band application of N fertilizer	Inter-row cultivation followed by band application of N and furrow opened for irrigation	June
	Band application of N fertilizer	Inter-row cultivation followed by band application of N and furrow opened for irrigation	July

3.2.3 Field preparation and sowing

Cotton

Details of field activities applied in both bed planting and conventional tillage in cotton are shown in Table 3.1. In 2008, fresh beds were prepared with a 90 cm spacing from furrow to furrow in BP. Cotton was sown as a single row at the recommended seed rate of 60 kg ha^{-1} in the center of the beds. In CT, seeds were sown on the flat field with the same spacing and seed rate as in BP. In 2009, the beds were kept as permanent bed and no soil tillage occurred apart from seed and fertilizer drilling. Under CT, three ploughings followed by rough leveling were performed before seeding. The same seed rate and spacing as in 2008 was used in both tillage methods.

Cover crop

After the second picking of cotton in mid October 2008, winter wheat was broadcast-seeded at the rate of 150 kg seeds ha^{-1} in both tillage systems to serve as a winter cover crop. No fertilizer was applied to the winter cover crop. Since salt leaching was practiced in the surrounding fields, single flood irrigation was applied to the experimental site to prevent salt movement from the adjacent fields into the experimental site. Two weeks before cotton sowing, glyphosate [N-(phosphonomethyl) glycine] was applied to the entire experimental area to fully terminate wheat growth. At this time, wheat was near the booting stage (Zadoks et al. 1974), and had accumulated a dry biomass of 1.8 to 2 t ha^{-1}. In the BP treatments, the cover crop was retained on the soil surface, while in the CT treatments it was incorporated into the soil during field preparation.

3.2.4 Fertilizer and irrigation application

Phosphorus (P) and potash (K) at 140 and 100 kg ha^{-1}, respectively, were applied as basal applications during sowing in all treatments (Table 3.1). Phosphorus was applied as single super phosphate (10% P_2O_5) in the N-0 treatments, while ammonium phosphate (11% N and 16% P_2O_5) was applied in all other N treatments. Muriate of potash (60% K_2O) was applied in all plots. Nitrogen was top dressed as a band application in two equal split during budding (38 days after sowing; DAS) and flowering (52 DAS) in both years. In CT, after each cultivation and N application, furrows were opened in between two rows to apply irrigation water. Cotton was furrow irrigated five times in 2008 (totaling 450 mm ha^{-1}), and four times in 2009 (totaling 395 mm ha^{-1}). Irrigation water was applied as needed, which was determined by leaf rolling. The amount of irrigation water was measured for each plot. Methods of irrigation water measurement and calculation are presented in section 4.2.3, *Irrigation water*. Water samples were collected from the irrigation canal during all irrigation events and analyzed immediately for NO_3-N concentration.

3.2.5 Crop management

The cotton stand was thinned manually 20-25 DAS to achieve a uniform plant population, keeping 6-7 plants per m^2. In 2008, weeds were controlled with a single furrow cultivation at 40 DAS in BP and two cultivations (at 40 and 60 DAS) under CT. In 2009, although weed densities were lower, two cultivations (at 35 and 60 DAS) were needed for CT, but no cultivation for BP system (Table 3.1). After the formation of 12-14 sympodial branches, cotton growing tips were de-topped to stop indeterminate growth and to induce synchronous maturity. Similarly, a defoliant (magnesium chloride 9 kg ha^{-1}) dissolved in 200 l water was applied to induce boll opening, 10-15 days before the first cotton picking.

3.2.6 Measurement and analysis

Groundwater measurement

Across the experimental field, 20 piezometers were randomly installed up to 2.75 m depth. Groundwater depth and NO_3-N concentration were measured in 15-day intervals during the entire cotton and cover crop growing period in both years from March to November. The periods December to February were not sampled, since the groundwater level had dropped below the depth of the piezometers. The groundwater depth was measured using a hand-operated sounding apparatus with acoustic and light signals (Eijkelkamp 2002). The groundwater water was sampled in a water sampling bottle from all piezometers separately and analyzed immediately for NO_3-N concentration. The NO_3-N concentration was determined using nitrate test sticks (color scale in steps of 10-25-50-100-250-500 mg NO_3 l^{-1} (Merkoquant®, Merk® KGAA)) and photometrically with a calibration solution (0.5-20 mg l^{-1}) (Spectroquant®, Merk® KGAA).

Cotton growth, yield and yield components

Leaf area and aboveground biomass

Plant height, leaf area, branch number, boll density and aboveground biomass were recorded at the five major growth stages of cotton, i.e., 2-4 leaf stage, budding, flowering, boll formation and physiological maturity. At each stage, 40 plants from each plot were measured for plant height, branch number and boll number. In addition, five representative plants were sampled for leaf area, partitioned biomass determination, and N uptake. Each cotton plant was separated into leaves, stem, flowers and bolls. The leaf area of fresh leaves was measured with a leaf area meter (Li-Cor, LI-3100) in cm^2 and converted to leaf area index (m^2 m^{-2}) as leaf area per unit land area. Total aboveground biomass was calculated from the sum of plant parts, i.e., cotton stems, leaves, fruit elements, and seed cotton after oven drying the samples at 70 °C for 24 h. The harvest index (HI) was calculated as the ratio of raw cotton to total biomass (equation 3.1).

$$\text{HI (\%)} = \frac{\text{Rawcotton (g plant}^{-1}\text{)}}{\text{Total biomass (g plant}^{-1}\text{)}} \text{X } 100 \qquad (3.1)$$

Yield and yield components

To measure cotton yield, an 8 m x 1.8 m area covering two central rows was delineated in each subplot. The cotton from each subplot was harvested manually at 142, 154, 171, and 179 DAS. The raw cotton yield was adjusted to 6% moisture level by oven drying a sub-sample of 100 g from each harvest at 70 °C for 16 h. The number of bolls and percentage of open bolls were determined prior to defoliation from 40 randomly selected plants from each plot. Similarly, 40 bolls were picked randomly at each picking and oven dried to calculate average boll weight. Ginning percent was calculated by separating the lint and seed from 200 g oven-dry raw cotton and weighed separately for each picking. It was calculated as the ratio of lint to seed cotton (equation 3.2).

$$\text{Ginning percent (\%)} = \frac{\text{Lint weight (g)}}{\text{Raw cotton (seed + lint) weight (g)}} \text{X } 100 \qquad (3.2)$$

Total plant N uptake

The plant samples were ground to pass a 1-mm sieve for N concentration. The samples were analyzed for percent N content in Cotton Research Institute, Tashkent, Uzbekistan by Kjeldahl method (Bremner and Mulvaney 1982). The N concentration of stem, leaf, seed cotton, senescence leaf, and fruit elements were determined separately. For the calculation of N uptake, the N content (%) was multiplied with the respective dry weight of the plant component (equation 3.3), and next summed to determine the total N uptake.

$$\text{N uptake (kg ha}^{-1}\text{)} = \text{Dry matter yield (kg ha}^{-1}\text{) X \%N} \qquad (3.3)$$

3.2.7 Soil sampling and analysis

Soil samples were collected before the start of the experiment and analyzed for total N (TN) and carbon (C) as well as mineral N to estimate the initial fertility status of the experimental site. Soil samples were furthermore collected from each plot after the cotton harvest in both years. They were collected from 0-10, 10-20, 20-30, 30-60 and 60-90 cm soil depths at three different points in each plot and mixed thoroughly to obtain a composite sample. Samples were collected by using a tube auger. The samples were dried in a solar drier until completely dry, ground to pass a 1-mm sieve, and mixed thoroughly.

Total and mineral N and total C were analyzed using standard procedures in Uzbekistan (Kuziev 1977). Total N was analyzed by the Kjeldahl method (Bremner and Mulvaney 1982), NO_3-N content (mg kg^{-1}) by the Granvald-Ljashu method, and NH_4-N content (mg kg^{-1}) by colorimetric analysis using the Nessler reagent (Protasov 1977). Organic carbon (C) was determined according to Tyurin (Cotton Research Institute 1977, Durynina and Egorov 1998), which is a modified Walkley-Black method (Nelson and Sommers 1982).

3.2.8 Nitrogen use efficiency

Apparent recovery efficiency of nitrogen (ARE_N), i.e., plant N uptake (kg ha^{-1}) per kg N applied, was calculated as suggested by Dilz (1988) (equation 3.4)

$$ARE_N = \frac{\text{N uptake (kg ha}^{-1}\text{) at N}_{app}\text{ plot - N uptake (kg ha}^{-1}\text{) at N0 plot}}{\text{N rate (kg ha}^{-1}\text{) at N}_{app}\text{ plot}} \text{X} 100 \qquad (3.4)$$

Physiological efficiency of nitrogen (PE_N), i.e., kg grain yield per kg N uptake, was calculated according to Isfan (1990) (equation 3.5).

$$PE_N = \frac{\text{Yield (kg ha}^{-1}\text{) at N}_{app}\text{ plot - Yield (kg ha}^{-1}\text{) at N0 plot}}{\text{N uptake (kg ha}^{-1}\text{) at N}_{app}\text{ plot - N uptake (kg ha}^{-1}\text{) at N0 plot}} \qquad (3.5)$$

Agronomic efficiency of nitrogen (AE_N), i.e., the yield (kg ha^{-1}) increase for each kg N applied, was calculated according to Nova and Loomis (1981) (equation 3.6)

$$AE_N = \frac{\text{Yield (kg ha}^{-1}\text{) at N}_{app}\text{ plot - Yield (kg ha}^{-1}\text{) at N0 plot}}{\text{N rate (kg ha}^{-1}\text{) at N}_{app}\text{ plot}} \quad (3.6)$$

where, N_{app}= nitrogen applied

3.2.9 Apparent N balance

The apparent N balance was estimated from total plant N uptake (cotton and cover crop), initial and residual (at crop harvest) soil mineral N in the top 90 cm soil profile, applied N fertilizer, and NO_3-N brought with irrigation water. Cumulative N input and output were calculated for each treatment. Nitrogen loss (via leaching and denitrification) and N supply from decomposition of cover crop and fallen previous season cotton leaves were not considered in the N balance. Nitrate N supply from irrigation water was 11 kg ha^{-1}, which was calculated from the total amount of irrigation water applied (920 mm ha^{-1}) in the system, i.e., 450 mm for cotton 2008, 750 mm for cover crop and 395 mm for cotton 2009, and the average NO_3-N concentration in irrigation water (1.2$\pm$0.14 mg l^{-1}). Nitrate-N concentration in irrigation water was measured by sampling irrigation water in three sampling bottles separately for each irrigation and analyzed immediately for NO_3 concentration as described in section 3.2.6, *groundwater.* Apparent N balance for cotton/cover-crop/cotton system was calculated according to formula modified from Timsina et al. (2001) (equation 3.7).

$$\text{Apparent system N balance (kg ha}^{-1}\text{) = Input (initial soil mineral N + amount N applied + N from irrigation)} - \text{Output (total plant N uptake (cotton + cover crop + cotton) + Soil mineral N at harvest (cotton 2009)} \quad (3.7)$$

3.2.10 Statistical analysis

Crop parameters, i.e., yield, yield components, N uptake and use efficiencies were statistically analyzed for analysis of variance as a split-plot factorial design with four replications for yield and yield components, and with three replications for N uptake and N use efficiency. Leaf area index and aboveground biomass production over different times were analyzed using repeated measures. Treatment effects were compared through the analysis of variance using GenStat Discovery Edition 3. Main and interaction effects were compared using Fisher's protected LSD (least significant difference; P=0.05), unless stated otherwise. Simple non-linear regression analysis was also carried out for the yield response to mineral N in soil and plant N concentration and biomass yield. The curves were fitted using a quadratic function in SigmaPlot version 11.0.

In the absence of an effect of tillage and N level on the groundwater NO_3 concentration and depth, the values presented hereafter are averaged across the experiment's twenty piezometers.

3.3 Results

3.3.1 Groundwater depth and nitrate concentration

Groundwater depth and NO_3-N concentration varied according to water availability and growing season. The groundwater depth ranged from 2.5 to 1.5 m in 2008 and from 2.5 to 0.9 m in 2009. The NO_3-N concentration in the groundwater varied between 3 and 14 mg l^{-1} (Figure 3.1).

The temporal dynamics of groundwater NO_3-N concentration were linked to the irrigation and fertilizer application events. The NO_3-N concentration always increased immediately after N fertilizer application followed by irrigation. Groundwater NO_3-N started with a maximum of 14 mg l^{-1} in the beginning of the 2008 cotton season and could have been even higher in March/April (immediately after leaching), but measurements were not available for that period. In 2009, after inclusion of a winter cover crop in the cotton-cotton system, the groundwater NO_3-N after salt leaching, i.e., in March-May was with <4 mg l^{-1} much lower.

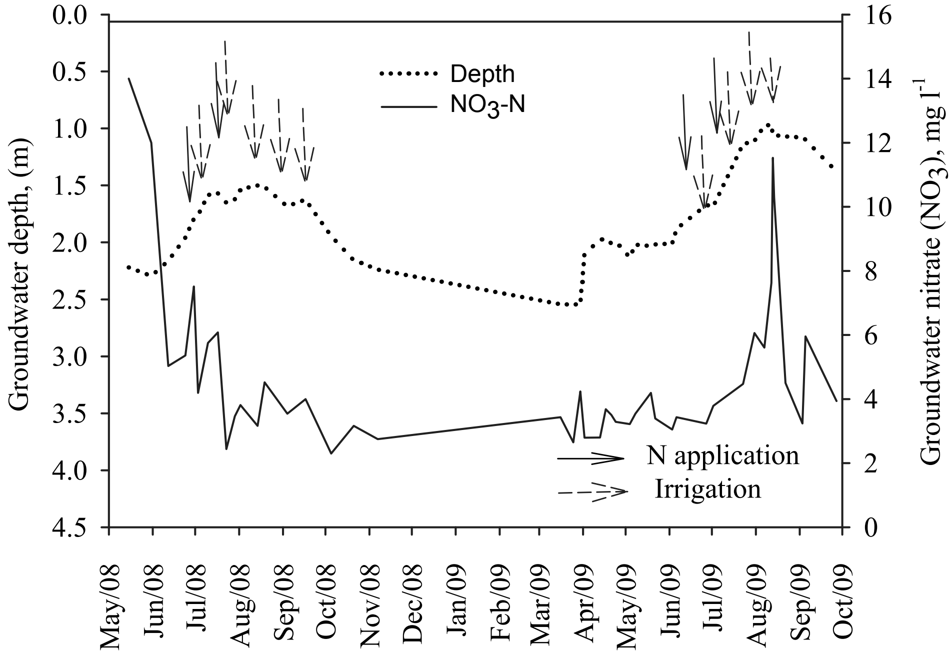


Figure 3.1 Nitrate concentrations (mg l^{-1}) in groundwater and groundwater depth (m) between May 2008 and October 2009. The dotted and solid arrows represent N fertilization and irrigation events, respectively.

3.3.2 Cotton growth and development

2008

Soil tillage did not significantly affect leaf area index (LAI) and aboveground biomass (AGB) production in 2008. Nevertheless, the initial growth (before flowering) was higher under CT than in BP, while after flowering (i.e., after applying fertilizer and irrigation) the growth rate in BP increased compared to CT (Figures 3.2A and 3.2B). An effect of N fertilizer level on LAI and AGB was observed only after flowering, where treatments with N had 57% higher ($p<0.05$) LAI and 33% higher AGB during boll formation (103 DAS) than with N-0. At maturity, both LAI and AGB increased ($p<0.05$) by 38% in the N treatments compared to N-0. The differences between N-125 and N-250 in LAI and AGB were insignificant at all growth stages (Figures 3.2A and 3.2B).

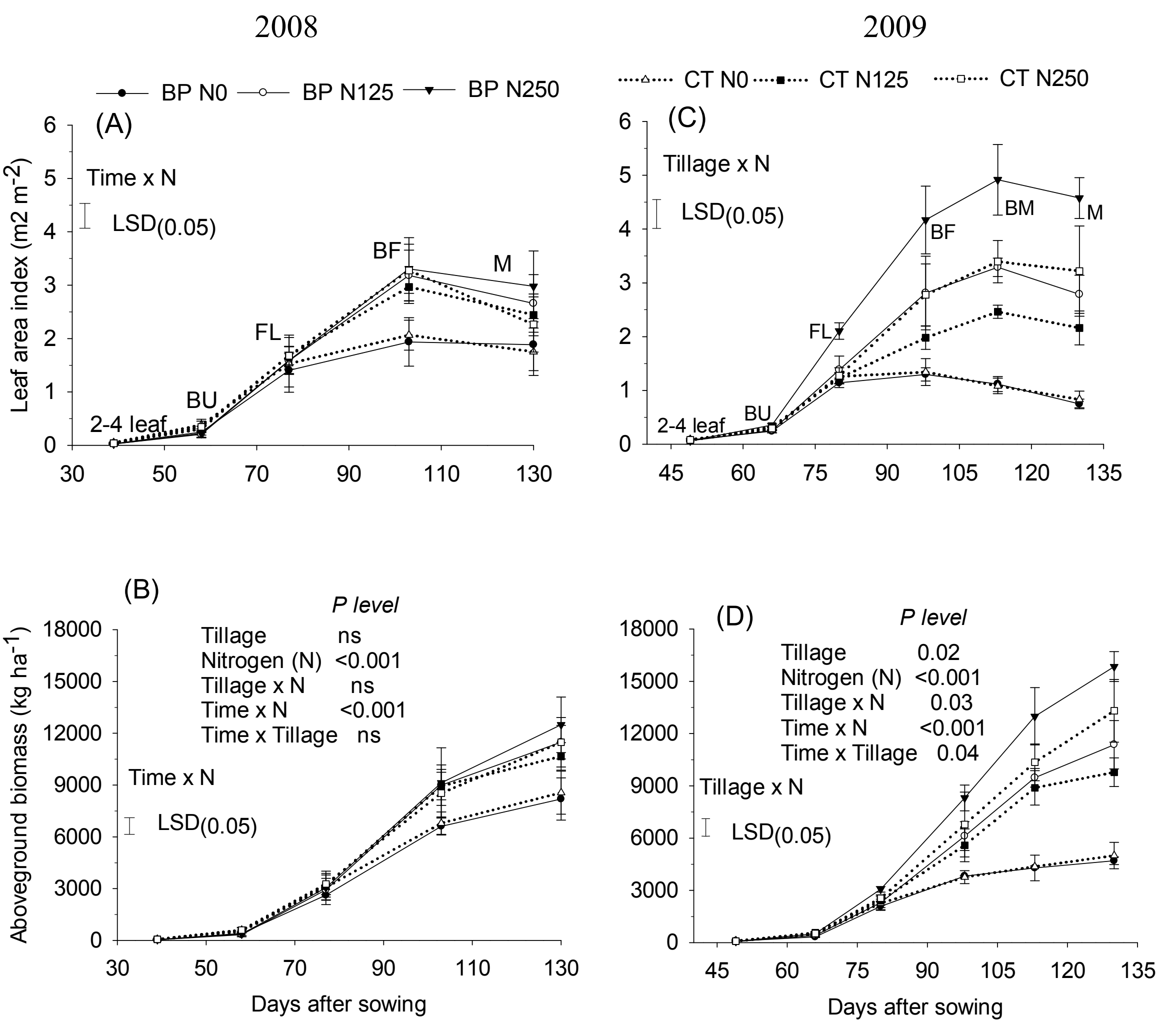


Figure 3.2. Leaf area index (A) and aboveground cotton biomass (B) in 2008; leaf area index (C) and aboveground biomass (D) in 2009 under two tillage (BP=bed planting, CT=conventional tillage) and three N levels (0, 125 and 250 kg ha^{-1}). BU=budding, FL=flowering, BF=boll formation, BM=boll maturation, M=maturity. Significance level is similar for LAI and AGB in respective year. LSD=least significant difference; ns=non significant. Bars represent standard error.

2009

The main and interaction effects of tillage and N level were significant for LAI and AGB production of cotton during the entire growth stages in 2009 (Figure 3.2). Tillage had no effect on cotton growth with N-0, but with the higher N levels BP had a significantly higher ($p<0.05$) LAI and AGB than under CT. With N application, LAI and AGB production increased significantly under both tillage methods, while the response of cotton to an increased N level from N-125 to N-250 was higher in BP than under CT. BP with N-250 showed an increase of LAI by about 55% and of AGB by 35% during the entire growing period compared to N-125. In contrast, under CT, the increase from N-125 to N-250 had a visible effect only after flowering, where a 37-48% higher LAI and 19-36% higher AGB were observed (Figures 3.2C and 3.2D).

3.3.3 Yield and yield components

The average raw cotton yield varied little and was 3.8-3.9 t ha^{-1} in both years (Table 3.2). The yield was not affected ($p>0.05$) by tillage method, while it increased significantly with N application in both years (Table 3.2). With N fertilizer, up to 5.1 t ha^{-1} cotton yield could be achieved (in 2009; Table 3.2). Irrespective of the tillage method, raw cotton yield with N-125 was higher than the average by 25% in 2008 and was more than two times higher (143%) in 2009 than for N-0. With N-125 to N-250, yield was not affected in 2008, while it increased ($p<0.05$) by 22% in 2009. A similar trend as for yield was observed for AGB production at maturity.

Tillage did not affect ($p>0.05$) harvest index (HI), which did, however, decrease ($p<0.05$) with N application rate in both years. A significant interaction effect between tillage and N level ($p=0.01$) was observed for HI in 2009. In BP, HI decreased by 17% with N-125 compared to N-0. In contrast, HI was not significantly affected by N application under CT in both years. The average ginning percentage was 39% in both years. It was not affected ($p>0.05$) by tillage method, but decreased ($p<0.05$) with N applications in both years (Table 3.2). Irrespective of the tillage method, ginning percentage decreased ($p<0.05$) by 6% with N-250 compared to N-0 in both years.

Tillage method did not affect boll density, boll weight, and plant height in either year except boll weight at third picking in 2008, where it was 6% higher in BP than under CT (Table 3.3). Nitrogen application significantly increased boll density in both years (Table 3.3). Averaged across both tillage methods, an application of N-125 increased ($p<0.05$) boll density by 20% in 2008 and by 86% in 2009 compared to N-0. With a further increase in N level from N-125 to N-250, boll density increased by 13% in 2009, but there was no difference in 2008.

Table 3.2 Main effects of tillage method and N level on raw cotton yield, aboveground biomass (AGB), harvest index and ginning percent of cotton in 2008 and 2009.

Treatment	Raw cotton yield (kg ha^{-1})		AGB (kg ha^{-1})		Harvest index (%)		Ginning percent (%)	
	2008	2009	2008	2009	2008	2009	2008	2009
Tillage								
BP	3901	3790	10633	10734	37.1	35.8	39.2	38.8
CT	3877	3777	10181	9372	37.7	37.6	39.9	39.1
LSD (0.05)	687	606	2206	1973	2.1	6.2	2.6	1.9
Nitrogen (kg ha^{-1})								
0	3269	2091	8234	5015	39.7	39.3	40.6	40.1
125	4084	4171	11004	10571	37.4	37.3	39.8	38.7
250	4313	5090	11984	14573	36.1	33.3	38.2	38.1
LSD (0.05)	254	456	1179	1236	2.8	3.9	1.5	1.6
ANOVA								
Tillage (T)	ns	ns	ns	ns	ns	ns	ns	ns
Nitrogen (N)	***	***	***	***	*	*	**	*
T x N	ns	ns	ns	ns	ns	**	ns	ns
LSD (0.05)	636	668	2152	1999	3.5	6.3	2.6	2.3
Mean	3889	3784	10407	10053	37.4	36.7	39.5	38.9

BP=bed planting, CT=conventional tillage. *$P \leq 0.05$, **$P \leq 0.01$, *** $p \leq 0.001$, ns=non significant

Nitrogen applications increased boll weight in both years. With N-125 boll weight was higher by 7% in 2008 and by 10% in 2009 than for N-0. With N-125 to N-250, boll weight increased only by 3% in 2008, while it was increased by 15% in 2009. Plant height was not affected by tillage and N level ($p>0.05$) in 2008, while significant ($p=0.03$) interaction effects between tillage and N were observed in 2009 (Table 3.4).

Table 3.3 Main effects of tillage and N level on boll weight, boll density, percent open boll and plant height of cotton in 2008 and 2009.

Treatment	Boll weight first picking (g)		Boll weight third picking (g)		Boll density (m^{-2})		Open boll at defoliation (%)		Plant height (cm)	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
Tillage										
BP	6.3	5.5	5.9	4.7	69	76	28	27	92	91
CT	6.2	5.4	5.6	4.7	68	71	43	41	93	92
LSD (0.05)	0.2	0.5	0.2	0.6	5.8	22	10.8	16.5	6.6	8
Nitrogen										
0	5.9	4.8	5.4	4.3	62	45	46	45	88	80
125	6.3	5.6	5.8	4.4	74	83	31	36	94	97
250	6.4	6.1	6.1	5.4	71	94	28	22	95	97
LSD (0.05)	0.3	0.35	0.4	0.5	9	12.6	12	7.6	7	5.2
					ANOVA					
Tillage (T)	ns	ns	**	ns	ns	ns	*	+	ns	ns
Nitrogen (N)	*	***	**	**	*	***	**	***	ns	***
T x N	ns	ns	ns	ns	ns	ns	ns	*	ns	*
LSD (0.05)	0.4	0.55	0.48	0.75	11	22	15.6	15.4	9	7.3
Mean	6.2	5.5	5.8	4.7	68.7	74	35.4	34	92	91.4

BP=bed planting, CT=conventional tillage. +*P* ≤0.1, **P*≤0.05, ***P*≤0.01, *** p≤0.001, ns=non significant

Table 3.4 Interaction effects between tillage method and N level on harvest index, plant height, and percent open bolls of cotton in 2009.

Tillage	Nitrogen (kg ha^{-1})	Harvest index (%)	Percent open boll at defoliation (%)	Plant height (cm)
BP	0	42	43	76
	125	35	29	96
	250	30	9	100
CT	0	37	46	84
	125	40	44	98
	250	37	34	94
LSD (0.05)		6.3	15.4	7.3

BP=bed planting, CT=conventional tillage

In both years, 35% of the bolls opened prior to defoliation. In 2008, the share of opened bolls was significantly affected by tillage and N level (Table 3.3). Irrespective of the N level, under CT 52% more (p=0.02) bolls opened than in BP. Percent open bolls decreased with N applications and was lower (p<0.05) by 33% with N-125 and by 39% with N-250 compared to N-0. The difference in the number of opened bolls between N-125 and N-250 was non-significant. In 2009, a significant interaction effects (p=0.03) between tillage and N level was observed for the percentage of opened bolls. The number of opened bolls was higher (p=0.03) under CT than in BP with N applications, but there was no significant effect in the N-0 treatments (Table 3.4).

3.3.4 Relationship between soil mineral N (residual plus applied N) and yield

Tillage had no effect on the relationship between cotton yield and soil mineral N content (residual mineral N plus applied N) (Figure 3.3). The combined data for 2008 and 2009 show that to obtain about 4500 kg raw cotton yield ha^{-1}, nearly 300 kg available mineral N ha^{-1} in the top 90 cm soil profile (either from residual soil N or applied N) was required under both tillage methods. However, cotton yield increased linearly with available soil N until 200 kg and then tapered off. Hence, any N added above 150 kg ha^{-1} (assuming that about 50 kg are residual) does not lead to the same relative effect on cotton yield.

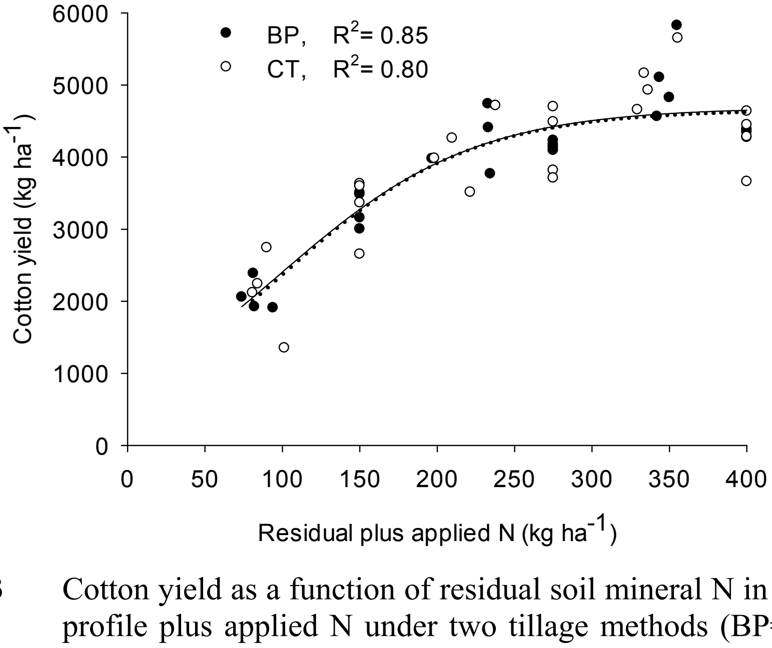


Figure 3.3 Cotton yield as a function of residual soil mineral N in the top 90 cm soil profile plus applied N under two tillage methods (BP=bed planting and CT=conventional tillage). Curve fit is sigmoid, 3 parameters.

3.3.5 Plant N concentration and uptake

Plant N concentration increased with N application in both years (Figure 3.4). With the same amount of AGB accumulation, cotton plants with N-0 had a lower N concentration than plants fertilized with N-125 and N-250 after accumulation of more than 2 t ha^{-1}

AGB in both years. In 2008, due to high initial residual soil mineral N, plant N concentration did not increase when N was increased from N-125 to N-250, while in 2009 the concentration was higher with N-250 than with N-125 (Figure 3.4). A similar response to N was recorded for cotton yield and AGB production (Table 3.2).

Averaged over N application rates, aboveground plant N uptake before flowering (i.e., before irrigation and fertilizer application) was higher ($p<0.05$) under CT than in BP in both years (Table 3.5). This increased N uptake coincided with the faster early growth and higher biomass production during the early stage under CT (Figure 3.2). After flowering, N uptake was not affected by tillage methods in 2008, while in 2009; N uptake was significantly higher in BP than under CT. A significant interaction effect between tillage and N level was observed in total N uptake at maturity in 2009. With N-250, BP showed 56% higher N uptake than CT, while with N-0 and N-125, tillage had no significant effect (Figure 3.5A).

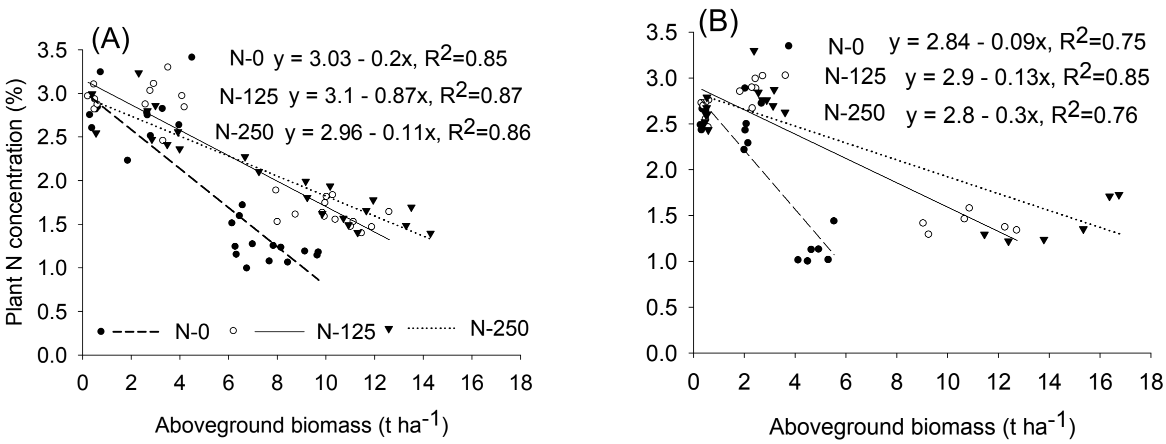


Figure 3.4 Relation between plant N concentration (%) and aboveground biomass (t ha^{-1}) of cotton at three N levels, i.e., N-0, N-125 and N-250 kg ha^{-1} (A) in 2008 (N=25); (B) in 2009 (N=18)

Table 3.5 Main effects of tillage method and N level on total N uptake at different growth stages of cotton during 2008 and 2009.

Treatment	Budding		Flowering		Boll formation	Maturity	
	2008	2009	2008	2009	2008	2008	2009
Tillage					(kg ha^{-1})		
BP	12	11.6	71	61	145	174	160
CT	17	13.7	87	64	132	181	128
LSD (0.05)	2.8	1.3	20.4	17.2	77.5	22.5	35.5
Nitrogen (kg ha^{-1})							
0	12.9	10.7	71.3	52.2	90	118	58
125	13.6	13.3	88.5	64.3	155	203	161
250	15.4	13.9	77.6	72.1	170	212	213
LSD (0.05)	4.9	2.2	20.9	12.8	20.3	26.9	30.2
			ANOVA				
Tillage (T)	**	*	+	ns	ns	ns	+
Nitrogen (N)	ns	*	ns	**	***	***	***
T x N	ns	ns	ns	ns	0.09	ns	**
LSD (0.05)	5.7	2.6	25.5	16.9	61.8	33.9	38.4
Mean	14	11	79	63	138	177	144

BP=bed planting, CT=conventional tillage. +$P \leq 0.1$, *$P \leq 0.05$, **$P \leq 0.01$, *** $p \leq 0.001$, ns=non significant

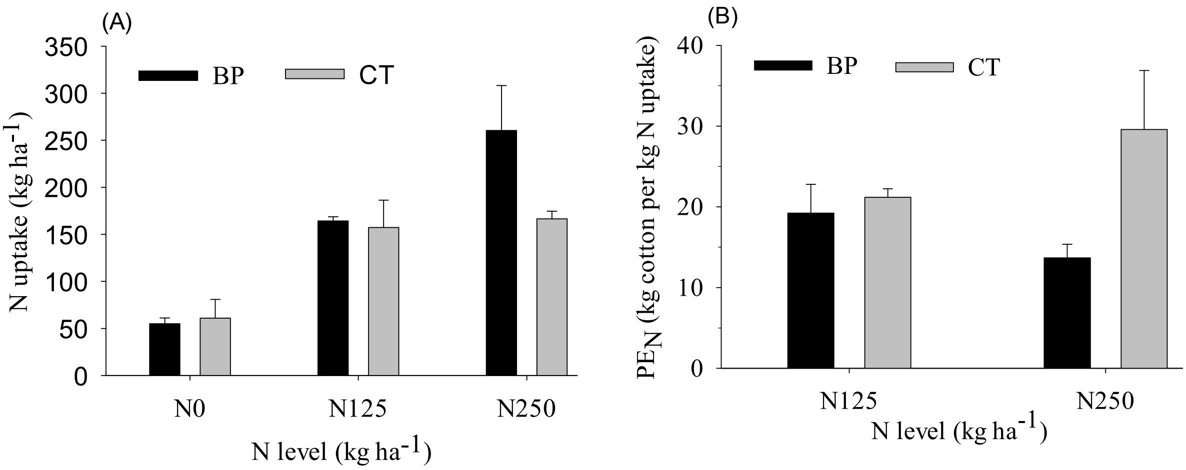


Figure 3.5 Interaction effects between two tillage (BP=bed planting and CT=conventional tillage) and three N levels (0, 125, 250 kg ha^{-1}) on (A) N uptake (kg ha^{-1}) and (B) physiological N use efficiency (PE_N) of cotton in 2009. Bars represent standard error.

3.3.6 Nitrogen use efficiency

All N use efficiency values were significantly higher in 2009 than in 2008. The average agronomic N use efficiency (AE_N) was 5.5 and 14.1 kg cotton per kg N applied in 2008 and 2009, respectively (Table 3.6). Tillage did not affect (p>0.05) AE_N. However, AE_N significantly decreased (p<0.05) with increased N level in both years, by 42% in 2008 and by 30% in 2009 with N-125 to N-250.

Table 3.6 Main effects of tillage and N level on agronomic N efficiency, physiological N efficiency, and apparent recovery N efficiency of cotton in 2008 and 2009.

Treatment	Agronomic efficiency		Physiological efficiency		Recovery efficiency	
	2008	2009	2008	2009	2008	2009
Tillage	(kg cotton kg^{-1} N applied)		(kg cotton kg^{-1} N uptake)		(%)	
BP	5.6	14	10.5	16.4	56.5	84.8
CT	5.4	14.3	11.9	25.4	50.3	59.5
LSD (0.05)	5.3	7.8	11.6	13.5	50	31.7
Nitrogen						
125	7.0	16.6	10.3	20.2	68.3	82.2
250	4.0	11.7	13.3	21.6	38.1	62.2
LSD (0.05)	2.4	5.1	4.8	6.6	20	23
ANOVA						
Tillage (T)	ns	ns	ns	ns	ns	+
Nitrogen (N)	*	*	ns	ns	**	+
T x N	ns	ns	ns	*	ns	ns
LSD (0.05)	4.9	6.5	10.7	10.7	50	27
Mean	5.5	14.1	11.2	20.9	53	70

BP=bed planting, CT=conventional tillage. +*P* ≤0.1, **P*≤0.05, ***P*≤0.01, *** p≤0.001, ns=non significant

The average apparent N recovery efficiency (ARE_N) was 53% in 2008 and 72% in 2009. Tillage did not affect the ARE_N in 2008, while in 2009 AER_N was 42% higher in BP than under CT. It also decreased with increased N level, i.e., by 44% in 2008 and by 24% in 2009 with N-125 to N-250.

Tillage and N level had no significant effect on physiological N use efficiency (PE_N) in both years, while a significant interaction effects between tillage and N level was observed in 2009. In 2009, BP with N-250 showed a 54% lower (p<0.05) PE_N than CT with N-250, while with N-125, tillage had no significant effects (Figure 3.5B).

3.3.7 Apparent N balance

A significant year effects was observed for apparent N balance. The average apparent N balance was positive, i.e., 10 kg ha^{-1} in 2008, while it was negative, i.e., -36 kg^{-1} in 2009. Tillage did not affect (p>0.05) the apparent N balance in 2008, while in 2009, BP had a higher negative balance than CT (Table 3.7). Nitrogen applications led to a significantly higher N balance compared to N-0 in both years. In 2008, the highest ($p<0.05$) positive N balance (+99 kg N ha^{-1}) was observed with N-250, while the N balance with N-125 (-19 kg N ha^{-1}) and N-0 (-50 kg N ha^{-1}) was negative.

In 2009, a significant interaction effects between tillage and N level was observed for the apparent N balance. With N-0 and N-125, tillage had no effect on the apparent N balance and was even negative with both tillage methods. In contrast, with N-250, CT showed a positive N balance (+42 kg ha^{-1}), while it was negative for BP (-29 kg ha^{-1}) (Table 3.7).

Table 3.7 Interaction effects between tillage and N level on total input, total out put and apparent N balance of cotton at maturity in 2008 and 2009.

Tillage	Nitrogen level	Apparent N balance 2008	Apparent N balance 2009	Total input 2008	Total input 2009	Total output 2008	Total output 2009
		(kg ha^{-1})					
BP	0	-40	-60	154	87.6	194	148
	125	-20	-44	279	234	299	277
	250	96	-29	404	353	308	383
CT	0	-59	-61	154	96	214	157
	125	-18	-64	279	221	297	285
	250	102	42	404	343	302	301
		ANOVA					
Tillage (T)		ns	***	-	ns	ns	+
Nitrogen (N)		***	**	-	***	***	***
T x N		ns	*	-	ns	ns	**
LSD (0.05)		41	37	-	20	41	36
Mean		10	-36	280	222	269	258

BP=bed planting, CT=conventional tillage. $+P \leq 0.1$, $*P \leq 0.05$, $**P \leq 0.01$ *** $p \leq 0.001$, ns=non- significant

3.3.8 System apparent N balance

In the cotton/cover-crop/cotton rotation system, system N input was 411 kg ha^{-1}, N output was 437 kg ha^{-1} and apparent N balance was -26 kg N ha^{-1} (Table 3.8). Total N input was the same for both tillage methods. A significant interaction effects was observed between tillage and N for the total N output. BP with N-250 had a higher ($p<0.05$) N output (597 kg N ha^{-1}), which was 78 kg N ha^{-1} higher than CT with the same N level (data not shown).

Table 3.8 Main effect of tillage and N on mineral N at harvest, total input, total out put and apparent N balance of cotton/cover-crop/cotton rotation system.

Treatment	Soil mineral N on top 90 cm, at harvest		Total N uptake			Total input	Total output	Apparent N balance
	2008	2009	Cotton 2008	Cover crop	Cotton 2009			
Tillage	(kg ha^{-1})							
BP	93	64	174	45	160	411	444	-33
CT	90	74	181	45	128	411	430	-19
LSD (0.05)	21.9	9.9	22.5	-	35.5	-	19.7	19.7
Nitrogen								
0	86	65	118	30	58	161	269	-108
125	95	68	203	53	161	411	484	-73
250	93	75	212	53	213	661	558	103
LSD(0.05)	13	9.5	26.9	-	30.2	-	44.7	44.7
ANOVA								
Tillage (T)	ns	*	ns		+	-	+	+
Nitrogen	ns	+	***		***	-	***	***
T x N	ns	ns	ns		**	-	*	*
LSD (0.05)	22	11.8	33.9		38.4	-	52.1	52.1
Mean	92	69	178		144	411	437	-26

BP=bed planting, CT=conventional tillage. +$P \leq 0.1$, *$P \leq 0.05$, **$P \leq 0.01$, *** $p \leq 0.001$, ns=non significant

The apparent system N balance was negative with N-0 and N-125, but positive with N-250 with both tillage methods. Irrespective of N level, BP had a 73% higher negative N balance than CT. A significant interaction effects between tillage and N level was observed where, with N-0, CT had a 32% higher negative N balance than BP. With N-250, CT had a significantly higher positive N balance (+142 kg N ha^{-1}), which was more than twice as high (66 kg ha^{-1}) as for BP (Figure 3.6).

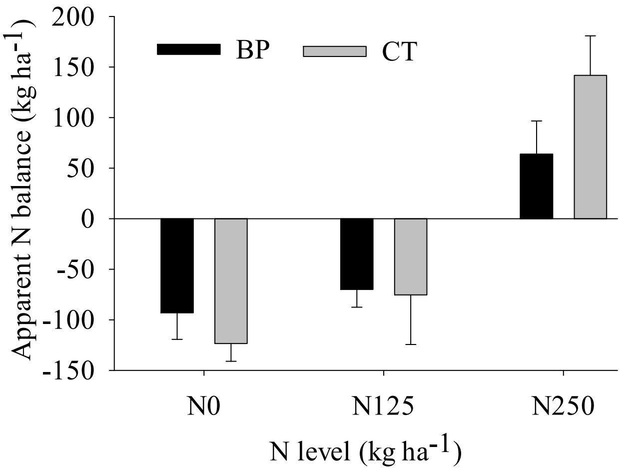


Figure 3.6 Interaction effects between tillage (BP=bed planting and CT=conventional tillage) and N level (0, 125 and 250 kg ha^{-1}) on apparent system N balance (kg ha^{-1}) in cotton/cover-crop/cotton rotation. Bars represent standard error.

3.3.9 Soil organic carbon

The average soil organic carbon (OC) content in the experimental field was less than 0.40% which is considered as very low according to the FAO soil classification. Averaged over tillage method and N level, it was significantly higher ($p<0.05$) in October 2009, i.e., after inclusion of the cover crop in the system, than at the other sampling dates in October 2008 and March 2008 at all soil depths. In contrast, in the top 30-cm soil depth in October 2008 it decreased significantly by 15-20% compared to the initial level. A significant interaction effects between soil depth and sampling dates was observed (Figure 3.7). Averaged across the treatments and sampling dates, soil organic C decreased with soil depth.

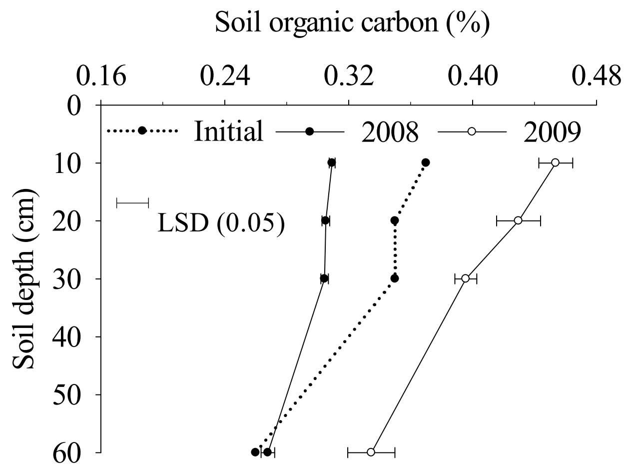


Figure 3.7 Soil organic carbon (%) averaged across treatments over time at different soil depths. Bars represent standard error.

3.4 Discussion

3.4.1 Cover crop and groundwater NO_3-N concentration

In salt-affected irrigated drylands, other studies have shown that nitrate leaching losses from the root zone and recharge of shallow groundwater occur primarily during winter months, due to low evapotranspiration and heavy use of irrigation water for salt leaching (Staver and Brinsfield 1998). Winter cover crops can reduce NO_3-N leaching and improve groundwater quality by influencing the water budget, affecting the soil NO_3-N content (Meisinger et al. 1991).

Although there was no separate cover crop treatment, the groundwater NO_3-N concentration at the beginning of the cotton season in 2009 was low compared to 2008. This could be due to the wheat as a cover crop in 2009. The winter cover crop could have reduced NO_3-N leaching to the groundwater primarily through N uptake. A reason could, also be the avoidance of early spring salt leaching as has been suggested in the other regions (Weinert et al. 2002; Huntington et al. 1985; Shipley et al. 1992). In the present study the cover crop assimilated about 50 kg N ha^{-1} from the soil before cotton seeding. This indicates that the inclusion of a winter cover crop in a cotton-cotton rotation may reduce the groundwater NO_3-N contamination. Likewise, Touchton et al. (1995) reported that the use of winter cover crops can reduce N leaching potential and degradation of groundwater quality. For instance, after seven years of cover crop use under continuous corn production, the groundwater NO_3-N contents decreased from 10-20 mg l^{-1} to less than 5 mg l^{-1} in shallow groundwater areas of the mid-Atlantic coastal plain (Staver and Brinsfield 1998). Since the study covered only the first two seasons of a long-term trial, further research results will have to confirm if the initial effects of the cover crops on groundwater NO_3 contamination are sustained.

3.4.2 Cotton growth yield and yield components

Effect of tillage

No difference between BP and CT with respect to raw cotton yield was observed in either year (Table 3.2). In 2008, this could be due to good field preparation, which could have helped avoiding the usually expected temporary reduction in yield when changing from conventional to conservation practices (Hicks et al. 1989; Boquet et al. 2004; Tursonov 2009). Despite the faster initial growth of cotton under CT, after fertilizer and irrigation applications, growth rates in BP surpassed those in CT, but later these differences became insignificant. After the field was ploughed several times and laser-leveled, the beds were freshly prepared, resulting in lower soil moisture contents in BP compared to CT. Volumetric moisture in top 10 cm soil during cotton sowing was $10 \pm 1\%$ in BP and $13 \pm 0.5\%$ in CT. The resulting lower soil moisture perhaps delayed germination and initial growth in BP by 3-5 days. The comparatively faster growth in BP after budding could be due to less soil compaction since field traffic was reduced and less root injury had occurred. For the Khorezm region, Tursonov (2009) reported that, due to effective field preparation, there was no yield reduction in cotton during the transition season from conventional to conservation agriculture.

The absence of differences in raw cotton yields between BP and CT especially in 2009 suggests that cotton can be planted on permanent raised beds without yield reduction. The cover crop may have been an additional element creating a more favorable environment for seed germination and stand establishment in BP, which in turn may have led to equal yields in BP and CT. The consistently better growth in BP with N applications can be attributed to a more evenly distributed N mineralization over the entire growing season, while under CT where the field was ploughed, a flush of N mineralization likely occurred following cultivation. This hypothesis is supported by the comparatively higher mineral N content with N-250 under CT at budding (60 DAS) than in BP in 2009. In contrast, at later stages, i.e., flowering and maturity, the mineral N content did not vary between the tillage treatments (Figure 3.8). Francis and Knight

(1993) reported that a flush of N mineralization occurs following cultivation prior to the onset of rapid early crop growth under CT, while under conservation tillage mineralization is more evenly distributed over the growing season. This further supports the hypothesis in this study. Also, Keeling et al. (1989) concluded this after recording similar cotton yields in conventional and conservation tillage practices while including a winter wheat cover crop. The findings from this short-term study suggests that cotton can be cultivated on permanent raised beds without yield differences compared to CT using a winter cover crop in rotation. However, it is important to assess whether the growth and active termination of the winter cover crop is also a financially feasible practice, since the cover crop cultivation and termination demand additional expenses. The present results indicate that these costs are not recovered by higher yields but perhaps compensated for by the reduced cost of using BP in general.

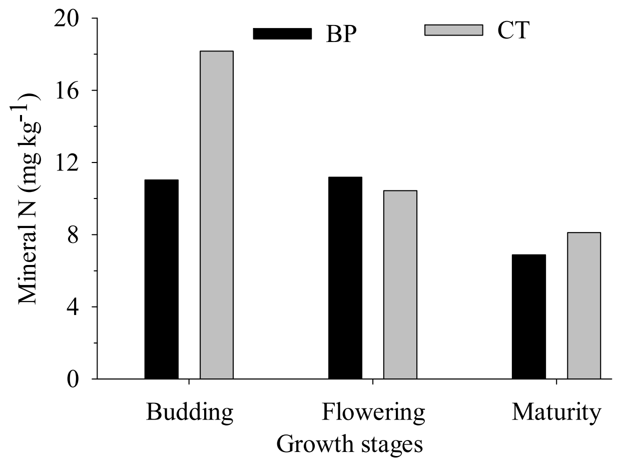


Figure 3.8 Mineral N content in top 30 cm soil under bed planting (BP) and conventional tillage (CT) at different growth stages of cotton with 250 kg N ha^{-1} in 2009.

Effect of nitrogen

Increased cotton growth (Figure 3.2), yield, yield components (Table 3.2), and plant N concentration (Figure 3.4) with N application under both tillage methods indicates that cotton yield in both tillage types can be increased with N application. The higher cotton yields with N applications compared to N-0 were mostly due to an increased boll density and increased boll weight (Table 3.3) which have been previously suggested as the major yield determining components for cotton (Pettigrew and Jones 2001; Wiatrak et al. 2005). Obviously, N applications increase the photosynthesis rates leading in turn to a higher accumulation of metabolites and thus higher boll weight.

In 2009, cotton yield was doubled with N-125 compared to N-0, but with the addition of another 125 kg N (double the farmer's investment) the relative gain was much lower (Table 3.2). Thus, it is not worth investing in 250 kg N ha^{-1} during the transition period from CT to BP under such soil and climatic conditions. Obviously, the effect of the amount of N applied depended on the initial soil mineral N content as indicated by the lower response of applied N in 2008 than in 2009. Also, there was a linear increase in cotton yield with the available soil mineral N until 200 kg ha^{-1}, which then it tapered off. Therefore, every kg of N added above 150 kg (assuming that about 50 kg N are residual) does not lead to the same relative effect. The effect of applied N was not so marked in 2008, where the raw cotton yield of the N-0 treatments was on average only 25% less than that of the N-125 and N-250 treatments; and there was also no further yield increment from N-125 to N-250 (Table 3.2). This could be due to the relatively high residual mineral N content in the soil, which was apparently sufficient to compensate for the absence of N fertilizer applications. Since the experimental field had previously been cropped with heavily fertilized cotton for virtually 20 years, the initial soil N analyses revealed nearly 135 kg residual mineral N ha^{-1} in the top 90 cm soil profile (Table 2.1). However, in 2009 only about 40-50 kg residual mineral N was available before cotton planting. This is related to the comparatively low mineral N during the cotton harvest in 2008 (92 kg N ha^{-1}) (Table 3.8) and also to the N uptake by the cover crop (50 kg N ha^{-1}) from harvest to before cotton planting.

The average yield of cotton under the recommended N application of 180 kg ha^{-1} in the study region is 2.7 t ha^{-1} (Statistical Department of Khorezm 2009). Even with the application of a lower than recommended N rate, i.e., 125 kg ha^{-1}, the average yield in both years was higher by 53% than the average yields observed in this region during the same periods. The yield increase could have been caused by a number of factors, not the least being the laser-leveling of the field prior to the establishment of the experiment. Previous studies had reported increased crop yields under laser-leveled fields compared to traditionally leveled fields (Tyagi 1984; Jat et al. 2003). The laser-leveled field reduces the water logging in low-lying areas and the soil water deficit at higher spots, which leads to uniform soil moisture distribution which results in good germination; it enhances input use efficiency and crop yields (Jat et al. 2006).

3.4.3 Nitrogen uptake and use efficiency

The AE_N and ARE_N were not significantly affected by tillage methods, although the values significantly decreased with increasing N rates in both years. The efficiency of the applied N decreases with an increased rate of N application because other factors usually become limited (De Wit 1992). Yet, this alone cannot explain the low N use efficiency in 2008. In addition, the high initial residual soil mineral N contents at the onset of the experiment in 2008 had decreased the applied N fertilizer response. Likewise, Rochester et al. (2001) reported that higher inherent mineral N reduced the reliance of the cotton crop on applied N fertilizer. This indicates that before applying N fertilizer, the residual soil mineral N need to be considered to increase its efficiency, hence it minimizes the N loss to the environment.

In a study by Kienzler (2010), the AE_N in the study region under CT with 180 kg N ha^{-1} was 4-8 kg cotton kg^{-1} N, which was near the AE_N in 2008 in the present study, where AE_N was 7 and 4 kg kg^{-1} with N-125 and N-250 kg ha^{-1}, respectively. In contrast, during 2009, AE_N increased and was 17 and 12 kg kg^{-1} with N-125 and N-250, respectively. This could be due to the lower initial residual mineral N in the soil profile, where a winter cover crop before cotton had taken about 50 kg N ha^{-1} from the soil. This N absorbed by the cover crop may have been available to the cotton crop at a later stage. This indicates that introducing a winter cover crop could increase N use efficiency of applied N in irrigated cotton-cotton systems.

The higher ARE_N under BP in 2009 than under CT is related to higher total N uptake in BP, which was 25% higher during maturity (Figure 3.5A). This increased N uptake particularly at this stage is related to the increased LAI and AGB accumulation in BP compared to CT (Figure 3.2). The increased LAI and AGB accumulation with N applications has been attributed to an increased root biomass. For example, Weston and Zandstra (1989) as well as Garten and Widders (1990) postulated that an increased LAI and AGB in BP with N-250 after flowering could have triggered root growth due to N fertilization. Slow release of mineral N on top 30 cm soil during initial stage of cotton growth in BP (Figure 3.8) may have forced the plants to increase the rooting depth for nutrient uptake. As a result, cotton root in BP could have reached deeper soil layer compared to CT. Sainju et al. (2005) also observed that cotton root biomass increased more strongly under conservation tillage with 60 kg N ha^{-1} than under CT with 120 kg N ha^{-1} application. However, rooting depth was not measured throughout the study period, it can be neither confirm nor reject this postulation.

Significantly lower PE_N with N-250 in BP than under CT during 2009 could be due to increasing LAI and AGB in BP even at the time of defoliant application, which may be the reason why there was no increase in raw cotton yield. A significantly lower number of open bolls and increasing biomass accumulation and LAI at the time of defoliant application in BP with higher N application than under CT indicated that cotton was still actively growing. It also suggests that the growth duration of cotton in BP with higher N application tends to be longer than under CT. To reap the potential yield benefit from BP, cotton planting should either be earlier than under CT or short-duration cotton varieties should be introduced.

3.4.4 Apparent N balance

The greater positive N balance (N loss) with high N application in 2008 than in 2009 could be, as explained above, due to the higher initial residual mineral N in the soil profile that could have reduced the crop uptake of applied N. The applied N may have been lost either through gaseous loss to the environment or leaching to the groundwater. A previous study in the region under a conventional system showed that about 40% of applied N could be lost through denitrification (Scheer et al. 2009). In contrast, the decrease in the positive N balance with a high N application in 2009 could be due to the presence of the cover crop, which had taken about 50 kg N ha^{-1} during the winter. This N might have become available to the following cotton crop. The slightly negative N balance (-29 kg ha^{-1}) observed in BP with N-250 could be related to an increased LAI and AGB production after flowering, which could also have increased N uptake in the later stage.

A greater negative N balance with N-0 and N-125 than with N-250 under both tillage methods could have been caused by various factors. Firstly, the cotton plants may have taken N from the decomposed cover crop and the fallen cotton leaves, which was not accounted for during the N balance calculation. Yet, previous findings showed that the rapidly increasing spring temperatures, adequate soil moisture, low soil organic matter and well drained soils favor a rapid accumulation of inorganic N during cover crop decomposition (Weinert et al. 2002). Malpassi et al. (2000) quantified that even up to 55% of the N contained in the roots of a spring-terminated cereal cover crop became available to the following crop.

A second reason for the negative N balance could be the ammonium concentrations in the irrigation water. Although not regularly measured, the occasional recordings showed a concentration of 4-5 mg NH_4-N l^{-1}. These amounts were not included in the N balance accounting, but indicate that irrigation may have added even more N to the soil. Although only irregularly measured, the available data indicated that at least 36 kg N ha^{-1} was added via the irrigation water. When taken this into account, the averaged N balances in the system could be almost equalized.

Furthermore, the groundwater could have been an additional source of NO_3-N as previously postulated by Kienzler (2010). In particular since the groundwater levels were relatively shallow during the study period, i.e., 1.4 m in 2008 and 0.9 m in 2009. The measured NO_3 concentration in the groundwater throughout the cotton growing period (budding to boll maturation) varied from 4-10 mg l^{-1} (Figure 3.1). Thus, it is not unlikely that groundwater at least at some stages may have contributed to satisfy crop NO_3-N demand. Kienzler (2010) estimated that groundwater NO_3 contribution to cotton grown under shallow groundwater conditions and a content of 8 mg l^{-1} NO_3 concentration, contributed about 29 kg NO_3-N during the cotton growing season.

3.4.5 Total soil organic carbon

Continuous mono-cropped cotton over the past two decades under intensive soil tillage in the study region could be the reason for the low organic carbon in the soil. Schwab et al. (2002) reported that as a low-residue crop, cotton, grown continuously for a long time as mono-crop, reduces the organic matter content in soil. A low carbon input in such a system is due to the sparse and stiff cotton residues, which take a longer time to release organic carbon. Furthermore, intensive soil tillage in the irrigated system could lead to a high mineralization of the soil organic matter, and as a result low organic carbon in the soil.

The significantly increased soil organic carbon in October 2009 compared to the other sampling dates could be due to the cover crop in the system. This may have increased the carbon inputs and soil organic carbon compared to bare fallow. This in turn suggests that growing cover crops in irrigated mono-crop cotton has the potential to increase carbon sequestration and improve soil quality. Likewise, Sainju et al. (2007) reported that an introduction of a winter cover crop in a mono-cropped cotton rotation increased the carbon inputs and soil active carbon fraction compared with bare fallow in two years of study under irrigated cotton in southern Georgia, USA. The significantly lower organic carbon in October 2008 than in the initial soil may thus be due to intensive soil tillage and laser leveling followed by deep ploughing, which may have destroyed the soil structure led to the low organic carbon content.

Several studies have shown improvements in soil quality in conservation tillage over time. For example, available organic carbon and total N were found to be higher in long-term conservation tillage than in short-term (Omonode et al. 2006). This could be why there was no difference in yield and soil quality (organic carbon) in the BP and CT treatments in this study. However, the increase in soil organic carbon with the winter cover crop in both tillage treatments could be due to the faster decomposition of root biomass in BP and shoot biomass decomposition in CT, where the cover crop was incorporated. As the present study is based on two years only, further research could explain the long-term affect of cover crop on soil organic carbon under conventional and conservation tillage practices.

3.5 Summary and conclusions

The findings show that in irrigated areas, cotton can be planted after cotton in permanent raised beds without reducing yield or biomass production compared to the conventional tillage system. Thus, cotton cultivation does not require intensive soil tillage, and reducing tillage can minimize the negative effects associated with intensive soil tillage in irrigated drylands.

The similar cotton yields at different N levels under both tillage methods in this study indicate that during the transition period, the necessary N level for irrigated cotton does not differ between conventional and conservation tillage methods. The cotton yield response to increased N application from N-125 to N-250 decreased in both study years, and also the linear increase in cotton yield up to 200 kg mineral N and beyond this N level the relative increment decreased. Thus it is not worth investing in 250 kg N instead of 150 kg N ha^{-1} during the transition period from CT to BP under such soil and climatic conditions. However, higher leaf area and biomass production, lower negative N balance (loss), higher N recovery efficiency but lower physiological N use efficiency together with lower number of open bolls during first picking is observed with high-N (N-250) application in BP than in CT. This shows the possibility to further yield benefits from the permanent raised beds with high-N application by advancing cotton seeding a few days compared to the present planting time with CT practices.

The introduction of a winter cover crop in cotton mono-cropping systems can increase the efficiency of applied N and reduce the NO_3-N concentration in the groundwater. It also seems to improve soil organic carbon.

Thus, if cotton mono-cropping is to be maintained, its cultivation on permanent raised beds combined with a winter cover crop and N applications rates of ~150 kg N ha^{-1} could be a suitable option for sustainable cotton production in the salt-affected irrigated drylands of Uzbekistan.

4 THE IMPACT OF NITROGEN AMENDMENTS ON GROWTH AND WATER PRODUCTIVITY OF IRRIGATED COTTON, WINTER WHEAT AND MAIZE UNDER CONSERVATION AND CONVENTIONAL AGRICULTURE

4.1 Introduction

Irrigated agriculture makes a substantial contribution to world food security by providing 40% of the global agriculture production from just 20% of the total cultivated land. The demand for irrigation water is expected to grow significantly in the near future. For example, the FAO (2002) predicted that in order to meet the food demands of the growing population in developing countries, their irrigated area needs to be expanded from the 202 million ha in 1999 to 242 million ha by 2030. Irrigation water is particularly important in semi-arid climate conditions, where potential evapotranspiration always exceeds precipitation. Over 80% of Central Asia is arid and sustaining the agricultural production system is most important for food security, employment, livelihoods and environmental protection in the irrigated drylands of this region.

Cotton, wheat and maize are the major commercial and food crops grown in the five Central Asian counties (FAOSTAT 2010), often as mono-cultures on large areas using conventional agriculture practices. Intensive soil tillage, poorly managed flood irrigation and excessive use of chemical inputs are the typical for the conventional land use practices. These practices not only increasing production costs, but also reducing soil fertility, increasing soil salinity and threatening the sustainability of crop production systems in the irrigated drylands of Uzbekistan, Central Asia. Yields of the major crops in Central Asia, Uzbekistan, are reportedly one third of the yields elsewhere with the application of only half the amount of irrigation water has been reported by Vlek et al. (2001). Also, the previous findings confirmed that nitrogen (N) use efficiency in such conventional production systems is rather low, i.e., 33% (Kienzler 2010).

Conservation agriculture (CA) practices that imply reduced tillage, proper crop rotation, and retention of optimal level of crop residues have been adopted by farmers on more than 100 million ha world wide as of 2008 (Derpsch and Friedrich 2009).

Conservation agriculture is predominantly practiced in North and South America, but increasingly also in Australia, South Africa, and in semi-arid areas of the world (Holland 2004). Among the various CA practices, minimum tillage is considered as the predominant practice worldwide (Yau et al. 2010). Minimum tillage technologies effectively minimize soil disturbance, control evaporation from soils, minimize soil erosion losses, enhance soil carbon sequestration, and reduce energy needs and thus lowers production costs (Lal et al. 2007). Crop residue is a renewable source of soil organic matter. It improves the physical, chemical and biological properties of soil (Ding et al. 2002), reduces evaporation loss of water and increases the water retention capacity of soils (Gant et al. 1992).

The use of permanently raised bed planting (BP) is gaining importance, but the technology is still rarely applied in Central Asia. Previous studies have shown that BP with residue retention can have an advantage over zero tillage and CT (e.g., Limon-Ortega et al. 2000; Sayre and Hobbes 2004; Tursunov 2009; section 3.3.3). The benefits are attributed to better irrigation management (Sayre and Hobbes 2004; Hassen et al. 2005), plant establishment (Khalequei et al. 2008; Gursoy et al. 2010), and it also increases the ability to use inter-bed cultivation for weed control (Govaerts et al. 2005). Crop production on permanent beds is 9% more energy efficient than zero tillage, 12% more efficient than annually fresh made beds and 19% more efficient than conventional practices (Rautaray 2005). It has been further estimated that the costs of cultivating with BP in Central Asia can be reduced by one third (Gupta et al. 2009). Permanent bed combined with proper rotation and residue retention in maize and wheat produced similar grain and aboveground biomass compared to zero tillage, with advanced weeding and fertilizer application practices (Govaerts et al. 2005). Besides these advantages, permanent beds have been shown to increase grain yield and water use efficiency in wheat (Sayre and Hobbes 2004; Hassen et al. 2005; Wang et al. 2004; Gupta et al. 2009) and maize (Harris and Krishna 1989; McFarland et al. 1991; Hassen et al. 2005).

Conservation agriculture is equally important in both rainfed and irrigated agriculture to conserve moisture or save irrigation water (Erenstein et al. 2008). Increasing crop water productivity is a challenge for sustainable production in irrigated agriculture. In Central Asia, water productivity in irrigated agriculture has been drastically decreasing since decades (Abdullaev and Molden 2004). The average water productivity of the cotton-growing area in the Syr Darya basin of Central Asia is about 0.37 kg m^{-3}, which is much lower than the world average of 0.60 kg m^{-3} (Abdullaev and Molden 2004). Several studies showed the potential of permanently raised beds to increase crop water productivity in irrigated agriculture (Sayre and Hobbes 2004; Hassan et al. 2005; Akbar et al. 2007).

Conservation tillage technology is especially effective when combined with a surface mulch of crop residues (Lal et al. 2007). For example, reduced tillage with crop residue retention offers great potential to increase water availability to the crop (Unser et al. 1991; Fischer et al. 2002; Wang et al. 2010) increase soil organic carbon (Lal et al. 2007 Sainju et al. 2009) and nutrient availability (Verhulst et al. 2010), and decrease soil salinity (Egamberdiev 2007; Verhulst et al. 2010). However, delayed seedling emergence and slower initial crop growth under conservation tillage with residue retention has also been reported by Tursonov (2009) and Verhulst et al. (2011). Also, the N response in conservation tillage under retained residues differs from the situation where residues have been removed. Randall and Bandel (1991) concluded that in conservation tillage with residue retention, fertilizer N rates at the onset need to be increased by about 25% to counteract the adverse effect on yield from short-term N immobilization. However, Torvert and Revert (1994) concluded that, in the long-run, N applications can be reduced under CA practices due to an increase in N uptake efficiencies caused by reduced soil traffic.

The advantages of conservation over conventional practices have been repeatedly shown for rainfed conditions (Lopez-Bellido et al. 1996; Vita et al. 2007), but there still is much skepticism about the practicability and efficiency of CA under irrigation. This is particularly true in irrigated drylands of Central Asia, where also the effects of N application, residue management, and crop rotation on crop performance, production and water productivity of major crops such as cotton and wheat are still poorly understood (Gupta et al. 2009). In the present study, growth, crop yield, and water productivity of cotton, wheat and maize in rotation under CA crop management systems were analysed, while considering reduced tillage, crop residues retention and various levels of N fertilizer application.

4.2 Materials and methods

4.2.1 Site description

In the beginning of 2008, a long-term experiment in a cotton/wheat/third crop rotation system was implemented in the Khorezm region in western Uzbekistan (60°40'44"N, 41°32'12"E; 100 m a.s.l.). The experimental field of 3 ha had been mono-cropped with cotton under heavily mechanized production conditions for more than 20 years. For details see section 3.2.1.

Similar to the experimental field for cotton/cover-crop/cotton rotation (section 3.2.1) following salt leaching in February 2008 and field preparations that included deep ploughing and laser-leveling in March 2008, cotton was sown as the transition crop[1] in May 2008 and harvested in October 2008. In this experimental field the impact of tillage, N level, and residue level on the rotation of winter wheat (October 2008-June 2009) and maize (June-October, 2009) was studied. The experimental fields under cotton/cover-crop/cotton rotation and cotton/wheat/maize rotation were adjacent to each other; hence the soil and climatic conditions were similar (for details see sections 2.3 and 3.2.1).

4.2.2 Experimental design and treatments

A three-factorial, split-plot experiment with four blocks was implemented with tillage treatments bed planting (BP) and conventional tillage (CT) as the main factor. These were combined with two residue levels (residue retained: RR and residue harvested: RH) and three N levels (no application, and less than and more than the recommended dose) as the sub-plot factors. In the RR treatments, residues from the previous crop were retained, whereas in the RH treatments all residues were removed.

The officially recommended N rate for cotton and wheat is 180 kg N ha^{-1} (MAWR 2000) and 150 kg N ha^{-1} for short-duration maize. Previous research had shown that these rates, determined decades earlier, needed to be adjusted (e.g. Kienzler 2010). Therefore, in this experiment, three N fertilizer levels were applied in the subplots, i.e., no application (N-0), less than recommended (125 kg N ha^{-1} for cotton and 100 kg N ha^{-1} for wheat and maize), and more than recommended (250 kg N ha^{-1} for cotton and 200 kg N ha^{-1} for wheat and maize). The main and subplot treatments were completely randomized (Figure 4.1). The size of the experimental subplots was 550 m^2 (11 m x 50 m)

[1] The first crop planted when changing from conventional to conservation agriculture practices

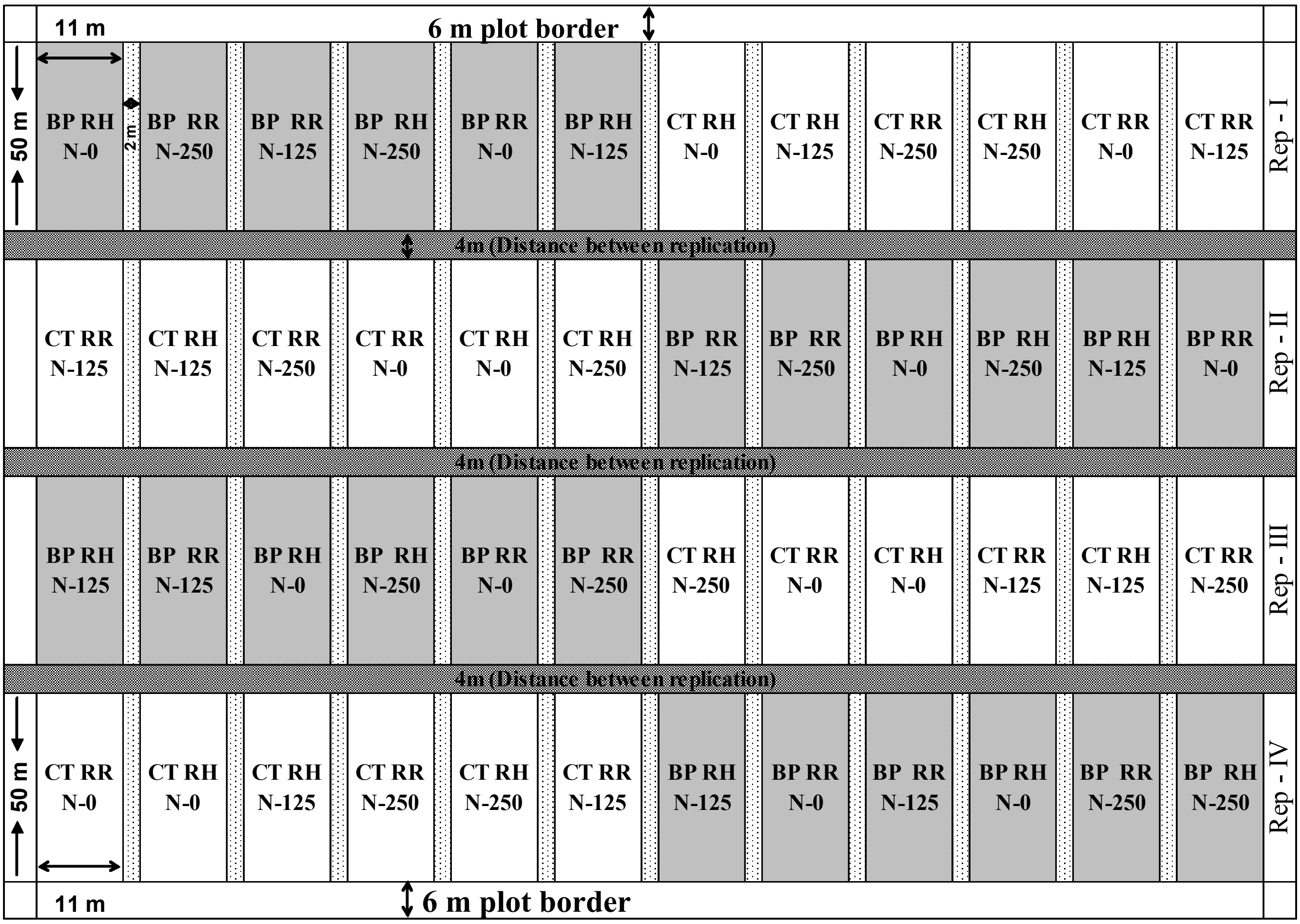


Figure 4.1 Layout of the experimental plots. BP=bed planting, CT=conventional tillage, RR=residue retention, RH=residue harvest, N-0=no N application, N-125=less than recommended N, N-250=more than recommended N application. Shaded area represents the bed planting.

Cotton planting method and time and all other crop management practices in cotton/ wheat/maize rotation were similar to those of the cotton in the cotton/cover-crop/cotton rotation in 2008 (section 3.2.3, *cotton*); a brief description is given below to make clear understanding of this chapter.

Before seeding cotton (*Gossypium hirsutum* L., cv. Khorezm 127) as a transition crop fresh raised beds were prepared with 90-cm spacing between furrows in BP. Next, cotton was seeded in the center of these beds in early May 2008 at the recommended seed rate of 60 kg ha^{-1} for each of the tillage treatments (CT and BP). Harvest occurred in October 2008. The average plant density was 45,000 plants ha^{-1}. In CT, cotton seeds were sown on flat land with the same spacing as in BP. Urea granules (a common N-fertilizer in the region) were top dressed as band application during the budding (38 days after sowing, DAS) and flowering stages (52 DAS). A defoliant (9 kg ha^{-1}

magnesium chloride dissolved in 200 l water) was applied to induce boll opening, 12 days before the first cotton picking.

Table 4.1 Field activities in bed planting and conventional tillage treatments for cotton, wheat and maize grown in rotation.

Crop	Bed planting	Conventional tillage	Time	Residue management
	Salt leaching		February, 2008	
	Deep ploughing and Laser leveling		March	
	Bed making	Flat leveling	April	
Cotton	Cotton sowing		May 6	Wheat residues at 3 t ha^{-1} applied externally during field preparation in CT and after planting in BP on residue retained treatments
	Furrow cultivation followed by band application of N fertilizer	Inter-row cultivation followed by band application of N fertilizer and furrow opened for irrigation	June	
	N application	Inter-row cultivation followed by band application of N fertilizer and furrow opened for irrigation	July	
Wheat	Drilling of wheat seed on beds without cultivation	Two cultivations and broadcast seeded wheat on standing cotton after 2nd picking	October	Chopping and spreading the cotton stalks on residue retained plots
	Wheat harvesting		Mid June	Equal distribution of wheat residue on residue retained plots
Maize	Maize sowing on bed without cultivation	Maize sowing after three cultivations and rough leveling	June 28, 2009	
	Phosphorus and potassium fertilizers were drilled at planting	Phosphorus and potassium fertilizers were broadcasted at field preparation		
	N application	N application	June	
	N application	Inter-row cultivation and N application	July	

Since crop residues from the previous crop were absent at the very onset of this long-term experiment, wheat stover was imported at a rate of 3 t ha^{-1} and equally distributed over the residue retention (RR) plots. During cotton season 29% in BP and 64% in CT of the applied wheat residues were decomposed. The cotton stalks from the previous year in these RR treatments were chopped and spread during the preceding winter. In the RH treatments, all cotton stalks were cut at ground level and removed (Table 4.1).

The beds were permanently maintained after the cotton crop. Winter wheat (*Triticum aestivum* L., cv. Krasnodar) was seeded at the recommended seed rate of 200 kg ha^{-1} on 10 October 2008 just after the 2^{nd} cotton picking and harvested on 16 June 2009. In BP, wheat was seeded in rows at a distance of 22.5 cm (4 rows on each 90-cm bed) with double disk seed openers. In CT, seeds were broadcasted manually into standing cotton after a single cultivation followed by a further cultivation to cover the seeds as is commonly practiced by local farmers. Average plant density was 400 plants m^{-2} in both tillage methods. N-fertilizer was broadcasted as urea granules in two equal splits at 172 DAS (F6 stage) and 190 DAS (F8). After the wheat harvest, stover was uniformly spread over the RR plots but removed from the RH plots.

After the winter wheat harvest, hybrid maize (*Zea mays* L., cv. Maldoshki) was sown as a summer crop at a seed rate of 40 kg ha^{-1} with 45 cm x 45 cm seed spacing on 28 June 2009, and harvested as grain on September 2009. The average plant density was 50,000 plants ha^{-1}. The seeder was equipped with a double disk seed opener for the BP treatments. In CT, maize was sown after three cultivations followed by rough leveling, whereas under BP, soil was not tilled aside from the drilling of seed and N fertilizer. In both tillage methods, urea (46% N) was top dressed as a band application at 32 and 42 DAS.

Phosphorus (P) and potash (K) at 160 and 70 kg ha^{-1} for wheat and maize and 140 and 100 kg ha^{-1} for cotton, respectively, were applied as basal applications during sowing. The P fertilizer was applied as single super phosphate (10% P_2O_5) in the N-0 treatments, whilst ammonium phosphate (AOP) (11% N or 46% P_2O_5) was applied in all other N treatments. A basic dressing of muriate of potash (60% K_2O) was applied in all plots.

4.2.3 Measurements and data collection

Irrigation water

All three crops were irrigated when needed, which was indicated by first leaf roll. Irrigation water was applied seven times during wheat and five times during cotton and maize cultivation (Table 4.2). During the cotton season, both BP and CT treatments received equal amounts of irrigation water, as both systems were furrow-irrigated. Based on the irrigation needs, wheat and maize in BP received, respectively, 11 and 23% less water than under CT (Table 4.2). Irrigation water was measured using a standard trapezoidal Cipolletti weir combined with a DL/N 70 diver, which measured the water flow through the weir based on pressure in one-minute intervals. To measure the amount of water applied, two weirs (with divers installed 40 cm in front of the weir crest) were installed. Each plot was irrigated separately, and the irrigation time during each irrigation event was recorded independently. Height of water above crest width was measured 4-5 times manually during each irrigation event. The pressure measured by the diver was transformed to height above crest (m) to estimate the discharge ($m^3 s^{-1}$) according to Kraatz and Mahajan (1975) (equation 4.1)

$$Q = 1.86\ L\ H^{\frac{3}{2}} \tag{4.1}$$

where, Q=discharge ($m^3 s^{-1}$), L=crest width (m), H=height of water above crest width (m)

Water productivity for wheat and maize was calculated as the ratio of grain yield (in kg at 12% moisture) over total water input (in m^3). Raw cotton yield was used for the estimates of water productivity in cotton.

Table 4.2 Amount of irrigation water applied (m^3 ha^{-1}) during cotton, wheat and maize growing seasons.

Cotton		Wheat			Maize		
Application time (DAS)	Amount applied for BP and CT (m^3 ha^{-1})	Application time (DAS)	Amount applied (m^3 ha^{-1})		Application time (DAS)	Amount applied (m^3 ha^{-1})	
			BP	CT		BP	CT
54	537	1	697	803	1	1555	2360
69	556	150	750	750	18	1181	1433
84	661	173	699	806	33	1213	1499
101	1350	190	582	670	43	1218	1427
115	1303	208	704	812	70	1118	1427
-	-	222	689	794	-	-	-
-	-	236	649	748	-	-	-
Total	4454	-	4770	5383	-	6285	8146

BP=bed planting, CT=conventional, DAS=days after sowing

Soil moisture

Before each irrigation event, soil was sampled at 0-10, 10-20, 20-30, 30-60, and 60-90 cm depths with a tube auger at six fixed points in each subplot for determining soil moisture content. In BP, soils were sampled both from the bed and furrow sections to obtain an average moisture level for the beds. To determine the gravimetric soil moisture content, soil samples were weight before and after drying in an oven at 105 °C for 24 h. The soil moisture content was calculated according to Gardner et al. (2001) (equation 4.2):

$$\text{Soil gravimetric moisture content } (\theta d) = \frac{\text{Wet weight - Dry weight}}{\text{Dry weight}} \tag{4.2}$$

The soil gravimetric moisture content (θ_d) was converted to volumetric moisture percent (%) by multiplying the gravimetric moisture content with the bulk density of the respective soil layers.

Leaf area and biomass

Leaf area and total aboveground biomass were recorded every 15 days for wheat and maize, but for cotton according to growth stages (i.e., 2-4 leaf, budding, flowering, boll formation and maturity). Wheat plants were sampled from a 0.25 m^2 area. For cotton and maize, five representative plants were sampled each time. Biomass was separated into green leaves, senescence leaves, stem and floral parts and oven dried at 70 °C till constant weight. The leaf area of fresh leaves was measured with a leaf area meter (Li-Cor, LI-3100) in cm^2 and converted to leaf area index (LAI, m^2 m^{-2}), i.e., leaf area per unit land area. The wheat leaf area was measured from a subsample of 25 g green fresh leaves. Total leaf area of the sample area was calculated on the basis of total dry weight of the green leaves. For cotton and maize, the whole green leaf material was used for measuring leaf area.

Yield and yield components

To measure cotton yield, a 15 m x 4 m area was delineated in each subplot, which covered the four central rows of each plot. The delineated area was harvested manually during four picks as is common practice in the region. The raw cotton yield was adjusted to 6% moisture level; the moisture level was determined with subsamples taken at each harvest after oven drying at 70 °C for 16 h. The cotton population density was determined by counting the number of plants in the harvest area on each plot. Boll density (bolls per plant), branches per plant and percentage of open bolls were determined prior to defoliation from 40 randomly selected plants (10 plants each row) in the harvest area. Next, 40 bolls were picked randomly at each picking and oven-dried to calculate average boll weight. The ginning percentage was calculated by separating the lint and seed from 200 g oven-dried raw cotton and weighed separately for each picking (equation 3.2).

Wheat was harvested from three areas in each plot, each covering 1.8 m^2 (2 beds with 1 m length). The ears were threshed and weighed. Subsamples of 150 g each of straw and grain were oven dried at 70 °C for 36 h to determine moisture content. To determine number of grains per spike and spike weight, 50 spikes were taken randomly from each plot, oven dried and weighed after which the grains were separated from the spikes, weighed and counted for each plot.

To measure maize yield and its yield components, three subplots of 4 m^2 each in each plot were harvested. Six cobs from each subplot were randomly selected to record the number of grains, cob weight, and 1000-grain weight. Ears were separated from stover, shelled, and the grain was weighed after 2-3 days of sun drying; then a subsample of 200 g was taken to determine moisture content. Stover was separated into tassel, leaf and stem, and each fraction was weighed separately fresh on-site; a subsample of each was taken and oven dried to determine the moisture content. Grain yields of wheat and maize were converted to 12% moisture content. The harvest index for each crop was calculated as a fraction of seed/raw cotton yield over total aboveground dry matter yield (equation 3.1).

4.2.4 Statistical analysis

Crop parameters, i.e., yield, yield component and water productivity for cotton, wheat and maize, were statistically analyzed as a split-plot factorial design with four replications. As no residue effect was observed for cotton growth and yield (data not shown), only the data from the residue-harvested treatments were used, for the statistical analysis of this crop. Crop growth and soil moisture content over time were analyzed using repeated measures. Treatment effects were compared through the analysis of variance using GenStat Discovery Edition 3. Main and interaction effects were compared using Fisher's protected LSD (least significant difference; P=0.05) unless stated otherwise. To examine associations with significant yield variation, correlation analyses were made based on treatment means. SigmaPlot version 11.0 was used for the graphical presentation.

4.3 Results

4.3.1 Crop growth and development

The leaf area development peaked at boll formation stage in cotton (102 DAS; 1.95 to 3.3 m^2 m^{-2}) (Figure 4.2), during heading in wheat (200 DAS; 0.95 to 7.8 m^2 m^{-2}) (Figure 4.3) and during silking in maize (51 DAS; 0.95 to 2.2 m^2 m^{-2}) (Figure 4.5). Nitrogen applications increased ($p<0.001$) LAI and aboveground biomass (AGB) production in both wheat and maize (Figures 4.3 and 4.5), while in cotton, an effect of N application in both tillage methods was observed only after flowering (i.e., after irrigation).

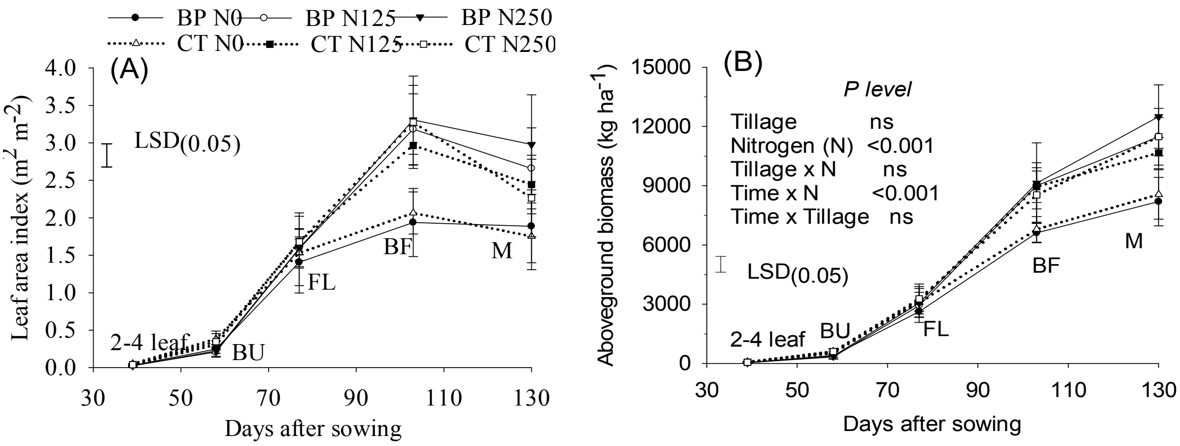


Figure 4.2 Leaf area index development (A) and aboveground biomass accumulation (B) in cotton as affected by tillage method (BP=bed planting, CT=conventional tillage) and three N applications level (0, 125 and 250 kg ha^{-1}). P level similar for A and B. P values are derived from an analysis of variance; ns=non significant. LSD is between time and nitrogen. BU=budding, FL=flowering, BF=boll formation, M=maturity. Bars represent standard error.

Irrespective of N level, LAI and AGB production in cotton was higher ($p>0.05$) under CT up to flowering than in BP (Figures 4.2A and 4.2B). However, after flowering, LAI and AGB production in BP was higher ($p>0.05$) than under CT. Nitrogen applications significantly increased LAI and AGB production only after flowering (75 DAS), resulting in 45% higher LAI and 38% higher AGB compared to N-0 at boll formation and maturity stages. There were no differences ($p>0.05$) in AGB and LAI between the N-125 and N-250 treatments.

Irrespective of time and N level, LAI and AGB production in wheat were consistently greater ($p<0.003$) under BP than in CT (Figures 4.3A and 4.3B). A significant three-way interaction effects ($p=0.01$), i.e., tillage by N by time was observed for LAI. The LAI under BP during flowering (200 DAS) was higher by 85% in N-0, 77% in N-100 and 20% in N-200 (Figure 4.3A) than in CT at the respective N levels. Similarly, AGB production under BP was higher by 41-69% in N-0, 10-20% in N-100, and 3-6% in N-200 during the different growth stages than in CT at the respective N levels (Figure 4.3B).

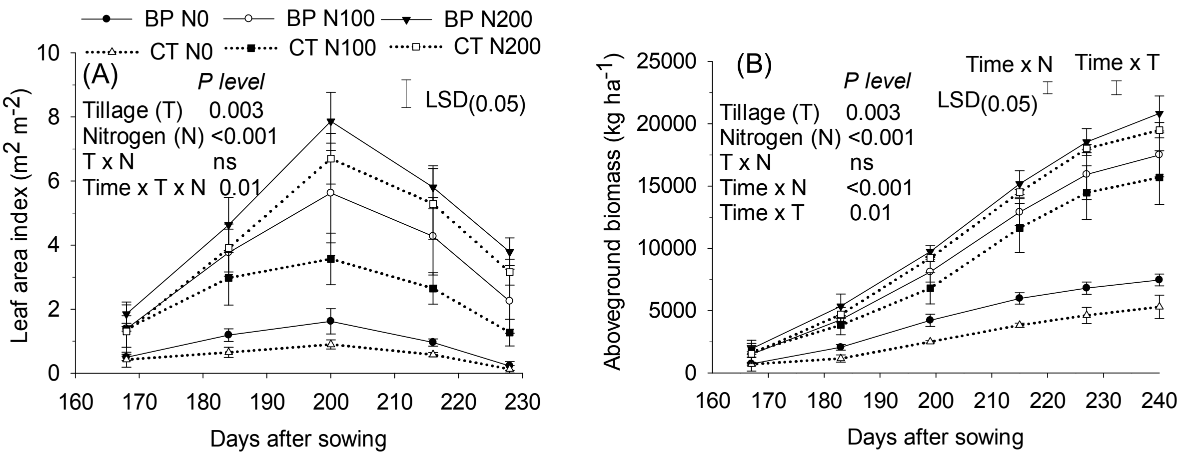


Figure 4.3 Leaf area index development (A) and aboveground biomass accumulation (B) in wheat as affected by tillage method (BP=bed planting, CT=conventional tillage) and N applications level (0, 100 and 200 kg ha^{-1}). P values are derived from an analysis of variance; ns=non significant. LSD is between (A) time, tillage and N and (B) time by N and time by tillage. Bars represent standard error.

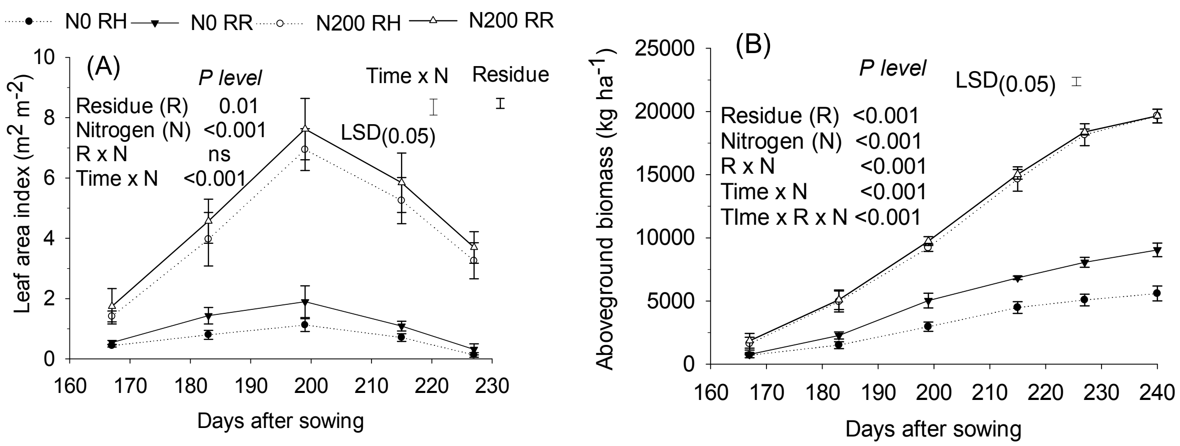


Figure 4.4 Leaf area index development (A) and aboveground biomass accumulation (B) in wheat as affected by N application level (0, 100 and 200 kg ha^{-1}) and residue management (RH=residue harvested, RR=residue retained). P values are derived from an analysis of variance; ns=non significant. LSD is between time, residue and N (A) and time by N and time by tillage (B). Bars represent standard error.

Averaged over time and N level, the RR treatment showed greater ($p<0.05$) LAI and AGB than the RH (Figures 4.4A and 4.4B). The increment was higher with N-0 compared to N-200. With N-0, RR increased ($p<0.05$) the LAI by 53-143% during the growing season compared to RH, while with N-200, increment of LAI due to residues was only 10-12%. Similarly, with N-0, RR increased ($p<0.05$) the AGB by 50-70%

compared to RH. However, RR did not affect AGB production with N-200 application (Figure 4.4B).

For maize, LAI and AGB production were significantly ($p<0.001$) affected by main and interaction effects of tillage, N and time (Figures 4.5A and 4.5B). In the BP plots, N-200 produced significantly higher LAI, AGB, and root biomass (Figure 4.7) throughout the growing season followed by N-100, while no effect of tillage was observed in N-0. In CT, the temporal curves of LAI, AGB, and root biomass were greater ($p<0.05$) with N application than with N-0. When doubling the N level from N-100 to N-200, LAI and AGB production in CT were only affected at maturity, where N-200 had a 32% higher AGB production than under N-100 (Figures 4.5A and 4.5B). In BP, RR increased ($p<0.05$) LAI by 19-21% after tasseling (40 DAS) compared to RH. Similarly, AGB production in BP with RR increased ($p<0.05$) by 28% during maturity compared to RH, while the increment was non-significant during the other growing stages (Figures 4.6A and 4.6B).

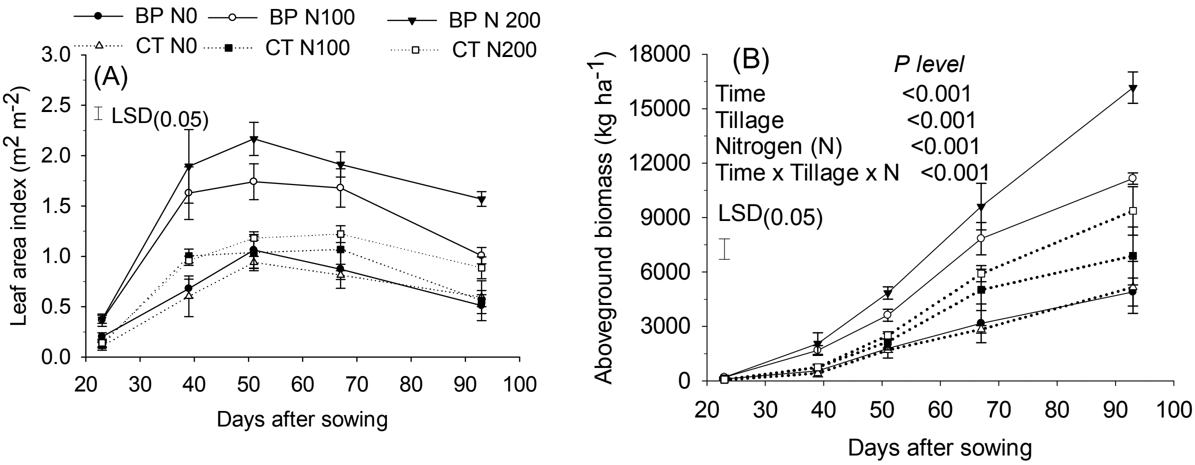


Figure 4.5 Leaf area index development (A) and aboveground biomass accumulation (B) in maize, as affected by tillage method (BP=bed planting, CT=conventional) and N application level (0, 100 and 200 kg ha^{-1}). P values derived from an analysis of variance. P level similar for A and B; LSD is the difference between time, tillage and N. Bars represent standard error.

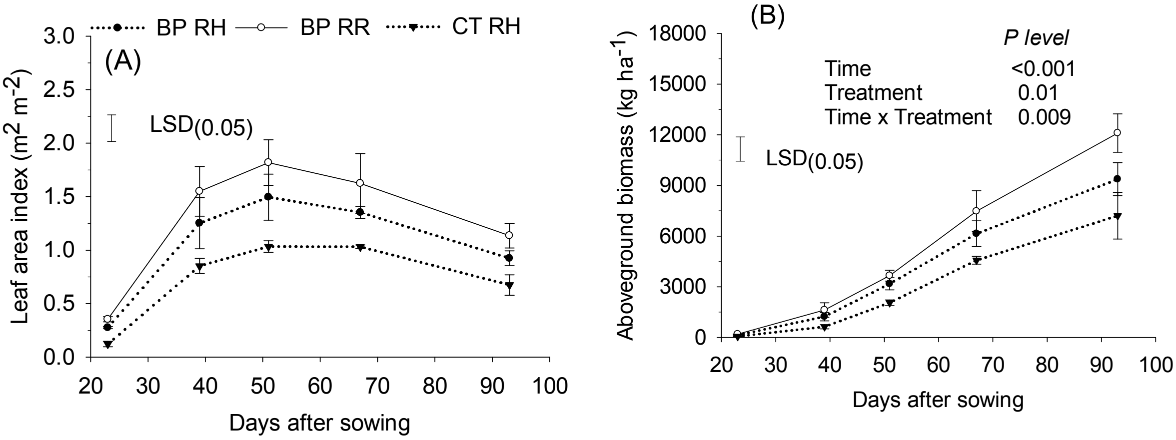


Figure 4.6 Leaf area index development (A) and aboveground biomass accumulation (B) in maize, as affected by tillage method (BP=bed planting, CT=conventional tillage) and residue management (RH=residue harvested, RR=residue retained). P level similar for A and B. P values derived from an analysis of variance. LSD is the difference between time and treatment. Bars represent standard error.

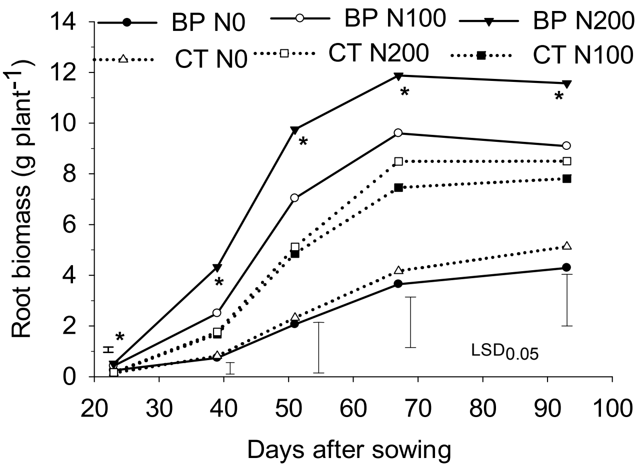


Figure 4.7 Maize root growth (g plant^{-1}) over time as affected by tillage (BP=bed planting and CT=conventional tillage) and N application level (0, 100 and 200 kg ha^{-1}); *=significance at p=0.05. LSD is difference between treatments and time.

4.3.2 Crop yield, yield components, and water productivity

Cotton

Cotton yield and biomass

Across tillage and N level, average raw cotton yield was 3923 kg ha^{-1}. Tillage method had no effect (p=0.81) on raw cotton yield or AGB production, while the effect of N was highly significant. Similar results were observed in the cotton/cover-crop/cotton rotation (Table 3.2). Irrespective of tillage, N-125 showed a 26% higher ($p<0.05$) raw cotton yield and 31% higher AGB than N-0. Raw cotton yield and AGB did not increase significantly with increased N level from N-125 to N-250. No significant tillage by N interaction effects was observed for yield, AGB, and yield components of cotton (Table 4.3). The harvest index (HI) of cotton was not affected ($p>0.05$) by tillage method, but was decreased ($p<0.05$) by N application.

Tillage method did not affect ($p>0.05$) the ginning percent of cotton, but this was decreased ($p<0.05$) with increased N level. Irrespective of tillage method, with N-125 to N-250 the ginning percent was decreased ($p<0.05$) by 6 and 3.8% compared to N-0 and N-125, respectively, while no difference was observed between N-0 and N-125 (Table 4.3).

Table 4.3 Main effect of tillage and N level on raw cotton yield, aboveground biomass (AGB), harvest index (HI) and water productivity (WP) in cotton.

Treatment	Raw cotton yield (kg ha^{-1})	AGB (kg ha^{-1})	HI (%)	Ginning percent (%)	WP (kg m^{-3})
Tillage					
BP	3929	10723	37.4	39.2	0.88
CT	3916	10221	38.4	39.9	0.88
LSD (0.05)	697	2235	2.07	2.6	0.16
N levels					
0	3299	8342	39.8	40.6	0.74
125	4168	11088	37.7	39.8	0.94
250	4301	11986	36.2	38.2	0.97
LSD (0.05)	257	1198.4	2.8	1.5	0.05
		ANOVA			
Tillage (T)	ns	ns	ns	ns	ns
Nitrogen (N)	***	***	*	*	***
T x N	ns	ns	ns	ns	ns
Mean	3923	10472	37.9	39.5	0.88

BP=bed planting, CT=conventional tillage. Significance level: *$P\leq0.05$; **$P\leq0.01$; *** $p\leq0.001$; ns=non significant

Average water productivity (WP) of raw cotton was 0.88 kg m^{-3} irrespective of the tillage method. Furthermore, averaged over the tillage method, N-125 increased ($p<0.05$) WP, which was 27% higher than with N-0. Water productivity was not affected by N-125 to N-250 (Table 4.3). A similar trend was observed for raw cotton yield.

Yield components

No differences were detected between tillage methods for boll density and boll weight during 1st picking, while boll weight at the 3rd pick under BP was higher ($p<0.05$) by 6% than in CT (Table 3.3). Application of N-125 increased ($p<0.05$) the boll density by 20%, and boll weight at the 1st and 3rd picking by 6 and 9%, respectively, compared to N-0. With N-125 to N-250, boll weight during 3rd picking was increased only by 4%. The higher boll weight during 3rd cotton pick in BP with N application remained important for the cotton yield for BP. Where, the share of the 3rd pick in total cotton harvest in BP was 31% with N-250 and 28% with N-125, but in CT it was 20% in both N-125 and N-250.

Averaged over tillage and N level, 35% cotton bolls were opened just prior to defoliation. Percent opened boll was affected by tillage ($p=0.02$) and N ($p=0.01$), but an interaction effect of tillage by N was not observed (Table 3.3). Irrespective of N level, CT showed 52% more ($p<0.05$) opened bolls prior to defoliation than BP. Disregarding tillage method, percent opened bolls was decreased with N application, i.e., by 33% with N-125 compared to N-0. With N-125 to N-250, percent opened bolls decreased ($p>0.05$) by 10%.

Wheat

Grain yield and biomass

Tillage had a significant effect ($p=0.03$) on grain yield of wheat across the three N and two residue levels (Table 4.4). The BP system had a 12% higher grain yield than CT. The main effects of N on grain yield were highly significant. With N fertilizer, up to 11.2 t ha^{-1} winter wheat yield could be achieved (in BP; Figure 4.8). Wheat yield was increased ($p<0.05$) 3-fold with application of N-100 compared to N-0. However, when doubling the N level from N-100 to N-200 kg ha^{-1}, grain yield was increased ($p<0.05$) by only 18%. Irrespective of tillage method and N level, the RR treatment showed a 5% higher ($p=0.05$) grain yield than the RH.

Table 4.4 Main effects of tillage, N level, and residue on grain yield (12% moisture), aboveground biomass (AGB), harvest index (HI), water productivity (WP), spike density (spikes m^{-2}), grains $spike^{-1}$, 1000 kernel weight (TKW), and days to maturity of winter wheat.

Treatment	Grain yield (kg ha^{-1})	AGB (kg ha^{-1})	HI (%)	WP (kg m^{-3})	Spike density (m^{-2})	Grains spike $^{-1}$	TKW (g)	Maturity (days)
Tillage (T)								
BP	8269	15488	46.8	1.73	685	30.7	34.4	228
CT	7345	13517	47.6	1.36	620	30.1	34.9	228
LSD (0.05)	800.9	1540	-	0.2	44	-	-	0.25
Residue (R)								
RH	7615	14128	47.3	1.5	646	29.6	34.3	228
RR	7998	14877	47.1	1.6	659	31.3	35.1	228
LSD (0.05)	384	775	-	0.07	-	1.14	0.76	0.27
Nitrogen (N)								
0	3367	6516	45.8	0.67	389	25.7	33.9	226
100	9204	16948	48	1.83	718	33.1	34.9	228
200	10849	20043	47.8	2.15	851	32.5	35.2	230
LSD (0.05)	471	949	1.5	0.09	45.3	1.39	0.94	0.3
				ANOVA				
Tillage	*	*	ns	**	*	ns	ns	*
Residue	*	+	ns	*	ns	**	*	**
N level	***	***	**	***	***	***	*	***
N x T	ns	ns	ns	ns	ns	ns	ns	ns
N x R	+	+	ns	+	ns	*	ns	ns
T x R	ns	ns	ns	ns	ns	ns	*	ns
N x T x R	ns	+	ns	ns	ns	ns	ns	ns
Mean	7807	14503	47	1.5	685	30.7	34.4	228

BP=bed planting, CT=conventional tillage, RH=residue harvest, RR=residue retained. Significance level: +P≤0.1 (weakly significant); *P≤0.05; **P≤0.01; *** p≤0.001; ns=non significant

There were no significant three-way interaction effects, i.e., tillage by N by residue, but weak two-way interaction effects (p=0.08) were observed between N and residue levels for grain yield (Table 4.4). Although there was no significant interaction effects between tillage and N levels, grain yield under BP was higher for all N levels, i.e., by 32% in N-0, 14% in N-100 and 6% in N-200 than in CT at the respective N level (Figure 4.8A). BP with RR in the N-0 treatment increased (p<0.05) grain yield by 48% over RH, while RR did not affect yield significantly in the N applied treatments (Figure 4.8B).

Total AGB at harvest was highly significant with N level (p=<0.001), significant with tillage method (p=0.03) and weakly significant with residue level (p=0.058) (Table 4.4). Irrespective of N and residue levels, total AGB under BP was 14% higher (p<0.05) than in CT. Averaged over tillage and residue level, AGB increased (p<0.05) 2.6-fold with N-100 compared to N-0. However, when doubling the N level from N-100 to N-200 kg ha^{-1} AGB was increased (p<0.05) by 18%. A similar trend as for yield was observed for AGB production of wheat in all treatments. The AGB of wheat was strongly correlated (r=0.99, P<0.001) to grain yield (Table 4.5). The HI was affected (p<0.05) by N level but not by tillage method and residue level (Table 4.4).

Crop growth duration in wheat was increased (p<0.05) by N application, but tillage and residue did not extend the growing period (Table 4.4). In the N-0 treatment, wheat matured 2 and 4 days earlier compared to N-100 and N-200, respectively.

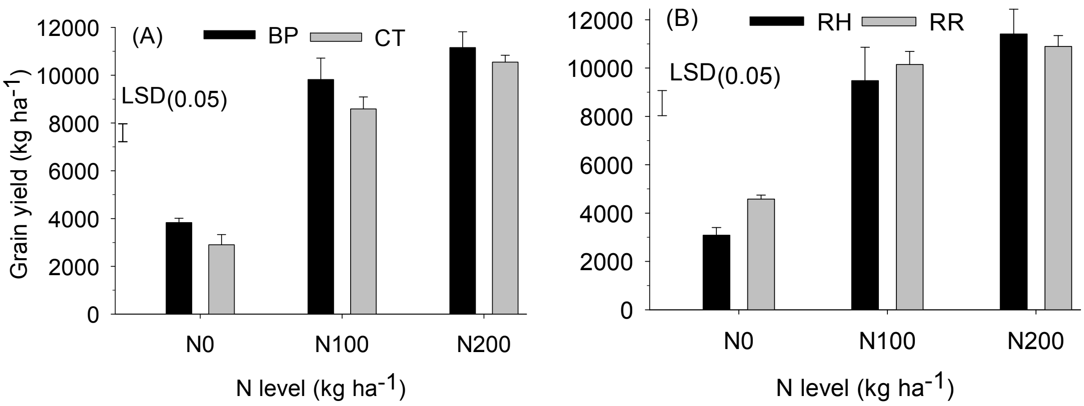


Figure 4.8 Interaction effects between (A) tillage method and N level and (B) N and residue level under BP on grain yield of winter wheat. BP=bed planting, CT=conventional tillage, RH=residue harvested, and RR=residue retained. LSD is the difference between (A) tillage and N and (B) N and residue level. Bars represent standard error.

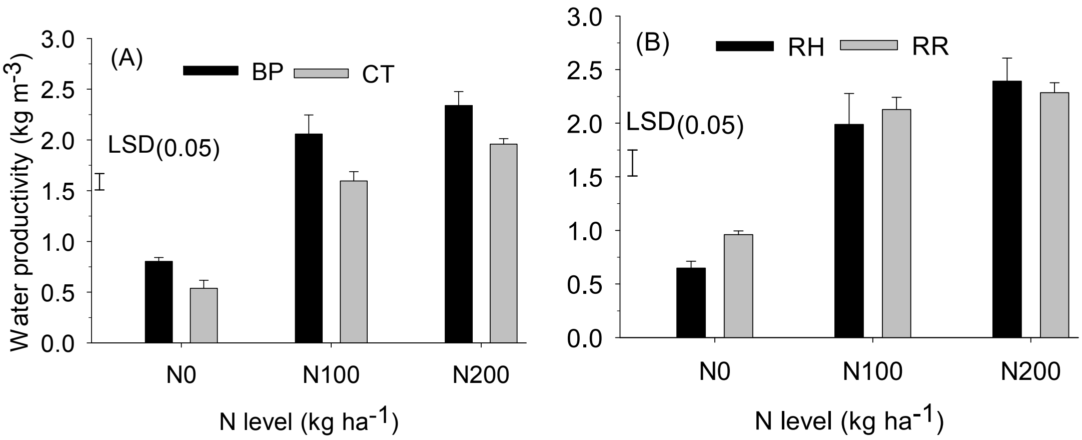


Figure 4.9 Interaction effects between (A) tillage and N level and (B) N and residue level under BP on water productivity (kg m^{-3}) in wheat. BP=bed planting, CT=conventional tillage, RH=residue harvested and RR=residue retained. LSD is the difference between (A) tillage and N and (B) N and residue level. Bars represent standard error.

Water productivity

The average water productivity (WP) in wheat was 1.5 kg grain per m^{-3} water application. Main effects of tillage and N level were highly significant for water productivity (WP) of wheat. There was a weak interaction effects ($p=0.05$) between residue and N level, and a significant effect of residue main effects ($p=0.04$) (Table 4.4). Averaged over N and residue levels, WP under BP was 27% higher ($p<0.05$) than in CT. The higher WP is shown by the lower water application (Table 4.2) and increased grain yield. Water saving in BP was 12% compared to CT. Water productivity increased significantly with increased N level (Table 4.4), and was 3 times higher ($p<0.05$) with N-100 compared to N-0. However, when doubling the N level from N-100 to N-200 kg ha^{-1}, WP increased ($p<0.05$) by only 17%. A similar trend to that of yield was observed for WP of wheat in all treatments.

Similar to grain yield, a weak interaction effects ($p=0.06$) was observed between N and residue levels for WP (Table 4.4). Water productivity under BP was higher ($p<0.05$) for all N levels, i.e., by 50% for N-0, 29% for N-100 and 19% for N-200 than in CT at the respective N level (Figure 4.9A). In BP, RR with the N-0 treatment showed a 47% higher ($p<0.05$) WP than with RH, but no effect of N application was observed (Figure 4.9B).

Table 4.5 Correlation coefficients (r) among grain yield, aboveground biomass (AGB), harvest index (HI), spike density (m^{-2}), 1000 kernel weight (TKW), grains $spike^{-1}$, and maturity days of wheat.

	AGB	Yield	HI	Spike density	TKW	Grains $spike^{-1}$
AGB	1					
Yield	0.99^{b}	1				
HI	0.68^{a}	0.70^{a}	1			
Spike density	0.99^{b}	0.99^{b}	0.67^{a}	1		
TKW	0.54^{ns}	0.55^{ns}	0.62^{a}	0.49^{ns}	1	
Grains $spike^{-1}$	0.92^{b}	0.92^{b}	0.70^{a}	0.89^{b}	0.62^{b}	1
Maturity days	0.95^{b}	0.95^{b}	0.65^{a}	0.91^{b}	0.55^{ns}	0.81^{b}

^{a} $P \leq 0.05$; ^{b} $P \leq 0.01$; ns=non significant

Yield components

Spike density (spikes m^{-2}) was significantly ($p<0.05$) affected by tillage method and N level (Table 4.4). Averaged over N and residue levels, spike density under BP was 10% higher than in CT, and was strongly correlated to grain yield (r=0.99, $P<0.001$) (Table 4.5). Spike density increased (p=<0.001) with increasing N level and was higher by 85% with N-100 than with N-0. However, with N-100 to N-200, spike density increased ($p<0.05$) by 18%. In BP, RR showed a 6% higher ($p>0.05$) spike density than RH.

The grains per spike were significantly affected by main and interaction effect of N and residue levels, but effect of tillage was non-significant (Table 4.4). Averaged over tillage method, RR in the N-0 plots showed 15% more ($p<0.05$) grains per spike than under RH, but RR showed no increase in grains per spike in the N applied treatments in both tillage systems. Grains per spike were strongly correlated with grain yield (r=0.92, $P<0.001$) (Table 4.5).

Thousand kernel weight (TKW) of wheat was not affected ($p>0.05$) by tillage method (Table 4.4). Irrespective of tillage method, TKW increased by 1.1 and 1.3 g with N-100 and N-200, respectively, compared to N-0, but there was no difference between N-100 and N-200. A significant interaction effect was observed between tillage and residue level. RR increased the TKW by 1.7 g in CT compared to RH, but had no effect on BP.

Maize

Grain yield and biomass

The main effects of tillage, N and residue levels were significant for maize grain yield, AGB and water productivity (Table 4.6). Averaged over N and residue level, grain yield under BP was 41% higher ($p<0.05$) than in CT. Irrespective of tillage and residue, grain yield increased ($p<0.05$) by two-fold with N-100 compared to N-0. However, when doubling the N level from N-100 to N-200 grain yield increased ($p<0.05$) by 23%. Irrespective of tillage and N levels, RR showed a 10% higher ($p<0.05$) grain yield than RH (Table 4.6).

There was a significant interaction effect ($p=<.001$) between tillage and N level, such that N response was greater in BP than under CT (Table 4.6). In BP with N fertilizer, up to 8.1 t ha^{-1} maize grain yield could be achieved (Figure 4.10). Grain yield in BP was 2.5 times higher ($p<0.05$) with N-100 than with N-0. However, with the increase from N-100 to N-200, grain yield in BP increased by 32%. In CT, grain yield was 2 times higher ($p<0.05$) with N-100 than with N-0, while it increased ($p>0.05$) by only 10% when going from N-100 to N-200. BP, however, showed a 34 and 61% higher ($p<0.05$) grain yield with N-100 and N-200, respectively, compared to CT at respective N level (Figure 4.10A). Tillage had no effect on grain yield at N-0.

A significant tillage by residue interaction effects was observed for maize grain yield (Table 4.6). In BP, irrespective of N level, RR increased ($p<0.05$) grain yield by 15% compared to RH. However, RR under CT had no effect ($p>0.05$) on grain yield (Figure 4.10B). Similarly, RR in BP increased grain yield by 54% (2966 kg ha^{-1} vs. 1929 kg ha^{-1}) with N-0, by 12% (6517 kg ha^{-1} vs. 5686 kg ha^{-1}) with N-100, and by 6% (8334 kg ha^{-1} vs. 7797 kg ha^{-1}) with N-200 compared to RH.

Averaged over time and N level, the RR treatment showed greater ($p<0.05$) LAI and AGB than the RH (Figures 4.4A and 4.4B). The increment was higher with N-0 compared to N-200. With N-0, RR increased ($p<0.05$) the LAI by 53-143% during the growing season compared to RH, while with N-200, increment of LAI due to residues was only 10-12%. Similarly, with N-0, RR increased ($p<0.05$) the AGB by 50-70% compared to RH. However, RR did not affect AGB production with N-200 application (Figure 4.4B).

Table 4.6 Main effects of tillage, N level, and residue on grain yield, aboveground biomass (AGB), harvest index (HI), water productivity (WP), yield components and maturity days of hybrid maize.

Treatment	Grain yield (kg ha^{-1})	AGB (kg ha^{-1})	HI (%)	WP (kg m^{-3})	Ear density m^{-2}	Grains ear^{-1}	TKW (g)	Tasseling (days)	Maturity (days)
Tillage									
BP	5520	9551	50.5	0.88	6.2	375	200.4	38	86
CT	3910	6510	52.4	0.48	5.0	343	206.7	40	88
LSD(0.05)	922	1636	2.3	0.12	1.0	20.7	3.7	0.65	0.9
Residue									
RH	4490	7598	51.8	0.64	5.5	340	201.3	39	87
RR	4940	8464	51.2	0.72	5.7	378	205.7	38	87
LSD(0.05)	317	548	1.0	0.04	0.3	12.4	7.2	0.7	0.6
N levels									
0	2331	4161	49.7	0.33	4.9	264	180.7	42	88
100	5295	8893	52.5	0.76	5.6	392	206.3	37	86
200	6519	11038	52.3	0.95	6.2	421	223.6	37	87
LSD(0.05)	388	671	1.2	0.05	0.4	15.2	8.9	0.8	0.7
				ANOVA					
Tillage (T)	*	**	+	**	*	*	*	**	**
Residue(R)	**	**	ns	**	ns	***	ns	*	ns
N level (N)	***	***	***	***	***	***	***	***	**
N x T	***	***	ns	***	**	***	*	***	**
LSD(0.05)	855	1513	2.3	0.11	0.98	22.7	10.5	1.1	1.06
N x R	ns	ns	ns	ns	ns	**	+	+	ns
LSD(0.05)	549.6	949	1.8	0.08		21.5	12.5	1.27	
T x R	*	*	ns	*	ns	+	ns	*	ns
LSD(0.05)	848.	1508	2.1	0.11	0.98	19.9	7.6	0.85	
N x T x R	ns	ns	ns	ns	ns	ns	ns	ns	ns
Mean	4715	8031	51.5	0.68	5.6	359	203.5	8.3	87

BP=bed planting, CT=conventional tillage, RH=residue harvested, RR=residue retained, TKW=thousand grain weight. Significance level: +$P \leq 0.1$ (weakly significant); *$P \leq 0.05$; **$P \leq 0.01$; *** $p \leq 0.001$; ns=non significant

The main and interaction effect of tillage and N level on AGB production were significant (p=<0.001) (Table 4.6). Similar to the grain yield, AGB production in BP with N-100 increased (p<0.05) by 40% (10373 vs. 7412 kg ha^{-1}) and 67% (13810 vs. 8267 kg ha^{-1}) with N-200 compared to CT at respective N level (Figure 4.5B). Irrespective of N level, RR in BP increased (p<0.05) AGB production by 17% (10317 vs. 8785 kg ha^{-1}) compared to RR, while RR under CT had no effect on AGB production at maturity (Figure 4.6B). AGB production strongly correlated with grain yield (r=0.99, P<0.001) (Table 4.8). The HI was increased (p<0.05) with N application compared to the N-0. Tillage method and residue level did not, however, affect the HI (Table 4.6).

Nitrogen level and tillage method had a significant effect on growth duration of maize (Table 4.6). Tasseling was delayed by 3-9 days under BP and by 2-3 days in CT with N-0 as compared to N-100 and N-200. Similarly, maturity was delayed by 2-3 days with N-0 compared to N-100 and N-200 under BP, but the crop matured at same time in CT for all N levels. Crop residue did not affect growth duration of maize in any of the tillage treatments (Table 4.6).

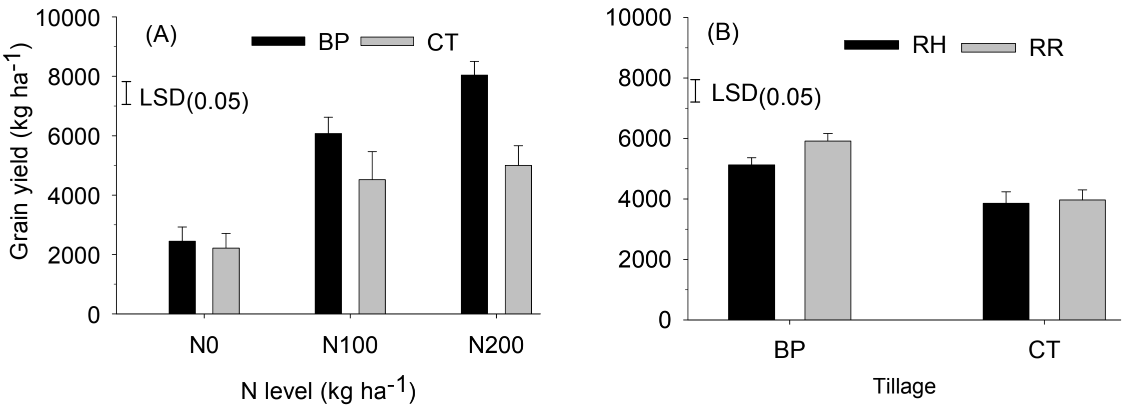


Figure 4.10 Interaction effects between (A) tillage and nitrogen level and (B) tillage and residue level on maize grain yield (kg ha^{-1}). BP=bed planting, CT=conventional tillage, RH=residue harvested and RR=residue retained. LSD is interaction between (A) tillage and N and (B) N and residue level. Bars represent standard error.

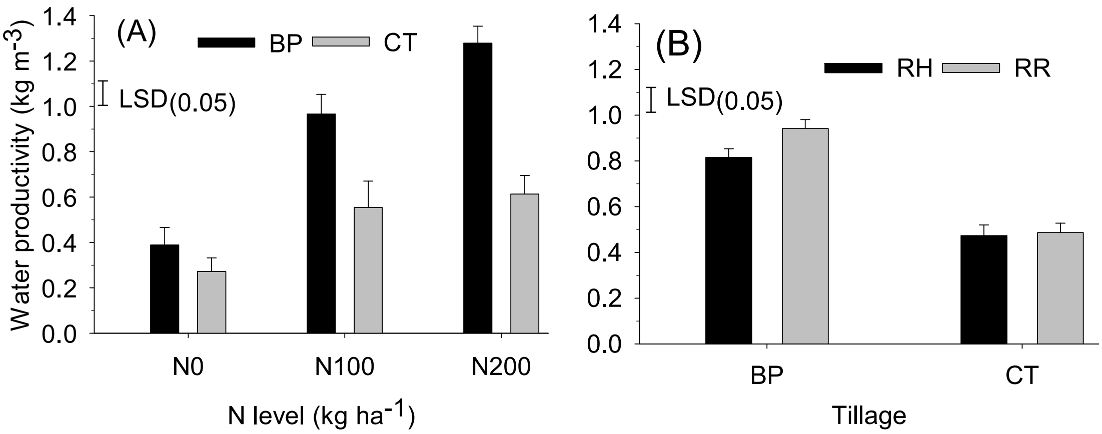


Figure 4.11 Interaction effects between (A) tillage and nitrogen level, and (B) tillage and residue level, on water productivity (kg m^{-3}) in maize. BP=bed planting, CT=conventional tillage, RH=residue harvested, RR=residue retained. LSD is difference between (A) tillage and N and (B) N and residue level Bars represent standard error.

Water productivity

There were a highly significant interaction effects between tillage and N, and a significant interaction between tillage and residue level on WP in maize (Table 4.6). Averaged over N and residue level, WP in BP was almost twice as high (85% higher) as under CT (Table 4.6). The highest WP (1.3 kg grain m^{-3} water applied) was observed in BP with N-200. Water productivity in BP was higher ($p<0.05$) for all N levels, i.e., by 44% with N-0, 73% with N-100 and 110% with N-200 than under CT at the respective N level (Figure 4.11A). In BP, it was 2.6 times higher ($p<0.05$) with N-100 than with N-0, and by 32% ($p<0.05$) with N-100 compared to N-200. Similarly, under CT, WP increased by 107% with N-100 compared to N-0, while no difference was observed between N-100 and N-200 (Figure 4.11A). Irrespective of the N level, WP in BP with RR was 15% higher than with RH. In contrast, RR had no effect on WP under CT (Figure 4.11B).

Yield components

There was a significant tillage by N interaction effects for yield components (ear density, grains ear^{-1}, and TKW) of maize (Table 4.6). In BP, ear density was higher ($p<0.05$) by 21% with N-100 than N-0, and for N-100 to N-200 ear density (m^{-2}) increased ($p>0.05$) by 15%. In contrast, under CT, N application had no effect on ear density. A strong correlation (r=0.9; P=0.01) was observed between ear density and grain yield (Table 4.8). Number of grains per ear and TKW were higher (p<0.05) with increased N level in both tillage systems. Grains per ear increased (p<0.05) by 76% under BP and by 33% in CT with N-100 compared to N-0, and doubling the N level from N-100 to N-200 led to an increase (p<0.05) of 8% in BP and 7% in CT. In BP, grains per ear was higher (p<0.05) by 14% with N-100 and 16% with N-200 than under CT at respective N level (Table 4.7). TKW was not affected by tillage method in N application treatments, while it was greater (p<0.05) by 13% under CT than in BP in N-0 treatments. TKW increased (p<0.05) by 21% in BP and 8% under CT with N-100 compared to N-0, and doubling the N level from N-100 to N-200 led to an increase (p<0.05) of 9% in both BP and CT.

Irrespective of tillage method, grain density per ear in the RR treatment was 31% higher (p<0.05) with N-0 and 8% higher (p<0.05) with N-100 than in the RH treatment, but were not affected by RR under high N application (N-200). Averaged over tillage method, RR in the N-0 plots increased the TKW by 8% compared to RR, but had no effect in the N applied treatments. Grains per ear and TKW were strongly correlated with grain yield (r=0.96 and 0.83; P=0.01) (Table 4.8).

Table 4.7 Interaction effects between N and tillage on yield components and maturity days of hybrid maize.

Tillage	N level (kg ha^{-1})	Ear density (m^{-2})	Grains ear^{-1}	TKW (g)	Tasseling (days)	Maturity (days)
Bed planting	0	5.1	254	170	42	87
	100	6.2	418	206.4	35	85
	200	7.1	453	224.7	36	85
Conventional	0	4.7	274	191.4	42	88
	100	4.9	366	206.1	39	88
	200	5.2	390	222.4	39	88
LSD (0.05)		0.98	22.7	10.5	1.1	1.1

TKW=Thousand grain weight

Table 4.8 Correlation coefficient (r) among yield, aboveground biomass (AGB), harvest index (HI), ear density, grains ear^{-1}, and 1000 kernel weight (TKW) of maize.

	AGB	Yield	HI	Ear density	Grains ear^{-1}
AGB	1				
Yield	0.99^{b}	1			
HI	0.31^{ns}	0.38^{ns}	1		
Ear density	0.92^{b}	0.90^{b}	0.06^{ns}	1	
Grains ear^{-1}	0.95^{b}	0.96^{b}	0.37^{ns}	0.79^{b}	1
TKW	0.80^{b}	0.83^{b}	0.60^{ns}	0.56^{ns}	0.88^{b}

^{a} p=0.05; ^{b} p=0.01; ns=non significant

4.3.3 Soil moisture

During the wheat season, no significant differences in soil moisture content were detected among tillage treatments in all stages, but BP showed a consistently higher soil moisture percent in the top 90 cm soil profile (average moisture 32%) over the wheat growing period than under CT (average moisture 30%; an increase of 6%). Similarly, soil moisture content in the top 90 cm soil in BP was higher by 10% during tillering and by 5% during heading and grain-filling stage than under CT (Figure 4.12).

During the maize growing period, soil moisture before irrigation was consistently higher in BP with RR followed by BP with RH and CT (Figure 4.12). On average, BP with RR showed the highest soil moisture content (average moisture 33.9%) followed by BP with RH (average moisture 32.3%) and CT (average moisture 30.6%) in the top 90 cm soil profile. There was a significant (p=0.01) three-way interaction effects for soil moisture, i.e., time, treatment and soil depth. Soil moisture before irrigation in the top 10 cm soil depth in BP with RR had a 3-6% higher moisture content than in BP with RH and a 13-19% higher moisture content than under CT.

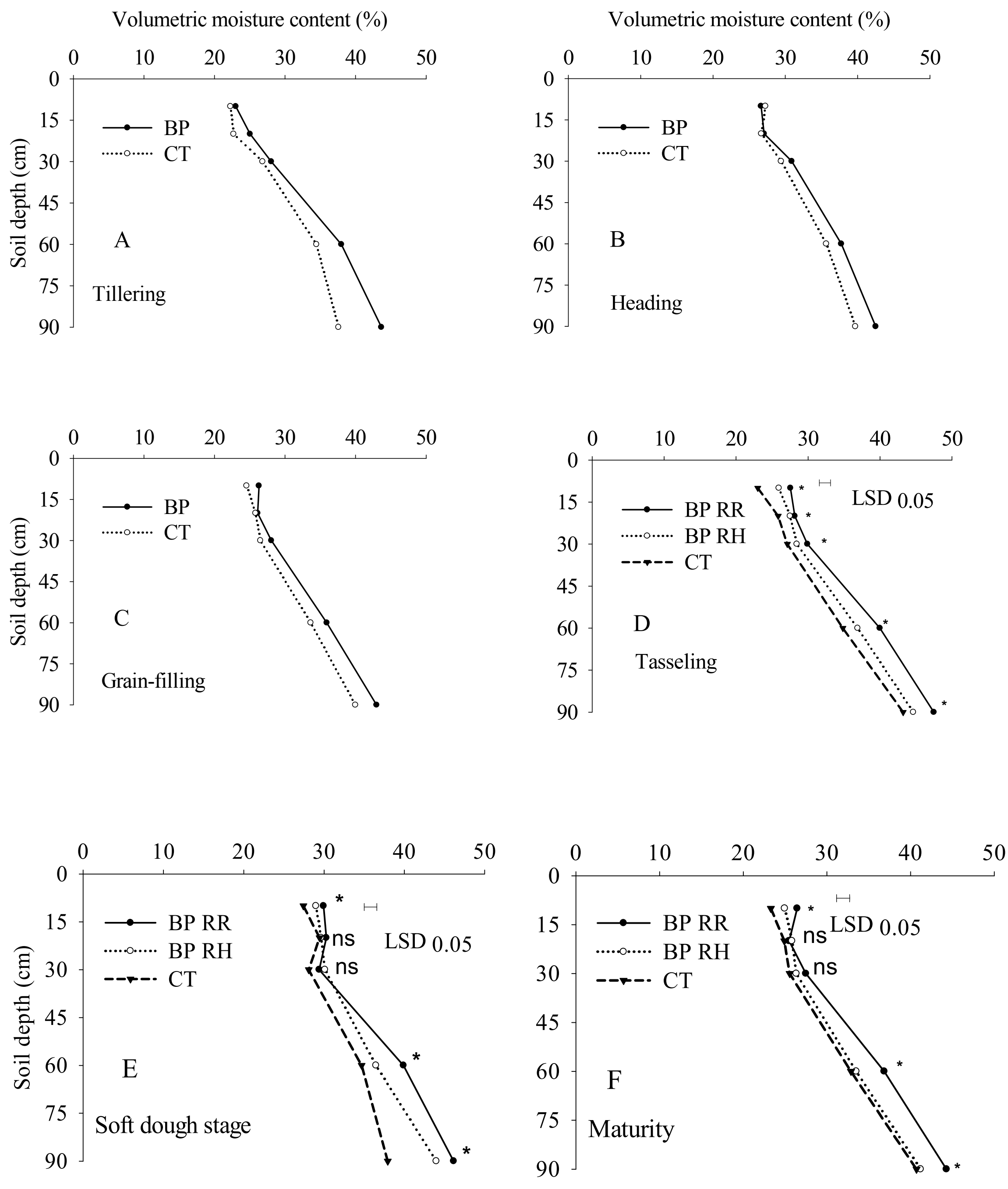


Figure 4.12 Soil moisture before irrigation in different soil depths under two tillage methods and residue levels in wheat season (A, B, and C) and in maize season (D, E and F). BP RR=bed planting with residue retention, BP RH=bed planting with residue harvest, CT=conventional tillage with residue harvest. *-significance at p=0.05; ns= non significant.

4.4 Discussion

4.4.1 Effect of tillage

Permanent raised bed (BP) planting has the potential to increase crop yield and water productivity in many row-grown crops (Sayre and Hobbes 2004). In this study, during the transition year from conventional to conservation agriculture (CA), cotton yield was not affected by tillage method. In contrast, after one season of CA practices, BP increased the grain yield of wheat by 12% and that of maize by 41% compared to CT when averaged over the residue and N levels. This suggests that cotton, wheat and maize cultivation in irrigated drylands may not need intensive soil tillage.

The higher grain yield of wheat and maize in BP than under CT in such short period of CA practice could have various reasons. Drilling of wheat seed in line under BP may have provided better soil-seed contact than broadcast seeding under CT, resulting in a more vigorous crop growth as indicated by higher LAI and AGB production (Figure 4.3), which again led to high grain yield. These findings confirm previous results from Gursoy et al. (2010) reporting higher winter wheat yields with drill-seeding than with conventional broadcast seeding in Turkey or from Mann et al. (2008) in Punjab, Pakistan.

The increased grain yield of wheat under BP was mostly due to the high number of effective spikes m^{-2}, even though the same seed rate was used for both tillage systems. As the wheat was sown in rows on the shoulders and not on the top of the bed, it was closer to the furrow, where the soil was moister. The constantly higher soil moisture content in BP may also have increased the nutrient availability and consequently the number of tiller-bearing plants per m^2 (143 m^{-2} in BP and 130 m^{-2} in CT, 10% higher). The combination of positive effects may explain the yield advantage of BP at the different N levels compared to CT. Likewise, Khalequei et al. (2008) observed a higher spike density in BP spring wheat compared to a CT in Bangladesh.

In maize, the absence of grain yield differences between BP and CT with N-0, averaged over residue level, indicates that bed-planting of maize in such a short time after the conversion to no-tillage operations is superior to CT only with N application. The increased maize grain yields in BP with N applications is attributed to various factors such as an earlier seedling emergence and stand establishment, faster growth rate, earlier tasseling, and longer grain filling periods in BP than under CT (Figure 4.5

and Table 4.7). All these factors could have contributed to the increased ear density and grains ear^{-1} in BP, which have previously been identified as prime yield determining components (Fischer et al. 2002). These authors also reported a better performance of maize in conservation tillage due to earlier seedling emergence and faster growth in the first few weeks compared to CT. Better early growth resulted in increased aboveground (Figure 4.5) and root biomass accumulation (Figure 4.7) and led to increased cob density and grains per cob (Table 4.8). That higher biomass production before silking increases the maize grain yield mainly by increased ear density was also reported by Nakaseko et al. (1978). The maize in BP was furrow irrigated, which could have led to a better microclimate, higher soil moisture, and better nutrient availability than in the conventionally tilled, flood-irrigated system. Similar findings are reported by Sayre and Hobbs (2004) and Govaerts et al. (2005).

Like the findings of Hobbs et al. (1998), Sayre and Hobbs (2004), and Govaerts et al. (2005), who reported permanent raised beds a better option for maize and wheat cultivation under rainfed conditions, the present results showed that there is a potential to grow these crops on permanent raised beds under irrigated conditions in dryland regions as well. The results, however, do not support the findings of Ishaq et al. (2001), who reported that wheat following cotton requires a plough-based method of seed bed preparation to alleviate surface compaction and to improve soil tilth in sandy clay loam soil in Pakistan. Also for maize, Cambel et al. (1984) reported higher grain yield under conventional tillage than under conservation tillage in irrigated system for three years.

The absence of differences in cotton growth, yield and biomass production between BP and CT supports previous evidence that good field preparation helps to avoid the usually expected temporary reduction in yields when changing from conventional to conservation practices (Hicks et al. 1989; Boquet et al. 2004; Tursonov 2009; section 3.3.3). The low percentage of boll opening made a chemical defoliation of BP cotton necessary. It was caused by the slow initial crop growth rate in BP, where emergence was delayed by 3-5 days compared to CT. The low rate of boll opening in BP before defoliation did, however, not affect the yield of raw cotton. It can be assumed that this initial disadvantage was counterbalanced by an increased crop growth rate in BP after irrigation and fertilizer application, which enhanced boll maturation that in turn resulted in the higher boll weight during the third picking in BP than under CT. Where, in BP with N application, cotton yield from the third picking shared one-third of the total cotton harvest. Tursunov (2009) observed in Khorezm that cotton planted on beds had slow initial growth, but compared to CT, the growth was stabilized after irrigation at the flowering stage. Bed-planted cotton delayed maturity compared to CT as indicated by the low percentage of open bolls prior to defoliation as also reported by Schwab et al. (2002).

The differences in water productivity in cotton under BP and CT were insignificant since an equal amount of water was applied in both tillage methods (Table 4.2), and owing to the non-significant differences in cotton yield (Table 4.3). However, the higher water productivity in BP than under CT for the subsequent crops wheat and maize suggests that a reduction in irrigation water use can be already expected without compromising yields after 1-2 growing seasons. Hassan et al. (2005) also reported 36 and 32% irrigation water saving and 50 and 65% higher water productivity in wheat and maize, respectively, when comparing BP to CT in a semi-arid region of Pakistan. Reduced amounts of irrigation water have been reported by Sayre and Hobbs (2004) as caused by the compaction in the furrow bottoms from machine traffic which in turn increased lateral water infiltration and forward water advance. It is very likely that the same occurred in the present experiment. Visual observations indicated greater soil cracking under CT during the maize season, which could also be the reason for higher irrigation amounts needed under CT especially during the maize season.

Increased crop water productivity in BP can be important for the irrigated dryland in Central Asia, particularly in Uzbekistan where crop water productivity is low compared to irrigated agriculture in other regions. As the experimental plots were sufficiently large (600 m^{-2} each), similar water saving can be expected in the farmers`fields.

4.4.2 Effect of nitrogen

Increased cotton yield with N application under both tillage methods (Table 4.3) illustrates that cotton in BP can be grown with the same level of N application as under CT during the transition period from conventional to CA without compromising yield. This finding contrast with the findings of Bronson et al. (2001) who stated that 19 to 38 kg additional fertilizer N would be needed for conservation tillage to produce similar lint yield to CT during the initial three years. Greater cotton yields with N application in this study not only increased boll density, as indicated by previous research (Wiatrak et al. 2005) but also significantly increased boll weight compared to N-0 (Table 3.3). Whereas previous research indicates that cotton yield components such as boll density and boll weight have an impact on yield (Pettigrew and Jones 2001), the impact of N is mainly through the boll density and boll weight in irrigated cotton (Wright et al. 1998; Wiatrak et al. 2005). Similar to the cotton/cover-crop/cotton rotation system, with increased N from N-125 to N-250 cotton yield and biomass did not further increase (section 3.4.3 *effect of nitrogen*). Hence, it is not worth investing in 250 kg N ha^{-1} instead of 125 kg ha^{-1} under such high initial residual mineral N conditions.

The decrease in ginning percentage with increased N levels was caused by an increase in seed weight under high N application. This implies that N not only increases lint weights but even more so seed weights, which confirms earlier findings (Elbehar 1991; Reiter et al. 2008; Kienzler 2010).

The increase in grain yield of wheat with N application in CT and BP was mainly caused by the increased spike density (r=0.99, P<.001) and grains $spike^{-1}$ (r=0.92, P<.001) (Table 4.5). This is supported by the higher spike density, grains per spike, TKW and growth duration of wheat in this study with N application than with N-0**.** It has been widely reported that an adequate N supply promotes tiller production and survival (Davidson and Chevalier 1992), delays leaf senescence, sustains leaf photosynthesis during the grain-filling period, and extends the grain filling period (Fredrick and Camberato 1995). The greater grain yield of wheat in BP with all N level than in CT suggests a greater response of applied N in BP. The higher soil moisture availability has let to a vigorous plant growth and hence has increased the response of applied N under BP.

The increased maize grain yield with N application in both BP and CT was caused by an increase crop growth rate and biomass accumulation which in turn increased the number of grains ear^{-1} (r=0.96, P<.001), and TKW (r=0.83, p<.001) compared to N-0 (Table 4.8). Similar to wheat, the response of applied N in maize was high in BP than under CT. As explained in section 4.4.1, the earlier crop germination and faster initial growth in BP with N application resulting in higher LAI, AGB and root biomass may have increased the N depend of crop and has fulfilled by N application. The lack of differences in yield and biomass production of maize between N-100 and N-200 under CT indicates low N use efficiency when N amendments are increased beyond N-100. This is supported by the findings of Ahmad et al. (2009), who reported significantly increased grain yields of maize under CT of up to 120 kg N ha^{-1}; additional N application beyond this failed to increase the yield.

All these indicate that under both low (N-100) and high (N-200) N application, BP can produce higher grain yields and biomass of winter wheat and maize grown in rotation than under CT in irrigated dry lands. Although wheat and maize grain yield increased with N application, the relative gain is much less with increasing N application from N-100 to N-200 (doubling the farmers' investment) in both tillage methods. Thus it may not be worthwhile for the farmers investing in 200 kg N ha^{-1} instead of 100 kg N ha^{-1} for irrigated winter wheat and maize under such soil and climatic conditions.

The average yield of cotton wheat and maize under the recommended N application in the region are 2.71, and 4.85, and 5.5 t ha^{-1}, respectively (Statistical Department of Khorezm Region 2009). Even with the application of a lower than recommended N rate (i.e., 125 for cotton and 100 kg N ha^{-1} for wheat and maize), the averaged yield of cotton, wheat and maize was nevertheless higher by 53, 90 and 14%, respectively, than the average yield of those crops observed in this region. This could be due to as explain in section 3.4.2 the impact of proper land leveling, which may have helped for the improvement in growth and yield components of the crop due to the better environment for the development of the plants on well-leveled fields. Tyagi (1984) also reported a 50% higher grain yield in laser-leveled plots compared to traditionally leveled plots

4.4.3 Effect of residues

Residue retention in BP had increased grain yield of wheat and maize with N-0 treatment compared to RH. This could be due to the higher amount of mineralizable N in the top soil layer (Campbell et al. 1993), where residues were left as surface mulch. This suggests that crop residues retained as mulch are the potential sources of N, which then can compensate for the 0-N level and can sustain the wheat and maize yields in this cropping system. Similar finding was reported by Limon-Ortega et al. (2000) for a maize-wheat system in Mexico. However, with N application wheat yield did not increase, while it was increased in subsequent maize crop. This could be due to immobilization of applied N in the surface-retained residue, where N fertilizer in wheat was surface broadcast applied. On the other hand in maize season, fertilizer N was band applied, hence avoided the contact of fertilizer on crop residues. All these indicate that the positive effect of residue retention in permanent raised beds under cotton/wheat/maize rotation system will increases over time. Thus, it is suggested to retained crop residues in permanent raised beds in irrigated drylands.

4.5 Summary and conclusions

During the transition phase from conventional to conservation agriculture, tillage had no effect on cotton growth, yield and biomass production. However, one or two seasons after introducing CA practices, wheat and maize yields and water productivity were already increased in BP compared to CT. This indicates irrigated cotton, wheat and maize crops grown in permanent raised beds have potential to increase crop yield by reducing cultivation cost and irrigation water demand. This is particularly important to the farmers to increase their farm income and food security. Yields of cotton, wheat and maize were increased with N application, while due to remaining residual N in the intensively used field, cotton yield under both tillage methods responded only up to 125 kg N ha^{-1}. Grain yields of wheat and maize were similar under BP and CT with N-0. Response to N fertilization of wheat and maize was greater in BP than under CT. It can therefore be concluded that winter wheat and short-duration maize cultivated on permanent raised beds can produce higher grain yield and biomass than under CT under low (N-100) as well as high (N-200) N application. Thus, permanent raised beds could be the best-bet agronomic practice for cotton, wheat and maize grown in rotation in the irrigated agriculture systems of Uzbekistan, Central Asia.

Residue retention in BP always had greater soil moisture and biomass production, and subsequently increased the grain yield and water productivity of wheat and maize in the N-0 compared to the RH treatments. In contrast, with N application, residue retention in BP had no effect on growth and yield of wheat, but grain yield was increased in subsequent maize crop (15% higher with N-100 and 7% higher with N-200). This indicates that in high-yielding environments the benefits of crop residue will increase over time.

Thus, from the initial 2-3 years study on conservation agriculture practices, it can be concluded that permanent raised beds with residue retention and proper N management in cotton/wheat/maize rotation can be the best alternative for the current conventional crop production system in Uzbekistan.

5 NITROGEN UPTAKE, USE EFFICIENCY AND BALANCE UNDER CONSERVATION VS. CONVENTIONAL AGRICULTURE PRACTICES IN A IRRIGATED COTTON/WHEAT/MAIZE SYSTEM

5.1 Introduction

Nitrogen (N) is the major fertilizer nutrient applied to enhance crop growth and yield. The efficiency of applied N in the world crop production system is however less than 50% (Raun and Johnson 1999). The ability of crops to use the applied N depends on the uptake and utilization efficiency. Nitrogen uptake can be increased through improved cultivation practices, while the utilization efficiency is genetically predetermined (Hirel et al. 2007). Furthermore, fertilizer use efficiency depends on fertilizer nutrient rate, soil properties and climatic conditions and also on cropping systems and tillage methods (Engelstad 1985; Etana et al. 1999; Habtegebrial et al. 2007). Higher fertilizer use efficiency is always associated with low fertilizer rates; therefore cultivation practices that promote nutrient efficiency can help to reduce the loss of applied fertilizers.

Cotton/wheat/summer-crop is the major crop rotation system in Uzbekistan (Conrad et al. 2010). Cultivation of these crops under intensive tillage using heavy inputs of water and N fertilizers is a common practice. Nitrogen management of cotton-wheat systems under conventional crop production practices in Uzbekistan was shown to be highly inefficient (Kienzler 2010), where the recovery of the applied N is not more than 37-40% in an irrigated meadow soil and 21-31% in a light soil (Khadjiyev 1998; Ibragimov 2007). High temperatures and intensive irrigation and tillage under conventional practices enhance the mineralization of soil N (Vlek et al. 1981), which leads to N losses through denitrification (Scheer et al. 2008) and leaching (Kienzler 2010).

Conservation agriculture (CA) practices, i.e., reduced tillage, residue management and proper crop rotation, is gaining importance with respect to sustaining the agriculture production systems in different parts of the world. These practices effectively minimize soil disturbance, control soil evaporation, minimize soil erosion losses, and enhance soil carbon sequestration (Lal et al. 2007). Among conservation tillage practices, permanent raised bed planting (BP) is gaining importance in irrigated systems, and has been introduced in row-spaced crops in Asia and arid western United

States (Sayre 2004). BP has numerous advantages, e.g., better irrigation management, plant establishment, and opportunity for inter-bed cultivation for weed control. It gives comparatively better yields through an efficient use of input resources, i.e., water, fertilizer and herbicides, whilst production costs can be reduced compared to conventional tillage (Limon-Ortega et al. 2000; Mehta and Bandyopadhyay 2004; Govaerts et al. 2005). Furthermore, nitrogen use efficiency (NUE) in BP could be improved by more than 10% because of improved N placement possibilities compared to conventional systems (Fahong et al. 2004).

Besides the numerous benefits, frequently cited concerns regarding CA refer to a decreased availability of plant-available N due to immobilization (Randall and Bandel 1991; Blevins and Frye 1993; Doran et al. 1998; Power and Peterson 1998). However, proper management of N in CA has potential advantages regarding NUE as reported by Reeves et al. (1993); Raun and Johnson (1999); Torbert et al. (2001). The initial lower fertilizer use efficiency due to N immobilization under crop residue retention which is a tenet of CA is counterbalanced by a conservation of soil and fertilizer N as soil organic matter. Thus, fertilizer requirements may decrease over time under conservation tillage (Karlen 1990).

Most of the existing research and field evaluations on CA practices have been conducted under rainfed conditions, but many of the benefits are possible in irrigated systems. Despite these apparent advantages, CA practices have mainly only been introduced in a few research projects in the irrigated areas of Uzbekistan. The few experiments previously conducted in the region have shown the potential of CA in cotton-wheat systems, which compared different tillage methods (Tursunov 2009) and N fertilizer effect under conventional systems (Kienzler 2010; Djumaniyazova et al. 2010), but these studies did not address the N fertilization effects and NUE under CA practices. Fertilizer N recommendations developed for tilled systems may be inadequate for optimum crop production under conservation tillage (McConkey et al. 2002).

In general, adoption of CA practices is considered if farmers see a gain in net benefits compared to conventional practices (Uri 1999). Among the crop production factors, fertilizer in general contributed 20-50% to crop productivity (Ahmad et al. 1996). To promote the adoption of CA practices, proper N management strategies and technologies, which can increase the efficiency of the applied N, need to be identified.

The main objective of this study was to assess the effect of different levels of N application on N uptake, use efficiency, and N balance in a cotton/wheat/maize rotation system under conservation and conventional agriculture practices in irrigated drylands of Uzbekistan.

5.2 Methodology

5.2.1 Experimental site

The study was carried out on a research site of the ZEF/UZESCO project in the Khorezm region, Uzbekistan during 2008 and 2009 in a cotton/wheat/maize rotation system. For details in experimental site see section 3.2.1.

5.2.2 Experimental design and treatments

A three-factor, split-plot experiment with four replications was implemented, with bed planting (BP) and conventional tillage (CT) as the main factor. These were combined with two residue levels (residue retained: RR and residue harvested: RH) and three N levels (no application (0-N), and less than (Low-N) and more than (High-N) the recommended dose) as the sub-plot factors. For treatment details see section 4.2.2.

5.2.3 Measurements and analyses

Total plant N uptake

Plant samples were collected to measure biomass accumulation and N concentration in respective plants parts in every 15 days for wheat and maize, and for cotton according to growth stages (i.e., 2-4 leaf, budding, flowering, boll formation and maturity). Wheat plants were sampled from a 0.25 m^2 area. For cotton and maize, five representative plants were sampled each time. Biomass was separated into green leaves, senescence leaves, stem and floral parts and oven dried at 70 $^{\circ}$C till constant weight. The dried plant samples were ground to pass a 1-mm sieve and analyzed for N concentration. The N concentration of each plant component was determined as % N content by Kjeldahl method (Bremner and Mulvaney 1982). The total plant N concentration was determined by the average N concentration of each plant part. For the calculation of N uptake, the N content (%) was multiplied with the respective dry weight of the plant component (equation 3.3), and summed to determine the total N uptake.

Soil sampling and analysis

Initial soil samples were collected before the start of the experiment and analyzed for total N and organic carbon (OC), available phosphorus (P_2O_5), exchangeable potash (K_2O) and mineral N (NO_3-N and NH_4-N) to estimate the chemical properties of the experimental site. Soil samples were furthermore collected from all plots after each crop harvest. Samples were collected from five different depths, i.e., 0-10, 10-20, 20-30, 30-60 and 60-90 cm, at three different points in each plot and mixed thoroughly to obtain a composite sample. The samples were dried in a solar drier until completely dry, ground to pass a 1-mm sieve, and mixed thoroughly. Total and mineral N, available P_2O_5, exchangeable K_2O and total C were analyzed using standard procedures in Uzbekistan as described by Kienzler (2010). Total N was analyzed by the Kjeldahl method (Bremner and Mulvaney 1982), i.e., wet oxidation of soil organic matter using sulfuric acid. The NO_3-N content (mg kg^{-1}) was analyzed by calorimetrically with phenol disulphonic acid according to modified methods of Granvald-Ljashu method from 1886 (Silber 1913; Haper 1924; Durynina and Egorov 1998), and NH_4-N content (mg kg^{-1}) was analysed using the Nessler reagent (Yuen and Pollard 1952; Yuen and Pollard 1954; Durynina and Egorov 1998). Organic carbon (C) was determined according to Tyurin (Cotton Research Institute 1977; Durynina and Egorov 1998), which is a modified Walkley-Black method (Nelson and Sommers 1982). Available P_2O_5 (mg kg^{-1}) and exchangeable K_2O (mg kg^{-1}) were analyzed according to the method described by Machigin-Protasov[2], which can be compared to the Olsen methodology (Olsen and Sommers 1982).

Nitrogen use efficiency

Nitrogen use efficiencies at crop harvest were calculated for each crop according the formula given in section 3.2.8. Agronomic efficiency (AE_N, grain yield per kg N applied) was computed following Novoa and Loomis (1981) (equation 3.6), physiological efficiency (PE_N, grain yield per kg N uptake) was computed following Isfan (1990) (equation 3.5), and apparent recovery efficiency (ARE_N, N uptake per kg of N applied) were calculated following (Dilz, 1988) (equation 3.4).

[2] Extraction of P and K compounds with 1%-solution ammonium carbonate, pH 9.0,flame photometer

Apparent N balance and system efficiency

The apparent N balance was estimated from total plant N uptake (cotton, wheat and maize), initial residual mineral N in the top 90 cm soil profile, applied N, and NO_3-N in irrigation water. The cumulative N input and output were calculated for each treatment. Nitrogen loss (via leaching and denitrification) and N supply from organic N and fallen leaves from the previous crop were not considered in the N balance calculation. Nitrate N supply by irrigation water was calculated from the total amount of irrigation water applied during the three cropping seasons multiplied by the average NO_3-N concentration in irrigation water (1.2 ± 0.14 mg l^{-1}). For details on the amount of water applied to each crop for bed planting and conventional tillage is presented in Table 4.2. Measurement for NO_3-N concentration in irrigation water is described in section 3.2.9.

Apparent N balance for cotton/wheat/maize systems was hence calculated according to formula modified from Timsina et al. (2001) (equation 5.1).

$$\boxed{\begin{array}{l}\text{Apparent system N balance (kg ha}^{-1}\text{) = Input (initial soil mineral N +}\\ \text{amount N applied + N from irrigation) - Output ((total plant N uptake}\\ \text{(cotton + wheat + maize)) + soil mineral N at maize harvest}\end{array}} \qquad (5.1)$$

Similarly, to calculate the apparent N balance for the individual crop, i.e., cotton or wheat or maize, input (mineral N before planting + amount N applied + N from irrigation) - output (N uptake by the crop + soil mineral N at crop harvest) were considered.

Nitrogen use efficiency of the cotton/wheat/maize system was calculated according to Timsina et al. (2001) as: (equation 5.2)

$$\boxed{\begin{array}{l}\text{System N efficiency (\%) =}\\ \dfrac{\text{Total N uptake (cotton + wheat + maize) + mineral N at harvest in top 90 cm soil}}{\text{Initial mineral N in 90 cm soil depth + N addition from fertilizer and irrigation}} \text{X100}\end{array}} \qquad (5.2)$$

5.2.4 Statistical analysis

Nitrogen uptake, use efficiencies and apparent N balance were statistically analyzed as a split-plot factorial design with four replications. Major soil nutrients changes over time under different treatments were analyzed using repeated measures. Treatment effects were compared through the analysis of variance using GenStat Discovery Edition 3. Main and interaction effects were compared using Fisher's protected LSD (least significant difference; P=0.05). Simple non-linear regression analysis was also carried out for the grain yield response to N rates and N uptake. The curves were fitted using a quadratic function using SigmaPlot version 11.0.

5.3 Results

5.3.1 Total plant N uptake and concentration

Cotton

The total aboveground plant N uptake before flowering (i.e., before irrigation and fertilizer application) was higher ($p<0.05$) under CT than in BP (Table 3.5). This increased N uptake coincided with the faster early growth and higher biomass production during the early stage under CT (Figure 3.2). However, after flowering, no significant difference was observed between tillage methods in N uptake. Nitrogen application increased total N uptake only after flowering (i.e., after irrigation) compared to N-0, while no difference was observed with increased N level from N-125 to N-250.

Wheat

Irrespective of N level, the total plant N uptake in wheat was higher in BP than under CT at all growth stages, but a significant difference was observed only at heading and at maturity (Table 5.1). Averaged over the N rates, the total N uptake at maturity was higher ($p=0.1$) by 14% in BP (170 kg ha^{-1}) than under CT (149 kg ha^{-1}), which is consistent with the 12% higher grain yield recorded for BP. Nitrogen applications increased ($p<0.001$) the total plant N uptake compared to N-0 for the whole period, being highest at 200 kg N $ha\text{-}^{1}$ with both tillage methods. A significant tillage by N interaction effects for total N uptake was observed at heading and grain-filling stages, where BP with N-100 showed higher ($p<0.05$) N uptake by 61% at heading and by 51%

at grain-filling than CT (Figure 5.1). But the tillage had no significant effect on total N uptake with N-0 and N-200.

Total plant N concentration in wheat was not affected ($p>0.05$) by tillage method, while it increased significantly ($p<0.05$) with N application compared to N-0 at all growth stages (Figure 5.2). Irrespective of tillage method, N-100 increased the plant N concentration by 74% at heading, by 58% at grain-filling and by 35% at maturity compared to N-0. However, with N-100 to N-200, total N concentration increased by 15% after heading (Figure 5.2). Although there was a significant tillage by N interaction effect only at heading, with N-100, BP showed a higher total N concentration than CT; it was higher by 20% at heading and by 14% at grain-filling and maturity. In contrast, with N-200, CT had higher total plant N concentration than BP; it was higher by 17% at heading and by 10% at grain-filling (Figure 5.2).

Maize

In maize, total plant N uptake during the growing season was significantly affected by the main effects of tillage and N application rate and their interaction effects (Table 5.1). Irrespective of the N level, the total N uptake in BP was higher ($p<0.05$) than under CT; it was higher by 2.3-fold at the vegetative, 47% at the reproductive, and 41% at the maturity stage (Table 5.1). The total N uptake at maturity in BP is consistent with the 42% higher grain yield recorded for BP.

Although total N uptake in maize increased with N application in both tillage methods, the uptake was higher in BP than under CT at all growth stages (Figure 5.3). During the vegetative stage, with N application BP had a more than two times higher (125% higher) N uptake than CT. Similarly, with N-100, total N uptake in BP was higher by 38% after the reproductive stage than under CT. This response was even higher with the increased N level, i.e., with N-200. In contrast, tillage had no significant effect on total N uptake with N-0.

Table 5.1 Main effects of tillage method and N fertilizer level (kg ha^{-1}) on plant N uptake of wheat and maize at different growth stages.

Treatment	Wheat growth stage (DAS)				Maize growth stage (DAS)		
	Spike initiation (167)†	Heading (199)	Grain-filling (215)	Maturity (240)	Vegetative (23)	Reproductive (51)	Maturity (93)
	(kg ha^{-1})						
Tillage							
BP	36	118	155	170	4.3	47	130
CT	34	103	137	149	1.8	32	92
LSD	41	8	43	35	1.2	16	25.8
Nitrogen							
0	13	26	35	53	1.7	15	51
100	42	123	169	178	3.4	41	117
200	51	183	233	247	4.1	63	165
LSD	14	16	38	30	0.87	4	16
				ANOVA			
Tillage	ns	**	ns	+	**	*	*
N level	***	***	***	***	***	***	***
N x T	ns	***	*	ns	**	***	***
LSD	31	19	48	42	1.2	12	26
Mean	35	110	146	159	3	39	111

BP=bed planting and CT=conventional tillage.
Significance level: +$P \leq 0.1$; *$P \leq 0.05$; **$P \leq 0.01$; *** $p \leq 0.001$; ns=non significant.
†Values in parenthesis represent the sampling time; DAS=days after sowing.

Irrespective of the N application, RR in BP increased total N uptake compared to RH at all growth stages of maize, and the effect was stronger in the early growth stages (Figure 5.4). Although there was no significant interaction ($p>0.05$) between N and residue level, the values were comparable. The RR in the N-0 treatment increased ($p<0.05$) total N uptake by more than two-fold at the vegetative (103% higher), and the reproductive (123% higher) stages and by 64% at the maturity stages compared to RH. However, RR had no significant effect in the N-applied treatments.

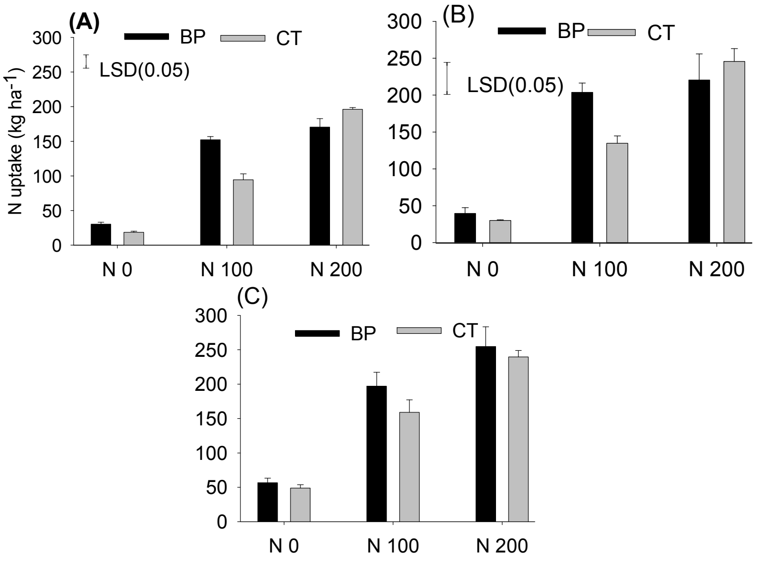


Figure 5.1 Interaction effects between tillage method and N level on N uptake (kg ha^{-1}) of wheat at (A) heading, (B) grain-filling and(C) maturity stages. BP=bed planting, CT=conventional tillage. Bars represent standard error.

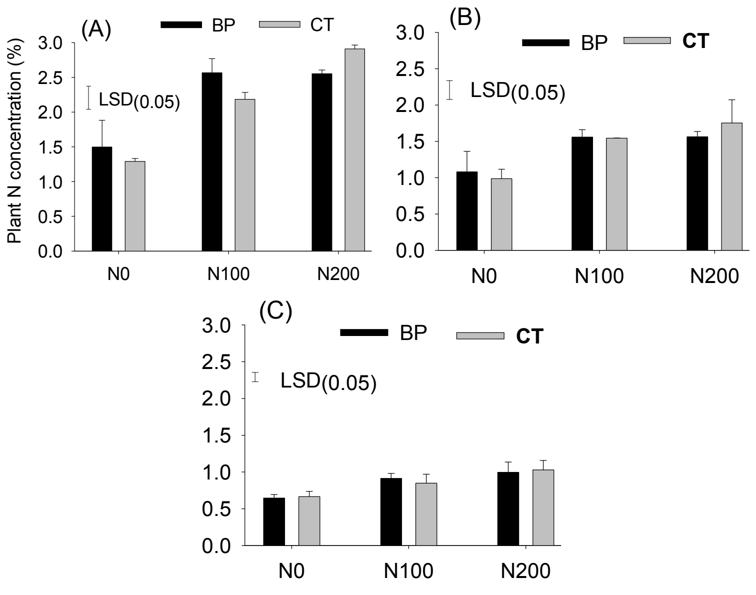


Figure 5.2 Interaction effects between tillage method (T) and nitrogen (N) level on total plant N concentration (%) of wheat at (A) heading, (B) grain-filling and (C) maturity stages. BP=bed planting and CT=conventional tillage. Bar represent standard error.

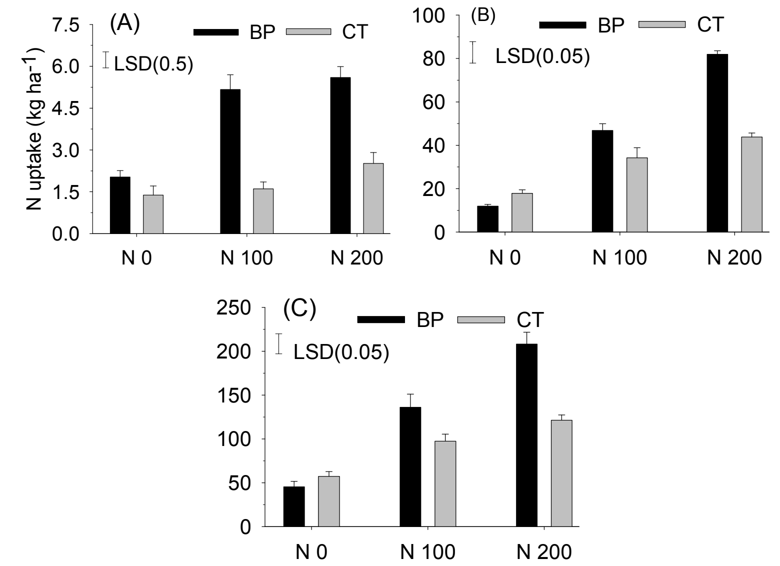


Figure 5.3 Interaction effects between tillage method (T) and N level on total N uptake (kg ha^{-1}) of maize at (A) vegetative, (B) reproductive and (C) maturity stages. BP=bed planting and CT=conventional tillage. Bars represent standard error.

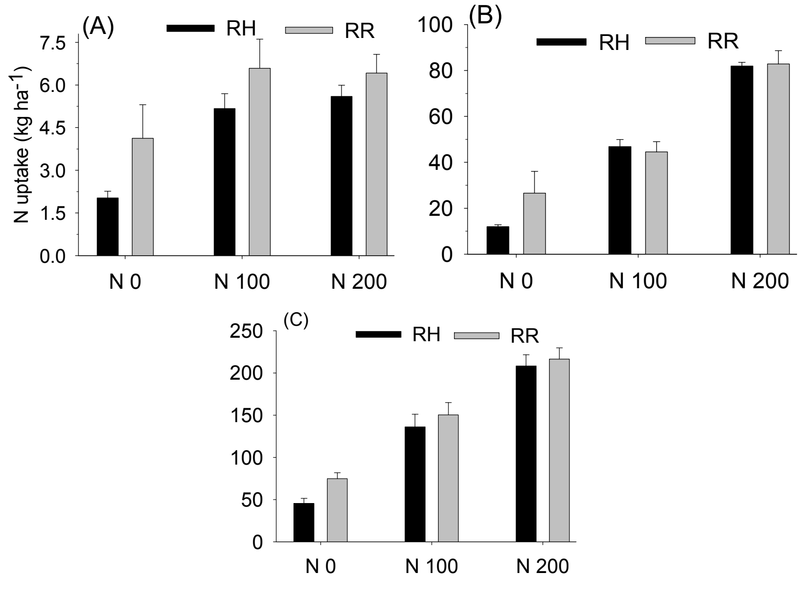


Figure 5.4 Interaction effects between residue (R) and nitrogen (N) level on total N uptake (kg ha^{-1}) of bed planted maize at (A) vegetative, (B) reproductive and (C) maturity stage. RH=residue harvested and RR=residue retained. Bars represent standard error.

5.3.2 Nitrogen use efficiency

Cotton

Tillage method did not affect ($p>0.05$) N use efficiency (NUE) parameters (i.e., AE_N, ARE_N and PE_N). The highest AE_N (7 kg raw cotton per kg N applied) and ARE_N (68%) were observed with N-125 in both tillage methods, but PE_N was highest with N-250 (13 kg raw cotton per kg N uptake). However, AE_N and ARE_N were significantly decreased ($p<0.05$) with increased N level, where AE_N decreased by 42% and ARE_N by 44% with N-125 to N-250 (Table 3.6).

Wheat

Similar to the cotton crop, none of the NUE parameters were significantly ($p>0.05$) affected by tillage method. Although the effect was non-significant, BP showed slightly higher AE_N and ARE_N values than CT (Table 5.2). The 12% higher ARE_N in BP than under CT is consistent with the higher grain yields recorded for BP. The highest NUE parameters were observed with N-100 in both tillage methods, i.e., AE_N was 51 kg grain per kg N applied, PE_N was 43 kg grain per kg N uptake, and ARE_N was 128%. Which, however were decreased significantly with increased N application rates from N-100 to N-200. Averaged over tillage method, the AE_N decreased by 55%, PE_N by 17% and ARE_N by 30% with increased N level from N-100 to N-200. Irrespective of tillage and N level, RR increased ($p<0.05$) the AE_N by 12% compared to RH.

Maize

In maize, the highest NUE parameters were observed with N-100 in both tillage methods, i.e., AE_N was 26 kg grain per kg N applied, PE_N was 40 kg grain per kg N uptake, and ARE_N of applied N was 67%. AE_N and ARE_N were higher ($p<0.05$) in BP than under CT, while PE_N was not affected ($p>0.05$) by tillage method (Table 5.2). Irrespective of N and residue level, AE_N and ARE_N in BP were higher by 75 and 82%, respectively, than with CT. With increased N level in maize all NUE parameters were significantly lower, where AE_N decreased by 41%, PE_N by 30% and ARE_N by 17% with N-200 compared to N-100.

Table 5.2 Main effect of tillage method, N level, and residue on agronomic efficiency (AE_N), physiological efficiency (PE_N) and apparent recovery efficiency (ARE_N) of N fertilizer applied in wheat and maize.

Treatment	Wheat			Maize		
	AE_N (kg kg^{-1})	PE_N (kg kg^{-1})	ARE_N (%)	AE_N (kg kg^{-1})	PE_N (kg kg^{-1})	ARE_N (%)
Tillage						
BP	42.5	39.1	120	28	34.7	80
CT	41.9	40.7	107	16	36.6	44
LSD (0.05)	9.5	8.9	26.9	5.9	14.2	12
Nitrogen (kg ha^{-1})						
100	51.4	43.1	128.1	26.1	40.4	66.6
200	33	36.7	98.8	18.4	30.9	56.7
LSD (0.05)	5.9	4.3	21.9	3.9	7.1	12.5
Residue						
RH	44.7	-	-	21.3	33.8	61.1
RR	39.7	-	-	23.2	37.5	62.2
LSD (0.05)	3.9	-	-	3.9	7.1	12.5
			ANOVA			
Tillage (T)	ns	ns	ns	**	ns	**
Nitrogen (N)	***	**	**	***	*	+
Residue (R)	**	-	-	ns	ns	ns
N x T	ns	ns	ns	ns	ns	ns
T x R	+	-	-	*	ns	*
LSD (0.05)	9.5	-	-	5.8	13.2	14.9
N x R	ns	-	-	ns	ns	ns
T x N x R	ns	-	-	ns	ns	ns
Mean	42	40	113	22	36	62

BP=bed planting, CT=conventional tillage, RH=residue harvested, and RR=residue retained. Significance level: +$P \leq 0.1$ *$P \leq 0.05$; **$P \leq 0.01$; *** $p \leq 0.001$; ns=non significant.

A significant interaction effects between tillage and residue level was observed for AE_N and ARE_N in maize. Under CT, RR increased ($p<0.05$) the AE_N and ARE_N by 42% compared to RH. However, RR in BP decreased ($p>0.05$) the AE_N by 7% and ARE_N by 15% compared to RH (Figures 5.5A and 5.5B).

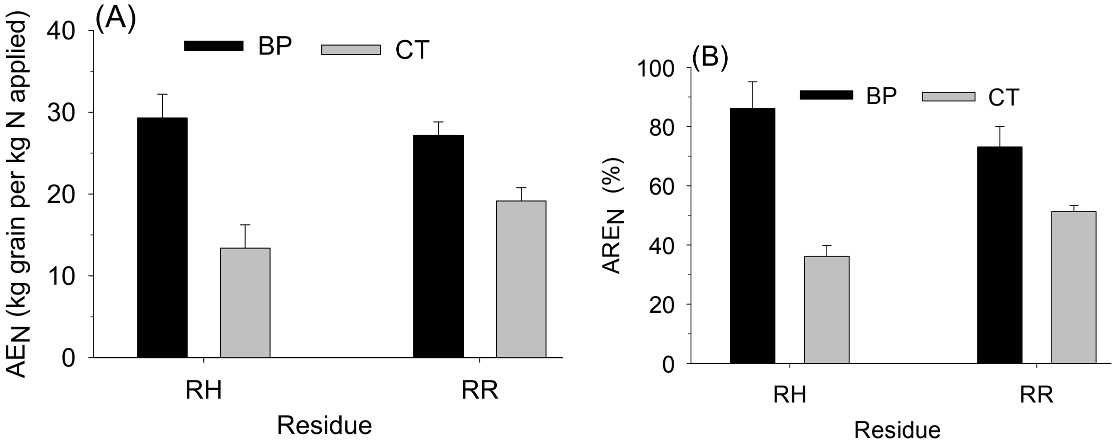


Figure 5.5 Interaction effects between tillage method and residue level in (A) agronomic efficiency (AE_N) and (B) apparent recovery efficiency (ARE_N), of applied N in maize. BP=bed planting, CT=conventional tillage, RH=residue harvested, RR=residue retained. Bars represent standard error.

5.3.3 Relationship between grain yield, N level and total N uptake

Wheat

Wheat grain yield vs. N level

Wheat grain yield as a function of N application for both tillage methods increased from 2.5 to 10 t ha^{-1} as the N level increased from 0 to 200 kg ha^{-1} (Figure 5.6A). In both tillage methods, grain yield was increased linearly with applied N up to 150 kg ha^{-1} after which the relative increase in yield was lower. Thus, every kg of N added above 150 kg ha^{-1} does not lead to the same relative effect. The average grain yield at all N levels was higher in BP than under CT, i.e., higher by 33% in N-0, 15% in N-100 and 5% in N-200. This shows that changing the tillage method from CT to BP tended to increase grain yield of wheat with both low and high N supply.

Wheat grain yield vs. N uptake

The relationship between grain yield and total N uptake is similar for both tillage methods up to 200 kg N uptake. However, grain yield in BP was higher than under CT when N uptake was more than 200 kg ha^{-1}, i.e., BP had an 8% higher grain yield (10196 kg ha^{-1}) than CT (9428 kg ha^{-1}) at 275 kg ha^{-1} N uptake (Figure 5.6B).

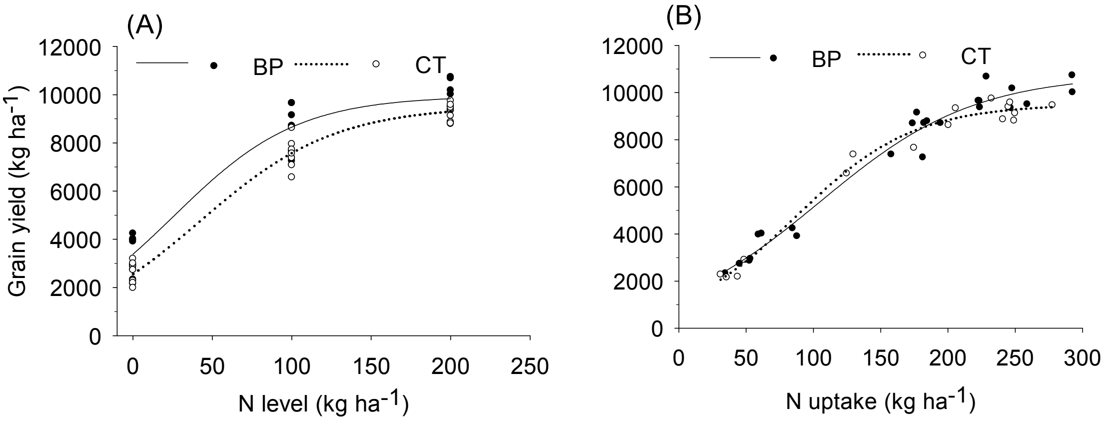


Figure 5.6 Relationship between (A) grain yield and N level and (B) grain yield and total N uptake, with two tillage methods in wheat. BP=bed planting and CT=conventional tillage. Fitted relationships between yield and N level: $Y_{(BP)}=9946/(1+\exp(-(x-25)/39)))$, $r^2=0.97$; $Y_{(CT)}=9521/(1+\exp(-(x-42)/42)))$, $r^2=0.98$; and between yield and N uptake: $Y_{(BP)}=10765/(1+\exp(-(x-105)/57)))$, $r^2=0.97$; $Y_{(CT)}=9503/(1+\exp(-(x-87)/43)))$, $r^2=0.98$

Maize

Maize grain yield vs. N level

Grain yield of maize increased from 1.7 to 7.2 t ha^{-1} as the N level increased from 0 to 200 kg ha^{-1} (Figure 5.7A). When changing the tillage method from conventional to conservation, with per kg N fertilized, grain yields in BP was always higher than under CT, except for N levels below 50 kg ha^{-1}, where yields under CT were higher (Figure 5.7A). The combination of RR and BP showed a high response of applied N, which exceeded that of all other treatments even at low N levels. However, RR under CT had a negative effect; as the grain yield with N application was always about 200 kg ha^{-1} lower than with RH.

Maize grain yield vs. N uptake

The relationship between grain yield and total N uptake was similar in both tillage methods up to 125 kg ha^{-1} N uptake. However, afterwards with per kg N uptake BP showed higher yield response than CT. With an uptake of 180 kg ha^{-1} N, BP showed a 19% higher grain yield (6646 kg ha^{-1}) than CT (5563 kg ha^{-1}) (Figure 5.7B). A further increase in N uptake was not observed under CT, while in BP it was up to 240 kg ha^{-1} with a grain yield of 7335 kg ha^{-1}.

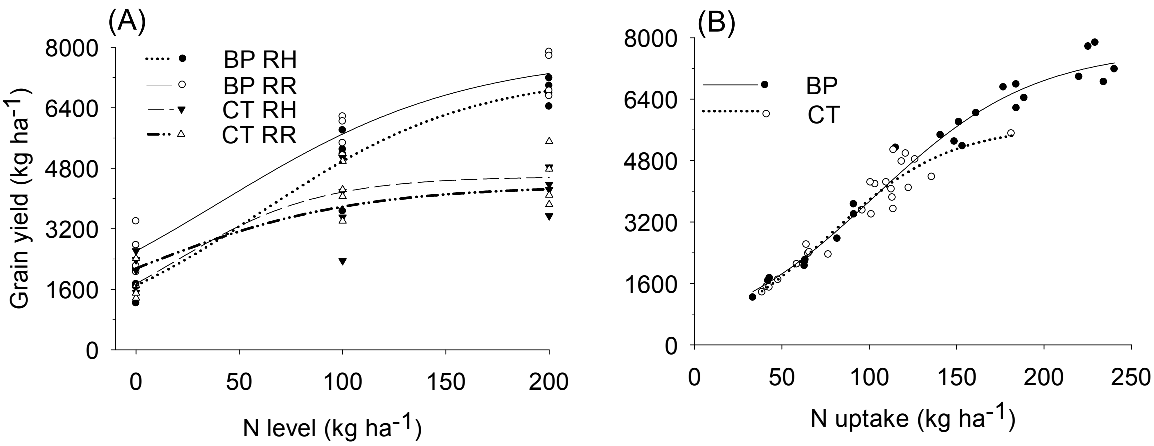


Figure 5.7 Relationship between (A) grain yield and N fertilizer level in two tillage methods and two residue levels and (B) grain yield and total N uptake under BP and CT in maize. BP RH=bed planting with residue harvested and BP RR=bed planting with residue retained, CT RH=conventional tillage with residue harvested, and CT RR=conventional tillage with residue retained. BP=bed planting and CT=conventional tillage. Fitted relationships between yield and N level: $Y_{(BP\ RH)}= 7209/(1+\exp(-(x-60)/51)))$, $r^2=0.94$; $Y_{(BP\ RR)}= 7798/(1+\exp(-(x-40)/59)))$, $r^2=0.94$; $Y_{(CT\ RH)}= 4334/(1+\exp(-(x-0.7)/51)))$, $r^2=0.64$; $Y_{(CT\ RR)}= 4581/(1+\exp(-(x-17)/35)))$, $r^2=0.84$; and between yield and N uptake: $Y_{(BP)}= 7705/(1+\exp(-(x-103)/46)))$, $r^2=0.98$; $Y_{(CT)}= 5701/(1+\exp(-(x-77)/34)))$, $r^2=0.92$.

5.3.4 Apparent N balance

In wheat, apparent N balance remained negative with both tillage methods (Table 5.3). Averaged over the N levels, BP showed a 38% higher (p=0.1) negative N balance (-80 kg ha^{-1}) than CT (-58 kg ha^{-1}). Nitrogen level had no significant effect on apparent N balance, and the balance remained negative with all three N levels (Figure 5.8A). This indicates, in wheat season N loss did not occur with high- and low- N applications in both BP and CT.

The main effects of both tillage and N level showed a significant effect on apparent N balance in maize (Table 5.3). Averaged over tillage method, with N-0 the apparent N balance was negative, while with N-100 and N-200 the N balance was positive. With N-0, BP showed a 40% higher negative N balance than CT (Figure 5.8B). Similarly, with N-100, BP showed an equal N balance (-0.4 kg ha^{-1}), while CT showed a positive N balance (+27 kg ha^{-1}). With N-200, CT showed a higher positive N balance (79 kg ha^{-1}) than BP (11 kg ha^{-1}).

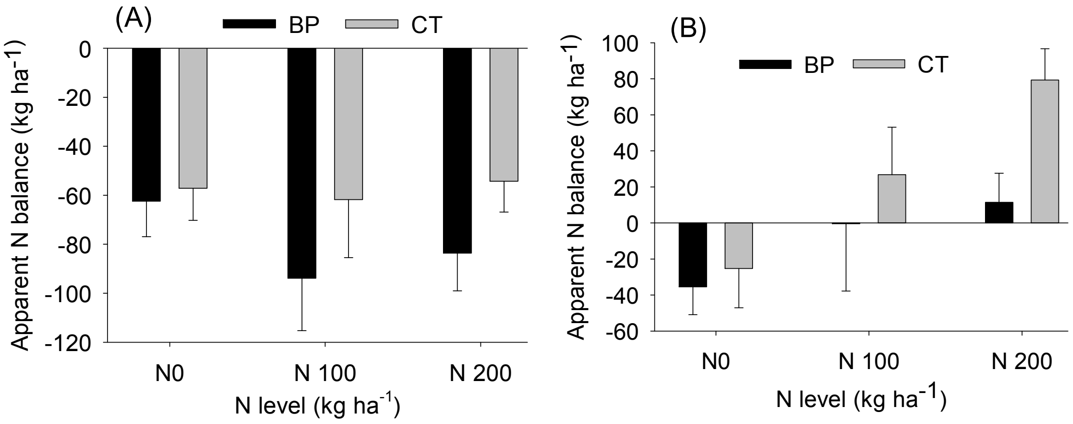


Figure 5.8 Interaction effect between tillage and N level in apparent N balance (A) for wheat and (B) for maize. BP=bed planting and CT=conventional tillage. Bars represent standard error.

Averaged over N level, the apparent N balance in the cotton/wheat/maize rotation systems was negative with both tillage methods, i.e., -83 kg ha^{-1} in BP and -37 kg ha^{-1} under CT. Irrespective of tillage, 0-N and low-N application level showed a negative N balance, while high-N showed a positive balance (Table 5.3).

With 0-N, BP and CT showed similar negative N balances (-154 kg ha^{-1}), while with low-N application BP showed a higher negative N balance (-127 kg ha^{-1}) than CT (-64 kg ha^{-1}). In contrast, with high-N application a positive N balance was observed, where CT showed a higher positive N balance (133 kg ha^{-1}) than BP (38 kg ha^{-1}). Under residues retained conditions in BP, the negative N balance was further higher in 0-N, but the effect of residue was not observed with high-N application (Figure 5.9A).

5.3.5 System N use efficiency

Irrespective of N level, the system N efficiency was higher ($p>0.05$) in BP (141%) than under CT (134%). The efficiency decreased ($p<0.05$) with increased N level in both tillage methods. Irrespective of tillage, system N efficiency was 200% with 0-N-0, 121% with low-N, and 91% with high-N (Table 5.3), which is consistent with the decrease in NUE with increased N level. System N efficiency in the RR treatments in BP was higher with 0-N, but no effect with high-N was observed (Figure 5.9B).

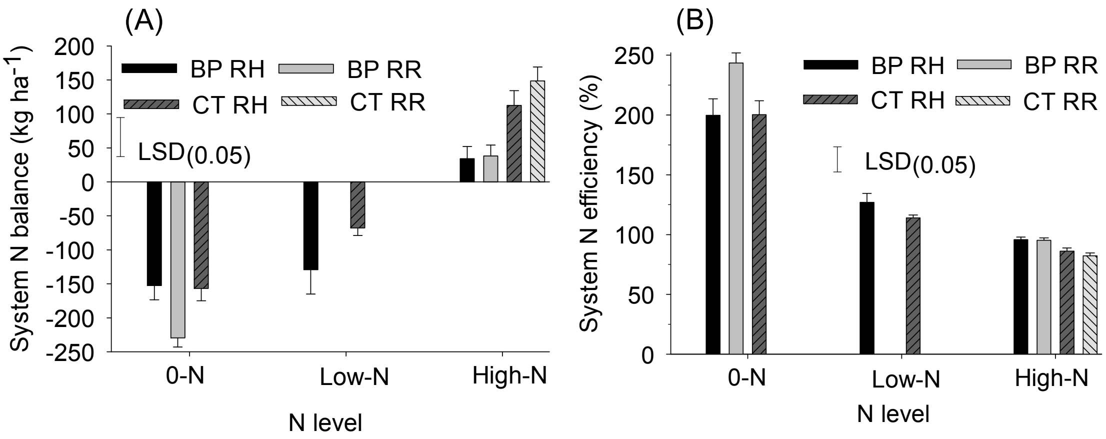


Figure 5.9 Interaction effects of tillage method, N level (0-N (no application), low-N (125 kg N ha^{-1} for cotton and 100 kg N ha^{-1} for wheat and maize, and high-N (250 kg N ha^{-1} for cotton and 200 kg N ha^{-1} for wheat and maize)), and residue level on (A) system apparent N balance (kg ha^{-1}) and (B) system N efficiency (%), in cotton/wheat/maize system. BP RH=bed with residue harvest, BP RR=bed with residue retention, CT RH=conventional tillage with residue harvest, and CT RR=conventional tillage with residue retention.

Table 5.3 Main effects of tillage method and N level (kg ha^{-1}) on mineral N at harvest, total input, total output and apparent N balance and system level N efficiency of cotton/wheat/maize system in irrigated drylands .

Treatment	Mineral N at 90 cm soil depth after harvest			Wheat			Maize			Total N from Irrigation	System level N balance[d]	System level N efficiency[e]
	Cotton	Wheat	Maize	Input[a]	Output[b]	Balance[c]	Input[a]	Output[b]	Balance[c]			
Tillage	(kg ha^{-1})											(%)
BP	93	106	93	191	271	-80	215	223	-8	17.7	-83	141
CT	90	107	101	196	254	-58	220	193	27	20.7	-37	134
LSD	22	13	33	17	25	32	13	40	42	-	76	29
Nitrogen												
0-N	86	106	95	92	152	-60	116	146	-30	19.2	-155	200
Low-N	95	104	85	202	279	-78	215	202	13	19.2	-99	121
High-N	93	109	111	287	356	-69	322	276	45	19.2	73	91
LSD	13	14	24	26	27	25	14	35	36	-	45	17
ANOVA												
Tillage	ns	ns	ns	ns	+	+	ns	0.09	0.07	-	+	ns
N level (N)	ns	ns	0.09	***	***	ns	***	***	**	-	***	***
N x T	ns	ns	ns	ns	ns	ns	ns	ns	ns	-	+	ns
LSD	22	18	36	32	35	36	18	48	50	-	76	29
Mean	92	107	97	194	262	-69	217	208	9	-	-60	137

BP=bed planting, CT=conventional tillage. Significance level: + $P \leq 0.1$ *$P \leq 0.05$; **$P \leq 0.01$; *** $p \leq 0.001$; ns=non significant, LSD- least significant difference at (p=0.05).

[a] Input = (mineral N during planting + mineral N from fertilizer and irrigation); [b] Output = (crop N uptake + mineral N at harvest); [c] N balance = (N input – N output). For N uptake by cotton see section 3.3.5 and N uptake by wheat and maize see Table 5.1. Mineral N before cotton was 135 kg ha^{-1} in all treatments.

[d] System apparent N balance = (N uptake by crops (cotton, wheat and maize) + mineral N after maize)-(N addition from fertilizer and irrigation + mineral N before cotton);

[e] System level efficiency = (N uptake by crops + mineral N after maize)/ (N from fertilizer and irrigation + mineral N before cotton).

Table 5.4 Major soil nutrients as affected by tillage method and N level in cotton/wheat/maize system.

Treatment			Total nitrogen (g kg^{-1})	Organic carbon (g kg^{-1})	Mineral nitrogen (mg kg^{-1})	Available phosphorus (mg kg^{-1})	Exchangeable potash (mg kg^{-1})
Crop	Tillage	N level (kg ha^{-1})					
Cotton	BP	0	0.54	2.63	6.13	24.2	94
		125	0.57	2.8	6.72	26.6	105
		250	0.51	2.66	7.56	22.5	104
		Mean	**0.54**	**2.7**	**6.8**	**24.4**	**101**
	CT	0	0.50	2.8	6.88	24.0	98
		125	0.56	2.71	7.34	20.0	106
		250	0.54	2.76	7.07	23.9	90
		Mean	**0.53**	**2.76**	**7.1**	**22.6**	**98**
	Mean		0.53	2.73	6.95	23.9	99.5
Wheat	BP	0	0.31	3.59	8.39	8.98	123
		100	0.41	4.16	8.07	9.9	116
		200	0.33	4.13	8.43	9.6	116
		Mean	**0.35**	**3.96**	**8.3**	**9.5**	**118**
	CT	0	0.33	3.73	9.06	10.1	119
		100	0.34	4.27	7.77	8.3	114
		200	0.37	4.15	8.27	9.1	114
		Mean	**0.35**	**4.05**	**8.37**	**9.1**	**116**
	Mean		0.35	4.01	8.3	9.25	116.8
Maize	BP	0	0.32	3.83	7.91	14	95
		100	0.35	4.01	7.01	14	93
		200	0.36	4.25	7.59	9.6	95
		Mean	**0.34**	**4.03**	**7.5**	**12.7**	**95**
	CT	0	0.36	4.14	6.99	12.3	96
		100	0.36	4.24	7.29	11.5	95
		200	0.32	3.82	8.32	10.9	85
		Mean	**0.35**	**4.1**	**7.5**	**11.6**	**92**
	Mean		0.34	4.1	7.52	12.0	93
				ANOVA			
Tillage			ns	ns	ns	**	*
Nitrogen (N)			***	***	**	*	*
Time			***	***	***	***	***
Time x Tillage x N			**	*	**	*	ns
LSD (0.05)			0.04	0.29	0.84	2.4	10.6
Mean			0.41	3.6	7.6	15.06	103.1

BP=bed planting and CT=conventional tillage. Significance level: *$P\leq0.05$; **$P\leq0.01$; *** $p\leq0.001$; ns=non significant

5.3.6 Changes in major soil nutrients

In the cotton/wheat/maize system, total soil nitrogen (TN) and organic carbon (OC) content were not affected ($p>0.05$) by tillage method (Table 5.4). Averaged over tillage and N level, TN decreased ($p<0.05$) by 35%, while OC increased ($p<0.05$) by 47% at wheat harvest compared to cotton harvest. However, at the end of the maize season, TN and OC were unchanged compared to wheat season. The effects of N level on TN and OC were inconsistent over the crop season, but in general increased ($p<0.05$) with N application with both tillage methods.

Irrespective of crop season and N level**,** available phosphorus (AP) and exchangeable potassium (EK) were higher ($p<0.05$) in BP than under CT. The effects of N level on AP and EK were inconsistent over the crop season, but in general decreased with N application with both tillage methods. Irrespective of tillage and N level, AP decreased ($p<0.05$) by 61% in wheat compared to cotton, but increased by 29% in maize compared to wheat season. In contrast, EP increased ($p<0.05$) by 17% in wheat season compared to cotton, but decreased by 20% in maize compared to wheat (Table 5.4).

Irrespective of time and N level, tillage had no effect ($p>0.05$) on soil mineral N concentration, while this increased with N application with both tillage methods except in few cases. Irrespective of tillage and N level, mineral N during the wheat season was higher ($p<0.05$) by 17% than in the cotton and by 11% than in the maize season (Table 5.4).

5.4 Discussion

The response of a crop to the amount of applied N and the nitrogen use efficiency are important criteria for evaluating crop N requirements for maximum (economic) yields. Low N use efficiency is not only responsible for increased production cost, but also for environmental pollution (Fageria and Baligar, 2005). Thus, a balanced use of N fertilizer is important for an economically and ecologically sustainable crop production system.

5.4.1 Total plant N uptake and crop yield

The higher total plant N uptake under CT than in BP during the initial stage of cotton growth is associated with faster initial growth (section 3.3.2, *2008)*. The slower initial growth in BP could be due to the delayed germination of 3-5 days; perhaps due to the lower soil moisture contents in BP compared to CT. Volumetric moisture percent in the top 10 cm soil during cotton sowing was 10±1% in BP and 13±0.5% under CT. After fertilizer and irrigation applications, growth rates in BP surpassed those under CT; hence the difference between total N uptake in BP and CT became non-significant. This indicates that during the transition season from conventional to conservation agriculture total N uptake by the cotton plants was not affected by tillage method, which is consistent with the no difference in cotton yields between BP and CT. Although previous studies indicated usually increased total N uptake with N application (Rochester et al 1997; Chua et al. 2003), some studies reported only slight difference in N uptake with varying N application (Kienzler 2010). The relatively high residual mineral N content in the soil was apparently sufficient to compensate for the absence of or low N fertilizer applications. An uptake of 118 kg N ha^{-1} with the N-0 treatment and no significant difference in N uptake between the N-125 and N-250 treatments supports this hypothesis (initial mineral N in top 90 cm soil was 135 kg N ha^{-1}).

After one season of CA practices, the higher total plant N uptake in BP than under CT with N application in both wheat and maize crops suggests that availability of applied N was higher in BP than under CT. Grain yield per kg of applied N for both wheat and maize crops was always higher in BP than under CT (Figures 5.6 and 5.7). This shows that to obtain the same yield benefits, BP demands lower N application levels than CT. In wheat, the increased N availability could have been due not only to the consistently higher soil moisture in BP than under CT (section 4.3.3), but also to a better contact between seeds and soil due to seed drilling compared to the broadcast seeding under CT (Gursoy et al. 2010). The greater difference in total plant N uptake between BP and CT with N-100 in this study suggests that BP was even more efficient than CT with low-N applications. This is supported by higher plant N concentrations (Figure 5.2) and a 10-20% higher aboveground biomass accumulation (Figure 4.3B) in BP with N-100 than under CT. Furthermore, the higher soil mineral N concentration in the top 90 cm soil, i.e., higher by 5% at heading, 30% at grain-filling and 10% at maturity in BP than under CT with N-100, also supports the high N availability in BP with N-100. Higher soil mineral N in the system led in turn to high plant N uptake (Anga's et al. 2006).

However, with N-200, the higher plant N concentration and uptake during the initial growth stage of wheat under CT than in BP could also have been caused by high initial soil mineral N concentration. For example, CT with N-200 had higher soil mineral N concentration by 23% (11.14 vs. 9.08 mg kg^{-1}) at spike initiation and by 32% (9.49 vs. 7.18 mg kg^{-1}) at heading than under BP. It may have been that a flush of N mineralization had occurred following cultivation prior to the onset of rapid early crop growth under CT as previously suggested (Francis and Knight 1993). Furthermore, previous research by Carter (1991) and Braim et al. (1992) showed that soil loosening prior to seeding in sandy loam soil increased the release of mineral N from SOC and applied fertilizer, which leads to increased N accumulation in plants, while under conservation tillage, mineralization used to be more evenly distributed over the growing season.

In maize, higher response of applied N in BP than CT could be due to earlier seedling emergence and faster growth and development of maize in BP than in CT (Figure 4.5). In an experiment in the central highlands of Mexico in moderately heavy soil, Fischer et al. (2002) observed that maize under conservation tillage emerged three days earlier and showed greater growth during the first week after seeding, which led to higher biomass accumulation than under CT. An improvement of early growth resulted in increased aboveground (Figure 4.5) and root biomass accumulation (Figure 4.7), which may have increased the plant N requirement that could be satisfied by the applied N fertilizer. Crop-N demand generally is determined by root and shoots biomass accumulation (Cassman et al. 2002). Furthermore, Gastal and Lemaire (2002) reported that N uptake rate of crops is regulated not only by N application and soil availability but also by crop growth rate. This could be the reason for low N uptake in CT in this study even with high-N application.

Furthermore, the higher availability of P_2O_5 in BP (15.4 mg kg^{-1}) than under CT (14.3 mg kg^{-1}), and higher exchangeable K_2O in BP (105 mg kg^{-1}) than under CT (102 mg kg^{-1}) could have contributed to the increased N uptake in BP. High P_2O_5 concentration in the soil stimulates crop root growth, which contributes to increase N uptake is also reported by Hollanda et al. (1998).

The increase in total plant N uptake in BP led to increased crop yield (section 5.3.3) while reducing N loss. This finding is important for farmers and for the environment. Increased wheat grain protein with high N uptake was also reported by Kienzler (2010) for the study region. This is important for Uzbekistan where the quality of the wheat grain is usually low (Kienzler 2010).

5.4.2 Nitrogen use efficiency

The higher AE_N and ARE_N in wheat and maize in BP than under CT in this study is related to the higher N uptake (Table 5.2) and grain yield (section 4.3.2). No significant difference in PE_N in both the wheat and maize crops indicates that the change in grain yield per unit N accumulation in the aboveground biomass is largely governed by genetic factors (Yusuf et al. 2009).

Nitrogen use efficiency was decreased as N fertilizer level increased in all three crops, i.e., cotton, wheat and maize (Table 5.2). This could be due to the fact that grain yield rose less than the N supply by fertilizer as indicated by the linear increase in grain yield of wheat and maize up to 150 kg N ha^{-1} application; beyond this N level, the relative increment decreased (Figures 5.6 and 5.7). Decrease NUE with increasing N level had also been reported by Lopez-bellido and Lopez-bellido (2001), Latiri-Souki et al. (1998), and Palta and Fillery (1995) for wheat. This indicates that it may not be worthwhile for the farmers to grow wheat and maize under such conditions with investing more than 150 kg N ha^{-1} during the transition phase from CT to BP practices.

Decreased AE_N in wheat, and AE_N and ARE_N in maize in BP with RR treatments compared to RH could be due to immobilization of applied fertilizer N in the surface residues which were also previously reported by Carter and Rennie (1984) and Verachtert et al. (2009). However, Karlen (1990) argued that the initial lower fertilizer use efficiency due to N immobilization under conservation tillage also indicated a conservation of soil and fertilizer N as soil organic matter, and thus that the fertilizer requirements may decrease over time under conservation tillage. The immobilization alone, however, cannot explain the low NUE with the RR treatments in both wheat and maize. In addition, the higher grain yield and N uptake of wheat and maize in N-0 with RR resulted in a larger supply and higher uptake of residual or mineralized N from residues which were also previously reported (Limon-Ortega et al. 2000) for a maize-wheat system in Mexico and for a rice-wheat-maize system in Bangladesh under conservation agriculture (Talkudar et al. 2008). In contrast, increased AE_N and ARE_N in maize under CT with RR treatments compared to RH could be explained by the rapid decomposition and slower release of applied and immobilized N, which may have increased the NUE. Beare et al. (1993) reported that incorporated residues decomposed 3-4 times faster than residues left on the soil surface.

In wheat, the AE_N was considerably higher (average 42 kg grain kg^{-1} N applied) than the 7-11 kg kg^{-1} observed by Kienzler (2010) in the same study region in a conventional system with 120 and 180 kg N ha^{-1}, and a 29 kg grain per kg N supply observed by Limon-Ortega et al. (2000) in northern Mexico in permanent bed planting. Similarly, the ARE_N (113%) of the applied N in the wheat in this study was higher than that reported by Kienzler (2010), who found only 37% in a conventional system in the study area, by Carefoot and Janzen (1997) who reported 30-45% in Canada, and Krupnik et al. (2004) 33-45% in India. Compared with others, the higher NUE of wheat in this study could be due to better management practices, i.e., better crop establishment, no weed infestation, proper soil moisture during the growing season and the properly laser-leveled field. Jat et al. (2006) reported that laser leveling significantly increased NUE in India. Thus, all this indicates that better management practices increase NUE of field crops which was also postulated by Peng and Cassman (1998), Dobermann et al. (2000), and Yusuf et al. (2009).

Similarly, in maize, the AE_N in BP (28 kg grain kg^{-1} N applied) and CT (16 kg grain kg^{-1} N applied) obtained in this study is not very different to that of Yusuf et al. (2009), who reported AE_N of 25 kg grain kg^{-1} N under conventional practices in a high rainfall area in Nigeria. Cassman et al. (2002) reported 40% ARE_N in maize in USA, which is nearly identical to that under CT (44%) in this study, while it is two times lower than that observed in BP (80%). The higher ARE_N in BP than under CT in this study, and also than in other regions, could be due to better micro-climatic conditions and for instance better growth. Fahong et al. (2004) reported that NUE in BP crops could be improved by more than 10% through better N placement possibilities in BP than under CT. Furthermore, upland crops normally can recover about 40-60% of applied N under field managed conditions (Vlek and Byrnes 1986).

However, with flood irrigation followed by N fertilizer application under CT, the applied N may have been lost by NO_3-N leaching to the groundwater as observed in other reasons (Elmi et al. 2002; Jaynes et al. 2001). This may have reduces the efficiency of applied N under CT. The increased groundwater NO_3 concentration (10-12 ppm) from mid July to mid August in 2009, i.e., at fertilization and irrigation events in maize, in this study (Figure 3.1) further supports the hypothesis.

5.4.3 Apparent N balance and system N efficiency

In this study, apparent N balance always remained lower in BP than under CT in wheat, maize and also in the cotton/wheat/maize rotation system. This could be related to less N input due to less N addition from irrigation water and high output due to increased yield and N uptake in BP.

The high negative N balance but decreasing response to increasing N application in wheat in this study (Table 4.4) indicates that N application in wheat was not adequately or timely administered. Hence, wheat plants might have taken N after the mineralization of organic N present in the soil and also might have been from other unknown sources. Soil fertility exhaustion at wheat harvest, where TN decreased by 32% and available P_2O_5 by 61% compared to the cotton season in this study (section 5.3.6) can support the assumption. Since N input from the mineralization of organic N was not considered while N balance calculation (equation 5.1). A negative N balance even with the application of 180 and 240 kg N ha^{-1} in winter wheat in a conventional production system has also been reported for the study region (Djumaniyazova et al. 2010).

During the maize growing season, the higher apparent positive N balance with increasing N level under CT suggests that the maize crop had poorly utilized the increased N offer by 100 kg ha^{-1}, as crop yield and N uptake did not differ between N-100 and N-200. This could be due to a slow initial crop growth and poor root growth under conventional flood irrigation. This indicates that under high-yielding environment N loss can be minimized with the adoption of permanent raised beds. From a two-year study in China, Liu et al. (2003) reported about 38 and 92 kg apparent N balance in maize under CT with the application of 120 and 240 kg N ha^{-1}, respectively, which is closer to the value observed in this study, i.e. 35 and 80 kg ha^{-1} with N-100 and N-200, respectively (Figure 5.8B).

In cotton/wheat/maize rotation system, BP showed a lower positive N balance (N loss) than CT under high-yielding environment (high-N application). Furthermore, an overall system level N efficiency was higher in BP than under CT in the system. This suggests that N loss from irrigated cotton/wheat/maize rotation system can be minimized by increasing the efficiency of applied N through the adoption of permanent raised beds compared to the conventional tillage practices.

Residue retention in BP showed a higher negative N balance and system N use efficiency than with RH at N-0, while no effect with N-200. Similar to this Limon-Ortega et al. (2002) reported high N uptake and yield of wheat and maize under RR in BP with N-0 and no effect in N applied treatments. This indicates the residue retention in permanent beds can be the potential source of N that compensate for the 0-N application to sustain the crop yield in this system. However, significantly higher negative N balance with crop residue retention without N application also indicates that this practice can slowly mine the soil-N resources in the system. Thus, under the present conditions, retaining crop residues without N application should be avoided. No effect of RR in BP with high N levels compared to RH indicates that residue may have immobilized the applied N. All these findings indicates the permanent raised beds with residue retention, and the application of ~150 kg N ha^{-1} for each crop in cotton/wheat/maize rotation can reduce the N loss to the environment.

5.5 Summary and conclusions

Application of fertilizer N increased grain yield and N uptake of wheat and maize grown in rotation under both CA and CT practices. Also, efficiency of applied N decreased with higher N levels. Yield, N uptake and NUE were higher in BP than under CT with both high and low N levels in both wheat and maize crops. Thus, in BP the same yield can be achieved as under CT but with lower N fertilizer amounts.

Lower partial N balance (N loss) and higher N use efficiency in BP than under CT with both low- and high-N applications indicates that the N loss with high-yielding environment can be minimized by adopting CA practices in cotton/wheat/maize rotation systems. This is important from the environmental point of view, as N losses into the environment are smaller, especially in irrigated drylands of Central Asia, where in a study by Scheer et al. (2009) 40% of the loss of applied N occurred from the cotton field under CT.

Residue retention in BP, however led to a high response of applied N as indicated by the small increase in N uptake and grain yield in maize and higher NUE especially in the N-0 and N-100 treatments compared to RH; the differences likely will increase with time under these management systems. However, RR under CT is counterproductive, as the grain yield with N application was always lower than for RH. Thus, BP and partial residue retention with proper N application under cotton/wheat/maize rotation could be an option to increase crop yield while reducing the N loss in the salt-affected irrigated lands of Uzbekistan.

6 SALT DYNAMICS AND MANAGEMENT UNDER DIFFERENT TILLAGE AND RESIDUE LEVELS IN A COTTON/WHEAT/MAIZE SYSTEM IN SALT-AFFECTED IRRIGATED DRYLANDS

6.1 Introduction

Soil salinity is a serious threat to global agriculture (Zhang et al. 2007). About 20% of the world's cultivated area and nearly 50% of its irrigated lands are affected by soil salinity (Zhu 2001). Dryland regions, which mostly depend on irrigation for crop production, are even more vulnerable to soil salinity (Brady and Well, 2008). About 1-2% of the irrigated areas in dryland regions are becoming increasingly unsuitable for crop production due to salinity each year (FAO 2002). In irrigated agriculture, salts are brought to the field with irrigation water (primary salinization). Next, when not leached out they can accumulate in the soil profile through evaporative water loss, a process that removes the soil water mainly from the topsoil but leaves the salts (secondary salinization). Intensive soil tillage with residue removal on salt-affected lands entails the dispersion of soil aggregates, and a reduction in soil organic substances, which leads to increased evaporation loss and salinity levels in soils (Lal et al. 2007; Egamberdiev 2007). Furthermore, the generally shallow groundwater levels in the study region (<1 m, i.e., above critical limit) during the summer are caused by heavy irrigation of virtually all crops including rice. However, this practice has also contributed to increasing secondary soil salinization (Forkutsa et al. 2009)

Salinity levels in the soil profile have to be reduced by appropriate soil and water management practices (Ayers and Westcot 1985; Dong et al. 2008), as salinity affects crop growth, yield and quality, and hence the sustainability of irrigated agriculture (Dong et al. 2008; Razzouk and Whittington 1991). To reduce soil salinity or its impact on crop establishment and growth in salt-prone areas, several management practices have been applied. Examples are irrigation at night to reduce evaporation loss (Rhoades et al. 1992; Rhoades 1999), pre-sowing seed treatments to enhance germination even under saline conditions, planting methods such as sowing on raised beds (Bakker et al. 2010; Sayre 2007; Egamberdiev 2007), increased seed rates per unit area (Minhaus 1998), increased amounts of nitrogen and potassium fertilizer (Minhas 1996; Tanji and Kielen 2002), mulching the soil surface with crop residues (Pang et al.

2009; Bezborodov et al. 2010; Egamberdiev 2007), plastic (Dong et al. 2008), or a combination of sand and soil (Bakker et al. 2010).

Conservation agriculture (CA) practices, i.e., reduced tillage and residue retention, can influence the location and accumulation of salts by reducing evaporation from the soil surface, which again reduces the upward transport of soluble salts (Brady and Well 2008). Among CA practices, raised bed planting is gaining importance in many parts of the world for row-spaced crops (Sayre 2007). Raised beds can save 25-30% irrigation water, increase water use efficiency (Hassan et al. 2005; Ahmad et al. 2010; Sayre and Hobbes 2004; Mallik et al. 2005; Chaudhary et al. 2008) and also provide the opportunity to leach salts from the furrows (Bakker et al. 2010). However, under saline conditions, salt accumulation on the top of the beds has been reported by Chaudhary et al. (2008) due to the upward movement of salts through capillary rise in response to evaporation gradients.

Mulching for example with crop residues is a promising option to manage the soil salinity, as it decreases soil water evaporation, increases infiltration and regulates soil water and salt movement (Tian and Lei 1994; Pang and Xu 1998; Pang 1999; Li and Zhang 1999; Li et al. 2000; Huang et al. 2001; Deng et al. 2003; Qiao et al. 2006). For instance, wheat straw mulching prevents salt accumulation in the soil profile and leads to a relatively constant salt level on the top 30 cm depth (Huang et al. 2001). Thus, a combination of raised bed planting with residue retention could be more effective than the effect of each practice alone, as it has the potential to reduce soil salinity in the long term in salt-affected irrigated areas.

Although residue retention has great potential to reduce soil salinity in salt-affected areas, residues may not be available in the quantities and qualities needed and residue retention on the field may also compete with the present farmers' practices in Khorezm of using this resource as livestock feed or, as in the case of cotton stalks, used as biofuel in bakeries. When crop residues are insufficient different irrigation techniques have been proposed as a supplement or alternative management approach to control salt on raised bed systems.

The amount, frequency, and method of irrigation collectively determine the quantity, status, and distribution of salts in soil (El-Swaify 2000). When irrigation water is applied to the furrows on every side of the bed, salts move to the centre of the bed, which may damage (young) plants planted there (Brady and Well 2008). The 'managed accumulation' approach, which proposes irrigating every other furrow and leaving alternate furrows permanently dry, could be an effective option in salt-affected drylands. The principle behind this approach is to direct salt concentrations away from the plant roots by applying irrigation water very rationally and targeted. In addition, this procedure can allow higher levels of salt to accumulate without damage to the crop, as salts are "pushed" across the bed from the irrigated side of the furrow, where plants are located, to the dry side without plants. This control of root zone salinity is considered a beneficial strategy to improve emergence, stand establishment and finally crop yield in saline fields (Meiri and Plaut 1985).

Salt leaching efficiency is determined also by the amount of water needed per unit depth of soil to achieve a reduction in the salt content of the soil as a fraction of the initial salt concentration (Bakker et al. 2010). In raised beds flow of irrigation water is rapid (Holland et al. 2007), thus from a salt-leaching point of view the benefit of rapid flow of irrigation water is uncertain because it provides less time to dissolve salts and to remove them from the soil (Scotter 1978). However, under the 'managed accumulation' approach, the salts accumulated in the dry furrow can be leached properly. Effective salt accumulation and leaching of salts in raised bed systems have not yet been explored in the dryland areas of Uzbekistan. Thus, the objectives of this study were (1) to compare salt dynamics under conventional and conservation agriculture practices, and (2) to investigate the effect of different furrow irrigation techniques on salt distribution, crop performance and salt leaching under raised bed cultivation in irrigated drylands.

6.2 Materials and methods

Two field experiments were conducted in the Khorezm region of Uzbekistan over two years (2008 and 2009). In experiment I, the salt dynamics under conservation and conventional agriculture practices were studied, and in experiment II, the effect of different furrow irrigation techniques on salt distribution, crop performance and salt leaching in raised beds were studied. For details of the study sites see section 3.2.1.

6.2.1 Salt dynamics under conservation and conventional agriculture practices

The study was conducted within an experimental area of cotton/wheat/maize rotation systems under conservation and conventional agriculture practices (see Chapter 4). To study the salt dynamics under this system, three treatments were evaluated: (i) bed planting with residue retention (BP+RR), (ii) bed planting with residue harvested

(BP+RH), and (iii) conventional tillage (CT). In the residue retained treatment, 3 t ha^{-1} wheat residues, 6 t ha^{-1} cotton residues and 10 t ha^{-1} wheat residues were retained during the cotton, wheat and maize season, respectively. In all residue harvested (RH) treatments, residues were removed from the field. Slightly saline areas (ranging from 2.3-2.7 dS m^{-1}) were selected randomly within each treatment during the cotton season of 2008 (Appendix 9.1). Each sample point was tagged and soil samples were taken each time around the fixed points over the three crop seasons, i.e., cotton, wheat and maize grown in rotation.

For each treatment three subplots with each 600 m^2 in size were randomly selected. Within each plot two points were selected randomly in central four beds, given thus a total of six replications for each treatment (Appendix 9.1).

Soil sampling and analysis

Soil was sampled from the predetermined sampling points with six replications for each treatment to measure the soil salinity level. In BP, soil was sampled from both the top of the bed and center of the furrow. Soils were sampled from 0-10, 10-20, 20-30, 30-60, and 60-90 cm soil depths, one day before irrigation and at each crop harvest. The collected soil samples were analyzed for gravimetric soil moisture content according to Gardner et al. (2001) (equation 4.2), and electrical conductivity (EC_p), which is the EC of 1:1 water soil paste, according to Chernishov and Shirokova (1999) cited by Forkutsa (2006) based on the EC of 1:1 water soil paste. The EC_p was converted to the international standard EC value of the saturated soil extract, ECe (Rhoades et al. 1999) derived from the relationship according to equation (6.1) (R^2=0.90) specially developed for the soils in the study region (Akramkhanov 2010).

$$EC_e = (2.06 \text{ x } EC_{p(1:1)}) \qquad (6.1)$$

6.2.2 Effect of furrow irrigation techniques on soil salinity in raised beds

To compare soil salinity dynamics on raised beds that were subjected to three different irrigation techniques, a separate experiment was conducted from July to September during the cotton growing seasons in 2008 and 2009.

Experimental set up and treatments

The experiment was laid out in a complete block design with three irrigation treatments replicated three times. Each replication consisted of 12 beds, sizes 0.9 m spacing and 25 m length. The irrigation treatments were arranged as shown in Appendix 9.2. In the same way the treatments were allocated for the other two replications.

In 2008, the study was conducted within the experimental area of the cotton/wheat/maize rotation systems, where beds were prepared in 90 cm spacing, before planting cotton in April 2008. The chosen parts within the experimental plots were without cotton plants, since plants had not germinated owing to high salinity. The average initial soil salinity in the top 30 cm soil of this selected area was more than 12 dS m^{-1}.

In 2009, the study was conducted along the side of the cotton/wheat/maize rotation experiment in a cotton field, where cotton was planted on 90 cm spaced beds under recommended practices; here the initial soil salinity before applying the irrigation treatment was 6-7 dS m^{-1} in the top 30 cm.

Three irrigation cycles in 2008 and four irrigation cycles in 2009 were applied in each treatment at 10-12 days intervals.

The three irrigation techniques used in the study were:

- **Every-furrow irrigation (EFI):** Irrigation water was applied uniformly in all furrows during each irrigation event (Figure 6.1A)
- **Alternating skip furrow irrigation (ASFI):** Irrigation water was applied alternately in each furrow. Irrigation was applied on one side of furrow while the other furrow was kept dry. During the next irrigation event the previously irrigated furrow was kept dry and the other furrow was irrigated (Figure 6.1B).
- **Permanent skip furrow irrigation (PSFI):** Irrigation water was applied always in the same furrow of the bed. Hence, the alternate furrow was never flooded and kept constantly dry (Figure 6.1C).

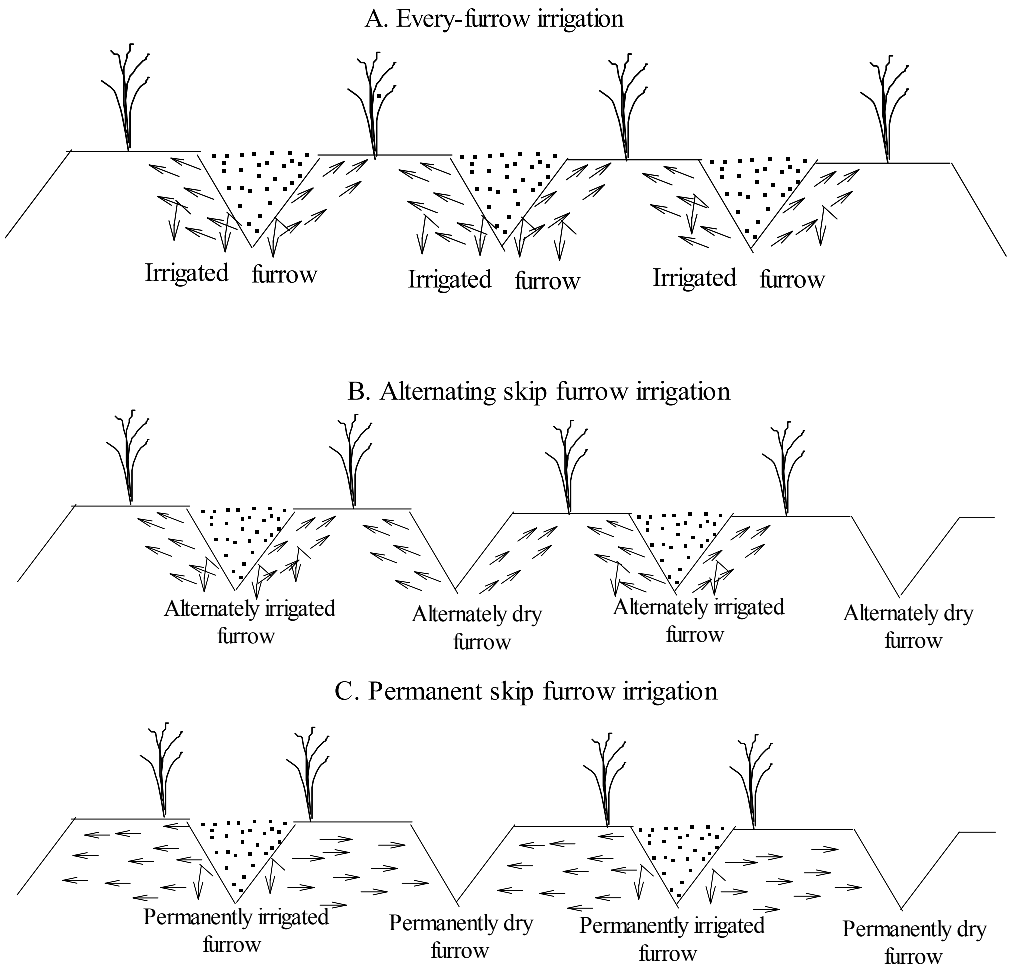


Figure 6.1 Methods of irrigation applied under raised bed planting. The arrows denote the direction of anticipated salt movement.

Salt leaching

After applying 3-4 irrigation cycles, the accumulated salt on top of the bed and furrows was leached for each treatment. Therefore irrigation water was applied in all furrows at the same time in the EFI and ASFI treatments. Under PSFI, salt leaching was started by applying irrigation water to the permanently irrigated furrow first and after filling the irrigated furrow, the dry furrow was irrigated. The hypothesis behind this procedure was that the salt accumulated in the dry furrow could then not move laterally anymore as the irrigation had already been applied to the irrigated furrows. Leaching was performed by keeping 5-6 cm of standing water (on the top of the bed) for about 24 h.

Soil sampling

Soils were sampled before applying the irrigation treatments and before leaching, i.e., after three irrigation cycles in 2008 and four irrigation cycles in 2009 and immediately (after 3 days) after leaching. Samples were taken each time from seven points (centre of the bed, two sides of the bed, slope of both furrows and centre of the furrows) from a bed as shown in figure 6.2 with three replications in each treatment. Samples were taken at every 15 cm soil depth down to 90 cm using a tube auger. After air-drying, samples were analyzed for ECe as described above (section 6.2.1, *Soil sampling and analysis*).

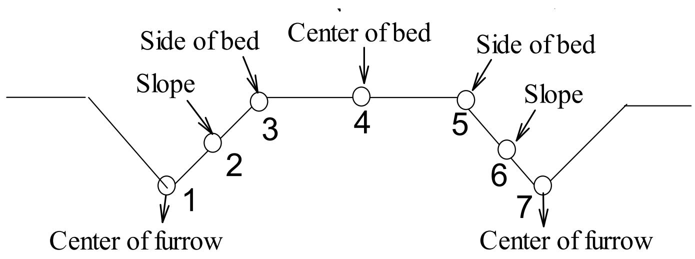


Figure 6.2 Vertical cut through a bed flanked by 2 furrows. Soil sampling points, the circle represents the position of sampling points in bed and furrow.

Yield and yield components measurement

In 2009, cotton yield and yield components were measured for each treatment with three replications. Cotton was harvested from an area of 0.9 m x 15 m of each replication (an entire bed where soil samples were taken) in three picks and weighed separately for yield measurement. The average number of bolls per plant was calculated by counting the bolls in each plant of the harvested row. Similarly, ten bolls were picked randomly at each picking and oven dried at 70 °C for 16 h and weighed to calculate the average boll weight.

6.2.3 Statistical analysis

Analysis of variance was conducted using repeated measures in the statistical analysis system GenStat Discovery Edition 3. The treatment means were separated by Fisher's protected LSD (least significant difference (P=0.05)). For yield and yield components, treatment mean ± standard error is reported.

6.3 Results

6.3.1 Salt dynamics under conservation and conventional agriculture practices

Soil salinity at different soil depth

A significant treatment effect on soil salinity was observed in the top 30 cm soil depth (Figure 6.3). Compared to the initial value, soil salinity in the top 30 cm depth increased in all treatments during the cotton and maize seasons, while negligible changes occurred during the wheat season. The effect of tillage method and residue level on soil salinity was reduced with increasing soil depth.

At cotton harvest, the salinity in the top 30 cm was 63% higher under BP+RH, followed by CT (49% higher) and BP+RR (29% higher) compared to the initial level (pre-experiment). However, at wheat harvest, soil salinity was significantly lower in all depths for all treatments than the cotton season. Salinity in the top 90 cm soil was decreased by 29% in BP+RH, by 35% in BP+RR and by 45% in CT, at wheat harvest. Similarly, compared to the initial value, salinity at wheat harvest was lower by 31% in the top 30 cm under BP+RR, but was slightly higher under BP+RH and CT. At maize harvest, salt was mostly accumulated in the top 10 cm soil. Compared to the wheat season, salinity at the maize harvest in the top 10 cm increased significantly in all treatments, i.e., by 87% in CT, by 24% in BP+RR, and by 13% in BP+RR. Similarly, in comparison to the initial value, salinity in maize was significantly increased in all treatments up to 60 cm soil depth, while it decreased thereafter (90 cm soil depth; Figure 6.3).

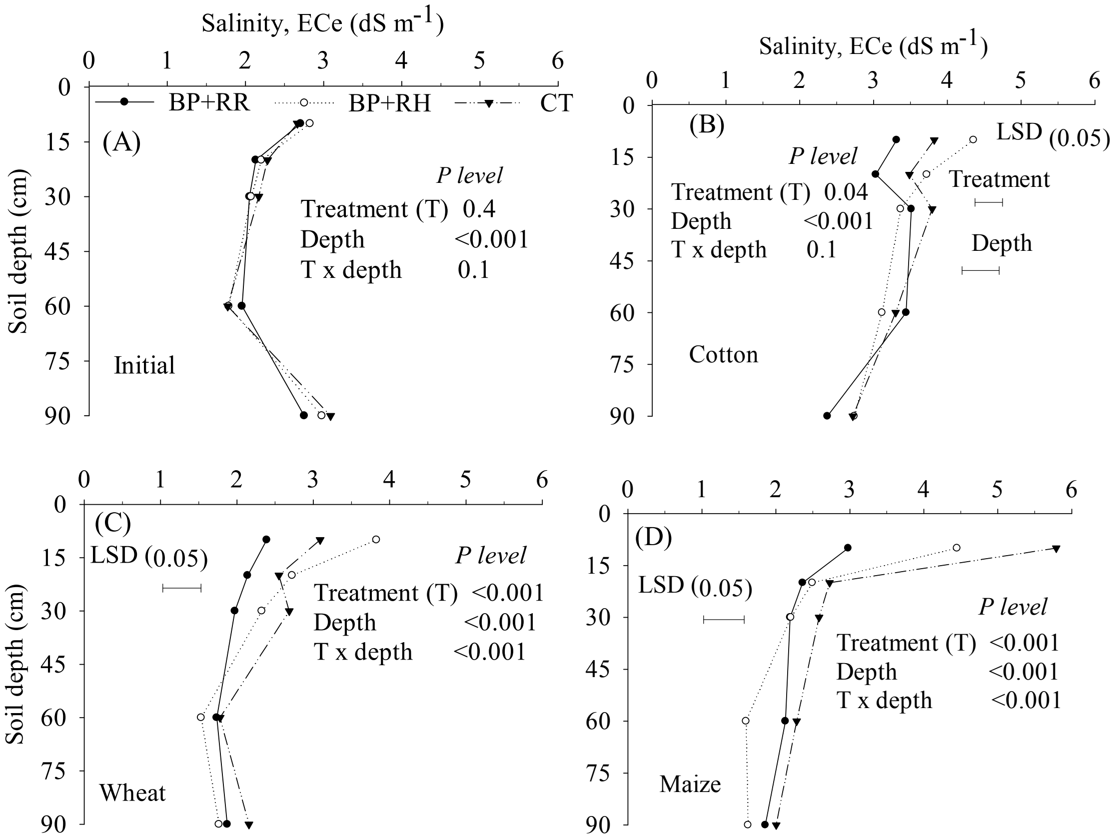


Figure 6.3 Soil salinity level expressed as ECe (dS m^{-1}) at pre-experiment and in different crop harvest seasons at different soil depths (10, 20, 30, 60 and 90 cm) as affected by tillage method and residue level. BP+RR=bed planting with residue retention, BP+RH=bed planting with residue harvest, and CT=conventional tillage. The horizontal bars indicate the least significant difference (LSD) between treatment and soil depth (B) and interaction between treatment and soil depth (C and D).

Salt dynamics in bed

The soil salinity in the top 10 cm soil increased significantly in all three treatments (i.e., CT, BP+RH, and BP+RR) over time compared to the initial levels. An effect of residue retention on soil salinity was observed at the end of cotton season at which the salinity level in BP+RR remained consistently lower than under BP+RH and CT (Figure 6.4A). Although soil salinity increased in all treatments, after three crop cycles, the salinity levels (dS m^{-1}) in the top 10 cm of soil were 7.1 dS m^{-1} in BP+RH, 5.8 dS m^{-1} in CT, and 3.9 dS m^{-1} in BP+RR, i.e., 2.6 times higher in BP+RH, 2.1 times higher under CT and 0.4% times higher in BP+RR compared to the initial level. The results show that the rate of soil salinity increase on top of the bed can be reduced by retaining crop residues, but without RR, soil salinity on top of the beds can be higher than under CT. A similar trend was observed for the top 30 cm soil (Figure 6.4B).

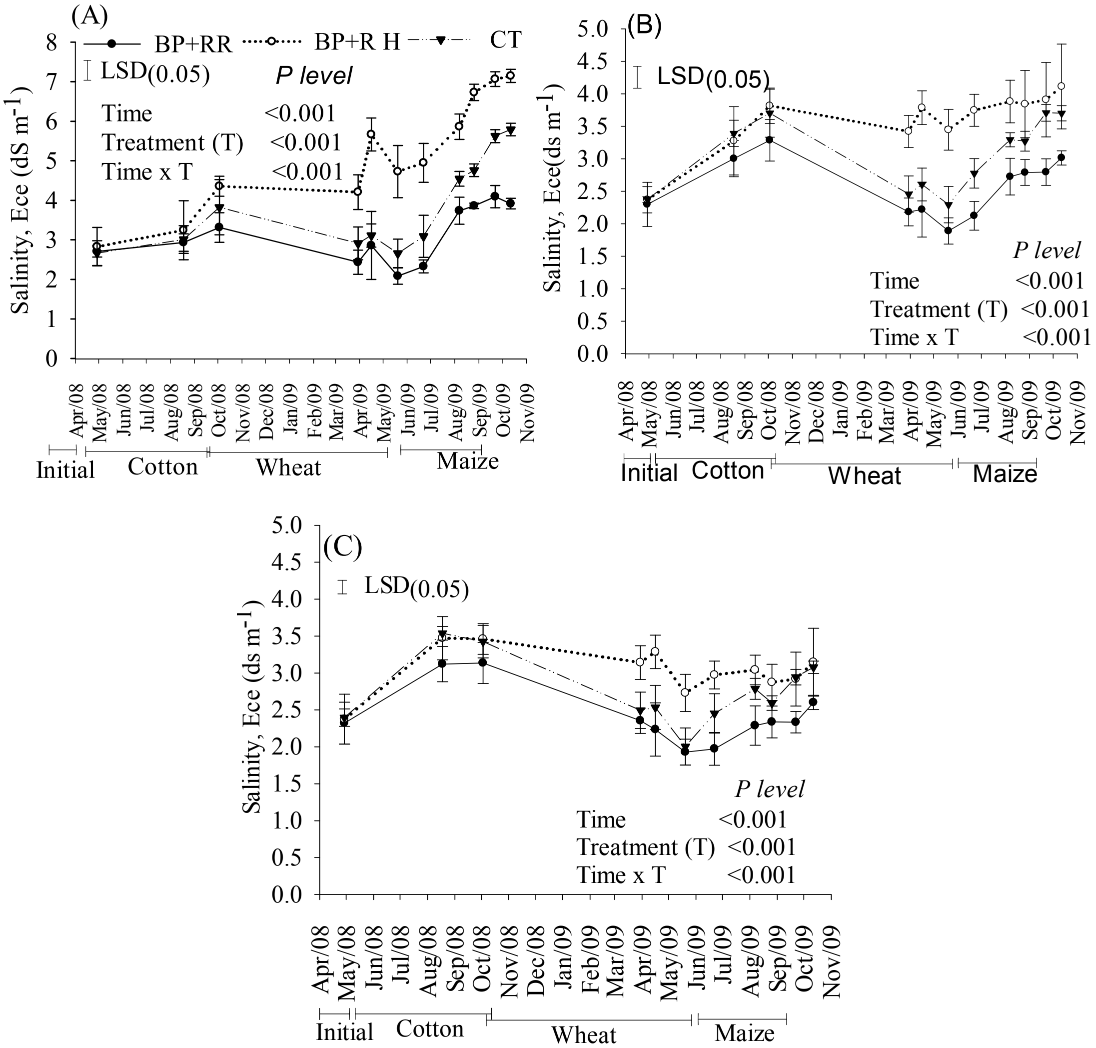


Figure 6.4 Soil salinity level over time, expressed as ECe (dS m^{-1}) in (A) top 10 cm soil, (B) top 30 cm soil profile and (C) top 90 cm soil as affected by tillage method and residue level in a cotton/wheat/maize system. BP+RR=bed planting with residue retention, BP+RH=bed planting with residue harvest and CT=conventional tillage. Bars represent standard error. LSD is the least significant difference of time and treatment.

The treatment effects in terms of salinity changes in the top 90 cm over time were not as large as in the case of the top 10 cm soil depth (Figure 6.4C). Like at the top 10 cm soil depth, the salinity level at the top 90 cm under BP+RR was consistently lower than in BP+RH and CT. At the end of three crop seasons, i.e., after cotton/wheat/maize, BP+RR showed a negligible increment in salinity, while this increased by 29% in BP+RH and CT treatments compared to the initial level (Figure 6.4C).

Salt dynamics in furrow

Irrespective of treatment and crop, salinity level in the furrow remained significantly low compared to the bed over the top 10 and 90 cm soil profiles. In the wheat season, the salinity levels in the top 10 cm of the furrow were equal in both residue harvested and retained treatments, i.e., 1.6 dS m^{-1} during growing season and 2.4 dS m^{-1} at harvest. An effect of residue on the salinity level on top of the furrow was observed only after the wheat season, when the amount of residue level increased, where the salinity level was significantly higher in RH furrows (30% higher) than in RR furrow (Figure 6.5A).

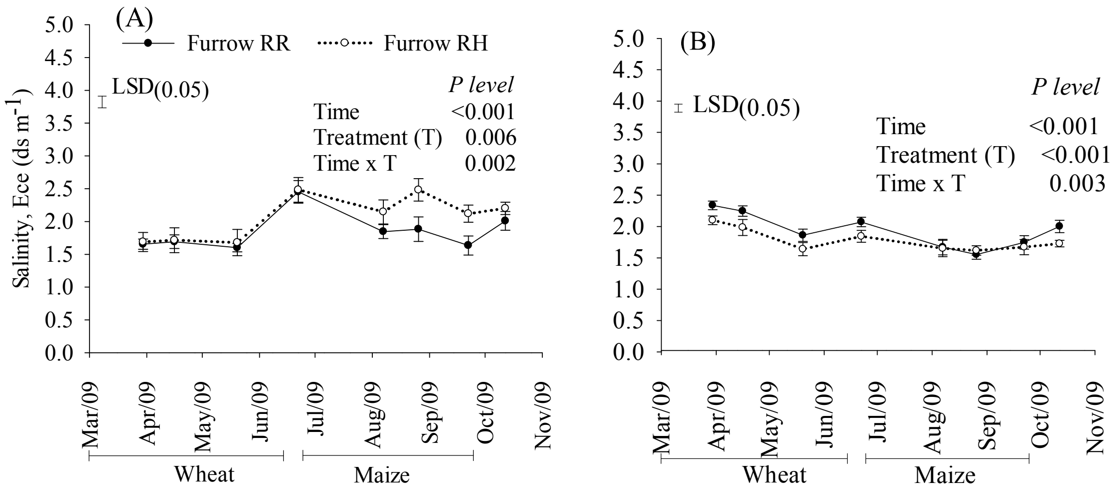


Figure 6.5 Soil salinity level over time expressed as ECe (dS m^{-1}) in the furrow of (A) top 30 cm soil and (B) top 90 cm soil; as affected by residue level in cotton/wheat/ maize system. RR=residue retention and RH=residue harvest. Bars represent standard errors. LSD is the least significant difference of time and treatment.

In the top 90 cm, the salinity level, however, was higher under RR furrows (11% higher, $p<0.001$) compared to the RH furrow during the wheat season. During the maize growing season, salinity level in both RR and RH furrows did not differ over the 90 cm soil profile (Figure 6.5B).

Salt dynamics combined over bed and furrow

Similar to the salinity on top of the beds, BP+RR had consistently lower ($P<0.05$) salinity levels, when averaged over bed and furrow than BP+RH and CT in all soil depths (Figure 6.6). Up to the wheat season, i.e., after two cropping seasons, the salinity level in the top 30 cm and 90 cm profile was higher ($p<0.001$) in BP+RH than under

CT. However, during the maize season, the averaged salinity level in the top 30 cm soil in BP (bed furrow) was lower in both the with residues harvested (by 15-30%) and with residue retained (by 36%) treatments than in the CT treatments (Figure 6.6A).

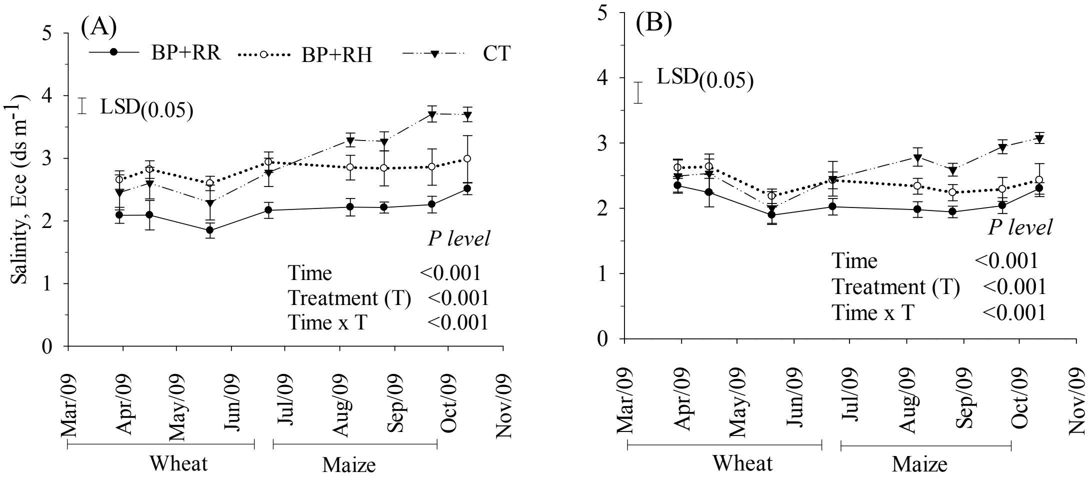


Figure 6.6 Salinity level over time, expressed as ECe (dS m^{-1}) in (A) top 30 cm and (B) top 90 cm soil depth; as affected by tillage method and residue level in cotton/wheat/maize system. BP+RR=bed with residue retention, BP+RH=bed with residue harvest and CT=conventional tillage. Bars represent standard error. LSD is the least significant difference of time and treatment.

With respect to the entire 90 cm soil depth, the treatment effects on salinity level over time were not as large as in the case of the top 30 cm soil depth. The effect of tillage and residue on salinity in the top 90 cm soil showed a similar trend to that in the top 30 cm soil in both crop seasons (Figure 6.6B).

6.3.2 Soil moisture dynamics

The temporal soil moisture curve indicated that volumetric soil moisture content in the top 10 and 90 cm soil during the cotton and wheat growing season was neither affected by soil tillage nor crop residue level (Figure 6.7). In contrast, during the maize season, BP had higher ($p<0.05$) soil moisture content than CT before and after irrigation. Irrespective of time, soil moisture in the top 90 cm soil was higher by 9% in BP (average moisture 33%) than under CT (average moisture 30%), while in BP, RR increased soil moisture content by 3% compared to RH. Similarly, in the top 10 cm soil moisture in BP was 17% higher than under CT. Residue retention in BP increased moisture content by 3-5% compared to RH (Figure 6.7A).

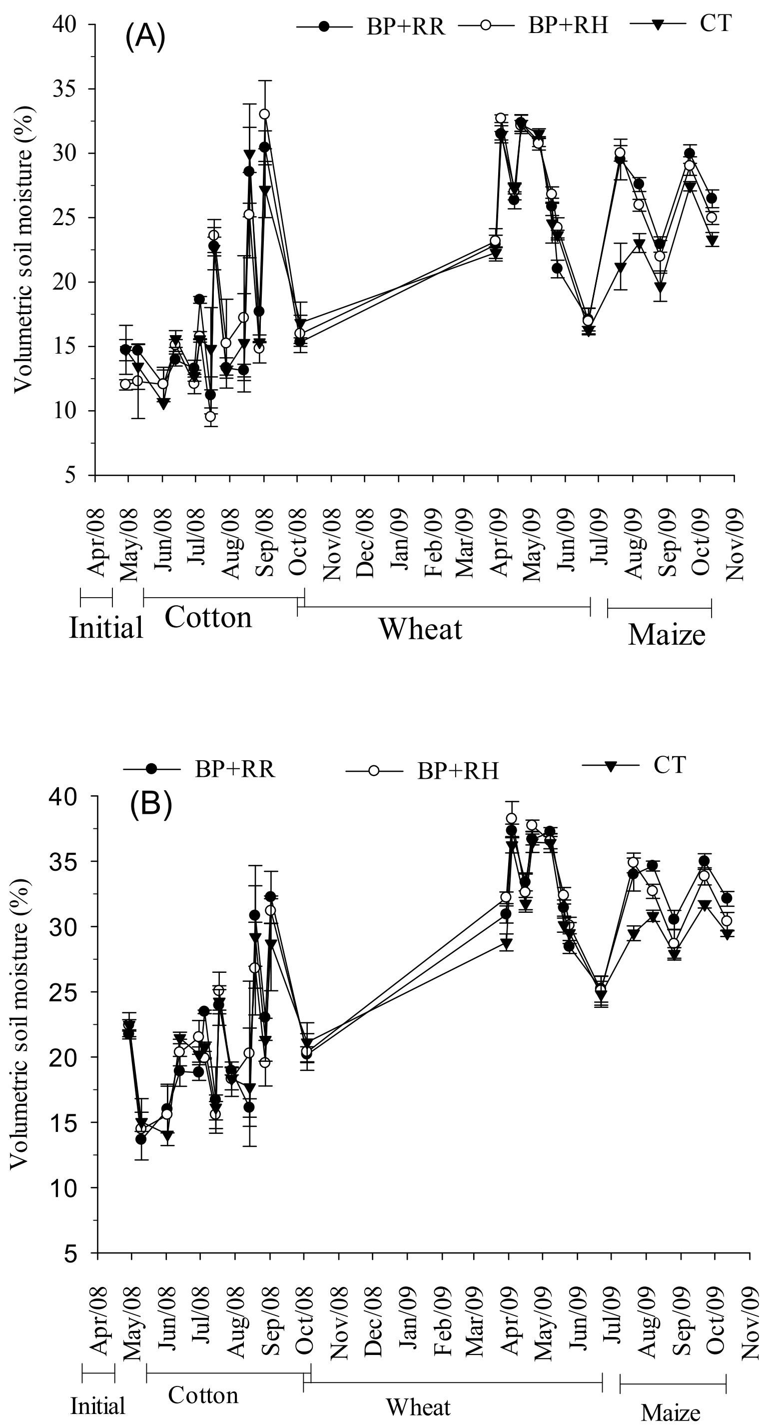


Figure 6.7 Soil moisture level expressed as volumetric moisture (%) in (A) top 10 cm and (B) top 90 cm soil; as affected by tillage method and residue level in cotton, wheat, maize in rotation. BP+RR=bed with residue retention, BP+RH=bed with residue harvest, and CT=conventional tillage. Bars represent standard error.

6.3.3 Effect of different furrow irrigation techniques on salt distribution and leaching under raised beds

Pre-experiment soil salinity

The pre-experiment soil salinity level in top 30 cm soil in terms of electrical conductivity (ECe) in 2008 was significantly higher than in 2009 (Table 6.1). The soil salinity levels at the different depths were in the range of 2.8-14.5 dS m^{-1} in 2008 and 5.7-6.8 dS m^{-1} in 2009.

Table 6.1 Pre-experiment soil salinity level at different soil depths during 2008 and 2009.

Year	Soil salinity (dS m^{-1}) at different soil depths (cm)					
	0-15 cm	15-30 cm	30-45 cm	45-60 cm	60-75 cm	75-90 cm
2008	14.5±1.5	12.2±0.6	5.12±0.5	3.2±0.3	2.8±0.15	-
2009	6.8±1.1	6.4±0.5	6.4±0.4	6.2±0.4	5.7±0.3	5.7±0.2

Salt distribution in raised beds under different irrigation techniques

Salt distribution after 3-4 irrigation cycles on raised beds was significantly affected by irrigation methods in both years (Appendix 9.3; Figures 6.8 and 6.9). The salinity level on top of the beds (15 cm depth) was significantly higher with the every-furrow irrigated (EFI) and alternating skip furrow irrigated (ASFI) methods compared to the pre-experiment salinity level in both years. However, under permanent skip furrow irrigation (PSFI) salinity level was decreased by 38% in 2008, while it remained unchanged in 2009 compared to the pre-experiment level (Table 6.2). With PSFI, the salts had moved towards the top 15 cm of the side and center of the dry furrow in both years, where the salinity level in the irrigated furrows and side of the beds was lower than in the dry furrows (Figures 6.8 and 6.9). The treatment effects in terms of salinity changes with increased soil depth were not as large as in the case of the top 15 cm soil depth (Figures 6.8 and 6.9).

Table 6.2 Soil salinity (dS m^{-1}) on top of the bed at top 15 cm soil depth before and after leaching under three different irrigation methods.

Treatment	Soil salinity (ECe) dS m^{-1} at top 15 cm			
	2008		2009	
	Before leaching	After leaching	Before leaching	After leaching
Every-furrow irrigation (EFI)	18.6	4.2	12.8	5.5
Alternating skip-furrow irrigation (ASFI)	17.4	6	9	5.2
Permanent skip-furrow irrigation (PSFI)	10.5	2.5	6.5	2.7

Salt distribution in raised beds after leaching

After applying leaching water, the accumulated salts were washed out of the raised beds, hence salinity levels in all irrigation treatments decreased significantly in both years (Appendix 9.4). Among the treatments, the salinity level on the top 15 cm soil in all positions and in the top 90 cm soil on the center of the beds was lower, i.e., <3 dS m^{-1} under PSFI. This was lower than the 5-6 dS m^{-1} that remained on the side to center of the bed in the top 60 cm soil depth in EFI and ASFI in both years (Figures 6.8 and 6.9). This indicates that the salts from the top of the bed in the PSFI treatment, i.e., under managed accumulation, leached properly compared to the EFI and ASFI treatments.

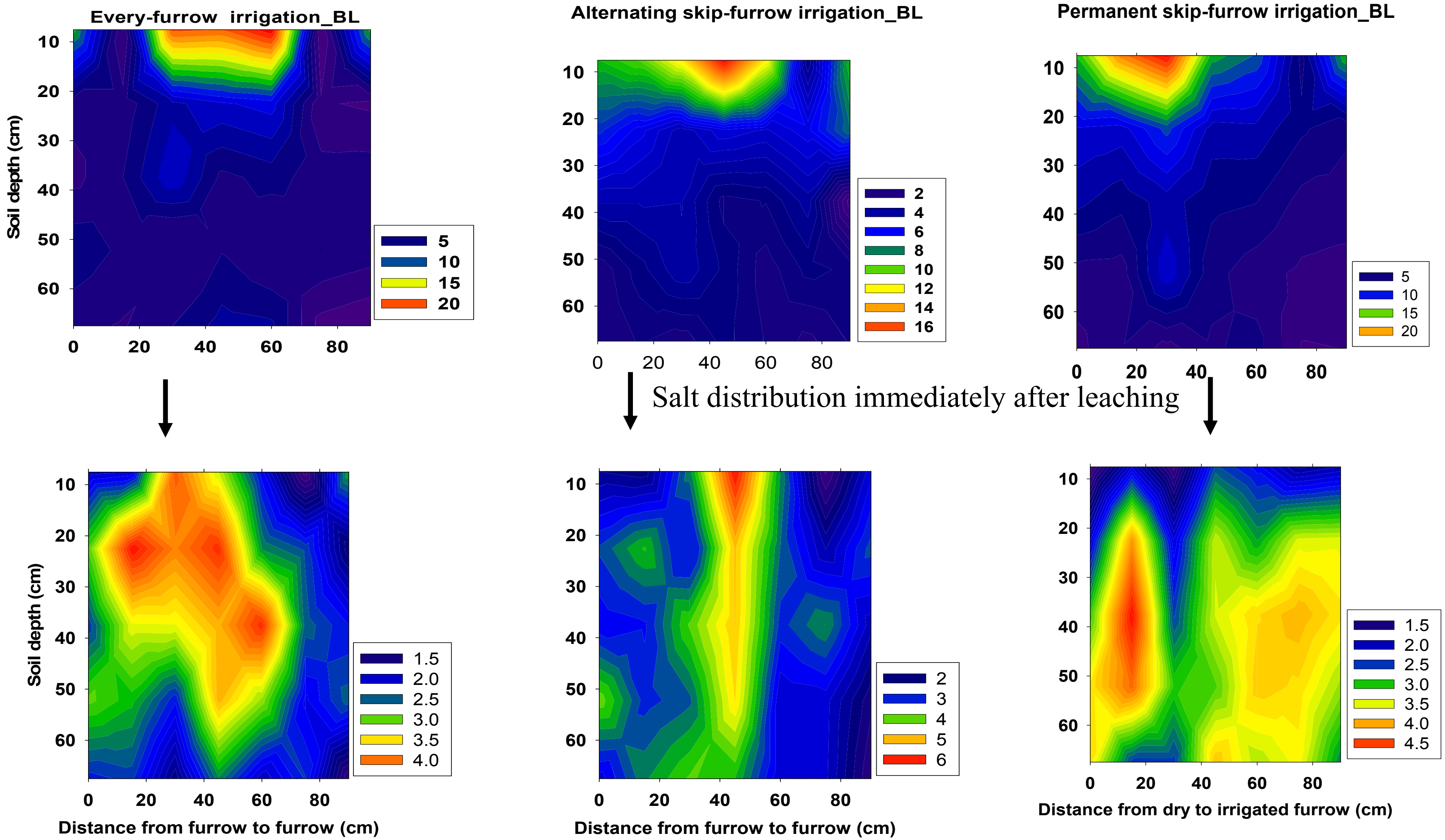


Figure 6.8 Salt distributions (ECe, dS m^{-1}) before leaching (BL) and immediately after leaching with different irrigation / leaching methods in 2008.

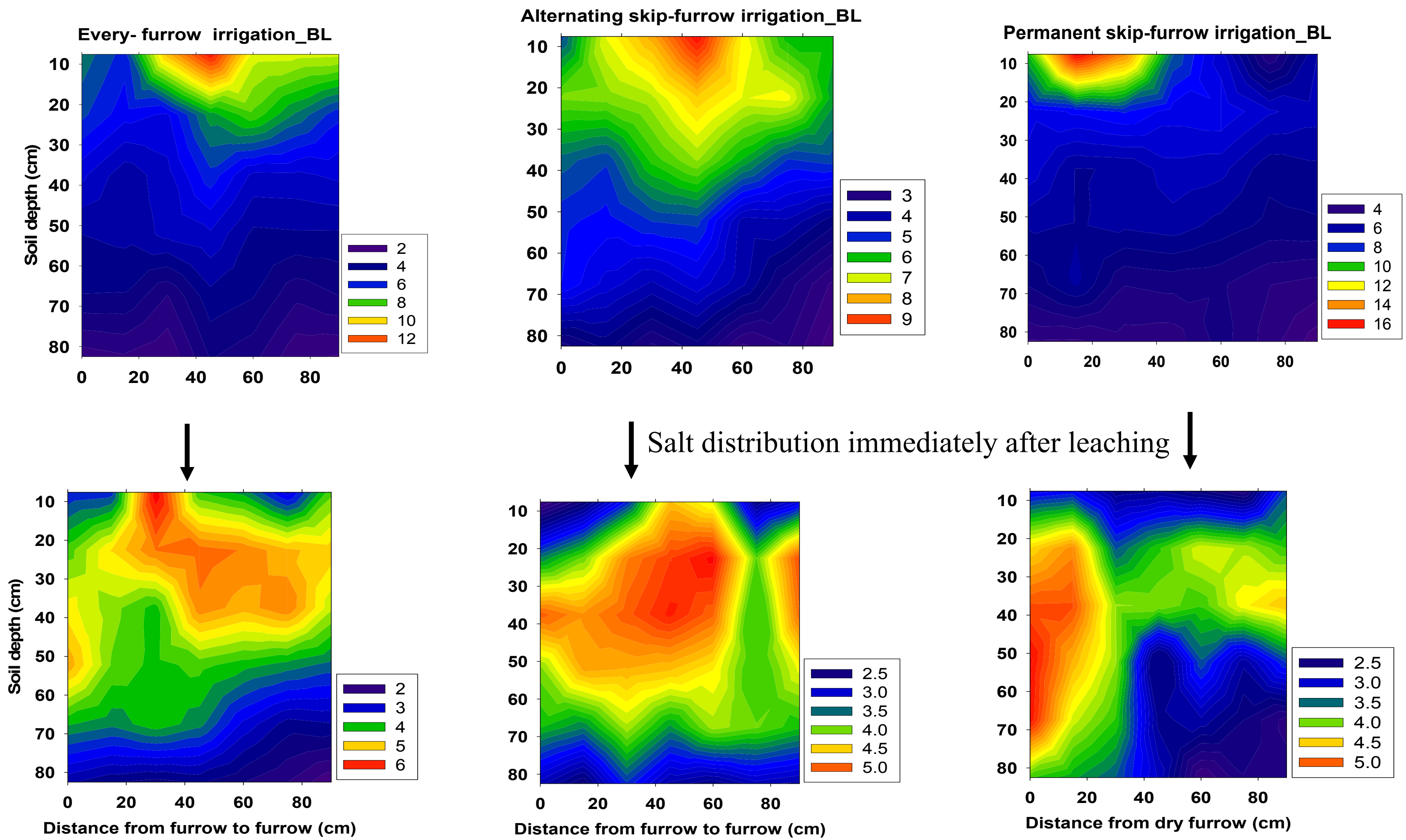


Figure 6.9 Salt distributions (ECe, dS m^{-1}) before leaching (BL) and immediately after leaching with different irrigation / leaching methods in 2009.

6.3.4 Cotton yield and yield attributes with different furrow irrigation techniques

The raw cotton yield was higher under PSFI than with ASFI (by 65%) and EFI (by 97%) (Table 6.3). Similarly, cotton yield in ASFI was higher by 19% than under EFI. Bolls per plant and per boll weight were higher in PSFI than under ASFI, where the number of bolls per plant was higher by 55% and boll weight by 15%, respectively. The difference in bolls per plant between ASFI and EFI was insignificant.

Table 6.3 Cotton yield and yield attributes in different irrigation treatments in 2009.

Irrigation method	Raw cotton yield (kg ha^{-1})	Bolls per plant	Boll weight (g)
Every- furrows (EFI)	1019 $\pm$40	5.6 $\pm$0.5	4.92 $\pm$0.04
Alternating skip furrow (ASFI)	1216 $\pm$120	5.6 $\pm$0.9	5.25 $\pm$0.23
Permanent skip furrow (PSFI)	2003 $\pm$182	8.7 $\pm$0.01	6.05 $\pm$0.15

$\pm$=standard error

6.4 Discussion

6.4.1 Effect of tillage and residue management on salt dynamics

Salt dynamics in soils are the result of the interaction between soil, water, and management practices, which contribute to the actual salt movement in the soil profile (El-Swaify, 2000). Soil salinity in irrigated drylands such as Uzbekistan is strongly determined by groundwater level (Forkutsa et al. 2009), which is associated with the growing season, management practices, soil type, and irrigation and drainage methods and efficiency. An application of agriculture practices that can minimize the increase in soil salinity is essential for sustainable crop production in salt-affected irrigated lands.

After irrigation, water moves through the soil and the soluble salts present in the profile will dissolve and lead to an increased concentration in the groundwater. When the water reaches an exposed surface, the water evaporates and the salts are left behind and in turn accumulate on the soil surface (Bakker et al. 2010). This was confirmed in the present study by a significant increase in soil salinity in the top 10 cm in all treatments compared to the top 90 cm soil profile (Figure 6.4).

Crop residues retained on the soil surface shade the soil, and in turn serve not only as a water vapor barrier against evaporation losses, but also slow down surface runoff, and increase infiltration (Huang et al. 2005; Mulumba and Lal 2008). In the present study, the decreased rate in soil salinity increase with BP+RR compared to CT and BP+RH indicates that this impact can be minimized with the retention of crop residues already after three cropping cycles. Although crop residues on the soil surface reduce evaporative water losses (Sauer et al. 1996; Jalota and Arora 2002), thereby regulating the upward movement of salt and water from the shallow and saline groundwater to the root zone (Qiao et al. 2006; Deng et al. 2003), it often is unclear how much crop residues need to be retained. In a study of salt dynamics under mulching and different water quality treatments in Central Asia, Bezborodov et al. (2010) reported an approximately 20% increase in surface soil salinity, after three crop seasons, of the non-mulching treatments compared to a mulching with 1.5 t ha^{-1} wheat residue under conventional tillage. In the present study, compared to the initial level, the almost similar salinity level (3 dS m^{-1}) in the top 30 cm soil under BP+RR, and the increased salinity under BP+RH and CT after three crop cycles suggests that BP with RR could be an alternative strategy to manage soil salinity in salt-affected irrigated drylands. However, the higher salinity level on BP+RH than under CT indicates that salinity can be worse in BP than under current conventional practices. Huang et al. (2001) also reported a reduced salt content in the top 30 cm soil and smaller reductions in salt content in the 30-60 cm soil depth than in those of the overlying layers when soil was mulched with wheat straw. The findings of the present study together with that of Huang et al. (2001), who confirm the effect of residues up to the 30 cm soil depth, while below this level, the effect on salinity was negligible.

High evaporation rate leads to a higher amount of salt accumulation in uncovered topsoil over shallow and saline groundwater tables (Chaudhary et al. 2008; Cardon et al. 2010). Hot and dry weather conditions during the cotton and maize season, a reduced ground coverage due to row and spaced planting could have contributed to the increased evaporation loss in this study. Remedies to reduce secondary soil salinity should focus therefore on preventing rising groundwater tables and minimizing the evaporation loss of water, for example by a mulch of crop residues. Although such practices should be applied irrespective of the crop cultivated, some crops demand a higher share in ground coverage than others, for example, wheat used to be more narrowly spaced than cotton and maize, which lowers soil temperatures. Given that groundwater tables during the wheat growing season were less shallow (Figure 3.1), evaporation losses from the soil profile were lower than during the cotton and maize season, resulting in decreased soil salinity. As a result, the salinity level during the wheat season was lower in all treatments than that in the cotton and maize crops.

Salinity at the soil surface increases as the soil dries out (Bakker et al. 2010). During maize cultivation, comparatively higher soil salinity under CT than in BP could be related to the low soil moisture content on the top 10 cm as well as in the top 90 cm soil profile (Figure 6.7). Visual observation indicated the greater soil cracking in CT, hence irrigation water may have been lost through the wide soil cracks. Moreover, bed and furrow configuration on raised bed can provide steady flow of irrigation water into the furrow and prevents water logging (Bakker et al. 2010), which could have increased the salt leaching from the soil profile in BP as suggested by Sayre (2007). All these indicate that furrow irrigation on raised bed planting is more effective to minimize soil salinization than CT with flood irrigation.

6.4.2 Effect of furrow irrigation technique on salt movement in raised beds

After 3-4 cycles of furrow irrigation, salts in the EFI and ASFI treatments were mostly accumulated on the top and sides of the beds, while in the PFSI treatments salts were mostly accumulated towards the dry furrow (Figures 6.8 and 6.9). The higher salt accumulation towards the side and center of the bed under EFI and ASFI indicates that when irrigation water is applied to both sides of the furrows in the raised beds, the salts tend to move towards the side and center of the bed. Consequently, in salt-affected irrigated lands the every-furrow irrigation system, which is a common method under bed and furrow system, increases the salt accumulation on the center of the beds. Under such a condition, crops grown on the bed will have high salt injury (Brady and Well 2008). This is supported by decreased yield and yield components of cotton grown under EFI compared to the PSFI treatment in the present study.

However, the accumulation of salts towards the dry furrow under PSFI treatment indicates that salts will move across the bed from the irrigated side (wet zone) of the furrow to the dry side (dry zone) if a sufficient amount of irrigation water is applied in the same furrow during all irrigation events. A similar salt movement under PSFI was reported by Cardon et al. (2010) for a salt-affected region in Colorado, USA. This implies that with the PSFI method in raised bed planting in salt-affected areas can lead to a distinguished zone suitable for plant growth due to the lower soil salinity level.

The explanation is that under such conditions, plant roots grow towards the irrigated furrow as to compensate for the reduced water and nutrient uptake by the roots exposed to higher saline areas. This is evidenced also by the increased yield and yield attributes of cotton under PFSI treatment compared to EFI and ASFI (Table 6.3). The experimental area had salinity of 6.8 dS m-^{1}; the raw cotton yield under PSFI (2.1 t ha^{-1}) in this study was almost similar to the averaged yield of cotton in the study region (2.7 t ha^{-1}). The determination of root growth and nutrient uptake fell beyond the scope of this study, but previous findings show that the root biomass and nutrient and moisture uptake decrease with increase salinity level (Chen et al. 2009; Maas and Grattan 1999). Based on these findings, it can be assumed that in salt-affected irrigated lands, PSFI techniques could be an effective irrigation alternative when introducing permanent raised beds.

Salinity measurements after 24 h of salt leaching under EFI and ASFI showed that 5-6 dS m^{-1} salt still remained on the top to side of the beds compared to the <3 dS m^{-1} observed under PSFI method. In spite of the similar amount of water used for leaching in all irrigation methods, the leaching efficiency with EFI and ASFI is lower than with PSFI. It can be assumed that to leach the accumulated salt from the top of the beds under EFI and ASFI, either more water would be needed or the beds would need to be dismantled.

In conventional agriculture practices on salt-affected irrigated lands of Uzbekistan, crop production, however, currently is possible only after leaching the accumulated salt in early spring (Forkutsa et al. 2009). Salt leaching in early spring by dismantling the beds, made for the irrigation during vegetative period, and applying of about 4500 m^3 ha^{-1} of water, is a common practice in the study region (Forkutsa et al. 2009). According to Ochs and Smedema (1996), in the Aral Sea Basin, even more water is applied for the leaching of seriously saline land; about 5000 to 10000 m^3 ha^{-1} yr^{-1}. Such practices can hardly be sustainable as the availability of irrigation water is declining in the region (Gupta et al. 2009; Forkutsa et al. 2009).

After leaching, the low salinity level (<3 dS m^{-1}) observed on the top of the beds under PSFI compared to EFI and ASFI in both years suggests that salinity in BP in irrigated drylands could be leached effectively with the use of PSFI method. This could be due to the fact that the accumulated salt in dry the furrow moved downward instead of laterally (Figures 6.8 and 6.9), because the water in the dry furrow was applied only after filling all the furrows designated for irrigation. There is no doubt that applying water in alternate furrow under PSFI can significantly reduce the amount of irrigation water compared to the conventional method. Thus, this practice also can reduce the harmful effect of over-irrigation in saline and shallow groundwater areas.

However, PSFI can be effective under controlled irrigation conditions, for example if high rainfall or accidentally irrigated water fills the normally dry furrows and pushes salts back across the bed toward the plants where it will cause salt injury to the plants. Moreover, under PSFI method there is also a possibility to leach the accumulated salts on dry furrow even during the vegetative growth stages. This practice further helps avoiding salt injury during crop growth stages, and increasing crop productivity in salt-affected irrigated lands.

In this study, the cotton was planted on the center of the bed. When planted on the side of the irrigated furrow, without reducing the plant population, it can be expected that cotton yield could be further increased under PSFI, as the salinity level on the irrigated side of the furrow is always low and crops can thus grow in a less saline environment (Figures 6.8 and 6.9). Benefits would be even greater if a salt-sensitive crop was planted on the side of the irrigated furrow and a salt-tolerant crop was planted on the side of the dry furrow.

6.5 Summary and conclusions

In the raised bed system, soil salinity on top of the beds increases over time in the absence of crop residues compared to the conventional practices. When retaining crop residues, the increasing salinity level on the raised beds can be reduced by 45% in the top 10 cm and by 18% over the top 90 cm soil profile. Such reduction in increasing soil salinity will have considerable importance in a region like Central Asia where land degradation due to increased soil salinity is widespread, and in particular in Uzbekistan, where more than 90% of irrigated lands suffer from soil salinity. Thus, raised bed planting with residue retention could be a promising option to slow down the on-going soil salinization in salt-affected irrigated drylands.

This study had only two residue treatments, i.e., residue retained and residue harvested, and at the end of three crop seasons about 13 t ha^{-1} wheat residues and

6 t ha^{-1} of cotton residues were retained. Retaining all residues after each crop cycle may, however, not be necessary. A partial removal of crop residues would also ease the present competition of residues for other uses than for mulch.

Soil salinity on top of raised beds increases if irrigation water is applied to every sides of the furrow. In permanent skip furrow irrigation, salts accumulate towards the dry furrows and hence, this technology reduces the salt concentration on the top and the side of the raised beds by 2-3 times compared to EFI and ASFI. Therefore, the salinity level on the irrigated side of the furrow under PSFI is always low, and crops can grow in a less saline environment. Cotton yield was significantly affected by irrigation methods; PSFI performed better and produced yields of 984 kg ha^{-1} (96% higher) and 787 (64% higher) kg ha^{-1} higher cotton yield than EFI and ASFI methods, respectively. The salts from the beds can be leached properly under PSFI compared to the ASFI and EFI method. After leaching, salinity level on top of the bed under PSFI reduced to <3 dS m^{-1} (i.e., by 100%) compared to 5-6 dS m^{-1} under ASFI and BFI. Permanent skip furrow irrigation, however, reduces the amount of irrigation water and thus can minimize the secondary soil salinization problem under saline and shallow groundwater table areas. Thus, in the absence of crop residues, permanent skip furrow irrigation could be an effective method to manage the salt under raised bed in salt-affected irrigated drylands. This practice could be more beneficial to farmers if salt-sensitive crops were planted on the side of the irrigated furrow and a salt-tolerant crop planted on the side of the dry furrow. Further research is needed to identify the combination of the salt- tolerant and susceptible crops to cultivate on raised bed with permanent skip furrow irrigation and its benefits to the farmers and to the environment.

7 GENERAL DISCUSSION AND CONCLUSIONS

7.1 Introductory remarks

This thesis addresses the scope for conservation agriculture (CA) practices with different nitrogen (N) fertilization levels in cotton-based systems in salt-affected, irrigated drylands in Uzbekistan, Central Asia. Crop growth, yield and water productivity of the major crop rotation (cotton/winter wheat/third crop, e.g., maize, and cotton mono-crop) as practiced by farmers in the study region Khorezm were compared under conservation and conventional agriculture practices with three different N levels during 2008 and 2009. The treatments examined were screened also for their effect on soil salinity and N use efficiency, and it was defined under what conditions certain CA practices, as advocated until now mainly under rainfed conditions can be suitable also for the irrigated drylands in Uzbekistan.

The following synthesis indicates how the separate research findings as outlined in the different chapters have overall contributed to a better understanding of the problems and potential solutions and to progressing science. The findings of this study could be extrapolated to areas with soils and agro-ecology similar to those in Khorezm.

7.2 Discussion

7.2.1 A rationale for conservation agriculture in Uzbekistan

In the former Soviet republic Uzbekistan, cotton mono-cropping with intensive soil tillage and excessive use of irrigation water and chemicals has been practiced since the Soviet Union era. Intensive soil tillage increases the production costs, contributes to greenhouse gas emissions, degrades cropland, compacts soils, deteriorates soil fertility, and renders soils susceptible to wind and water erosion (Cox et al. 1990; Lopez et al. 1998; Tursonov 2009). Cotton mono-crop production without rotation has also caused widespread soil exhaustion and degradation in Uzbekistan. The long-time practice of flood-and-furrow irrigation without adequate drainage has drastically increased soil salinity, which in turn requires large amounts of fresh water for salt leaching to ensure crop establishment. Soil salinity causes losses in crop yield even up to 50%, which is detrimental in Uzbekistan given that more than 90% of the irrigated land suffers from different levels of salinity (Vlek et al. 2001).

Conservation agriculture practices, i.e., reduced tillage, proper residue retention and crop rotation, have effectively reduced soil erosion, conserved soil moisture, improved soil quality, enhanced soil carbon sequestration and reduced the production costs, but these findings stem mainly from rainfed agriculture (Cantero-Martıne et al. 2003; Wang et al. 2007; Giller et al. 2009). On the other hand, critics have emerged on the use of CA as a blanket recommendation (e.g., Giller et al 2009). For example**,** the effects of CA practices on growth and yields have been inconsistent. Some studies showed that crop yields remained similar to or were not always higher with CA than with conventional agriculture practices (Daniel et al. 1999; Nyakatawa et al. 2000; He et al. 2009b; Gursoy et al. 2010). Others even reported lower yields (Ishaq et al. 2001; Pettigrew and Jones 2001; Schwab et al. 2002). Yet, accumulating evidence suggests that many of the benefits from CA practices may also occur under irrigated conditions (Sayre and Hobbs 2004; Tursonov 2009). Conservation agriculture practices may, therefore, minimize the adverse effects of the conventional crop production systems in the irrigated areas of Central Asia in general and in Uzbekistan in particular. Recent findings underpin that to ensure effective and sustainable outcomes, CA practices must be combined with appropriate N application levels, since N application requirements under CA practices differ from those of conventional systems (Randall and Bandel 1991; Torvert and Revert 1994). The identification of proper N management under CA may help to not only increase N use efficiency, but also water productivity, to decrease soil salinity, to decrease production cost and in the end also to increase carbon sequestration in the soil.

The effects of CA practices were examined in two cotton-based rotation systems, i.e., (1) cotton/cover-crop/cotton, and (2) cotton/wheat/maize while addressing agronomic and soil property aspects.

7.2.2 Impact of CA practices on crop yield and N use efficiency in a cotton/cover-crop/cotton rotation

In both study years, raw cotton yields in permanent raised beds (BP) and under conventional tillage (CT) practices were similar in the cotton/cover-crop/cotton rotation.

Yield is an important indicator for the state-ordered cropping system in Uzbekistan, which includes cotton and wheat and focuses in the first place on satisfying imposed production quota for these crops. Hence, the absence of yield differences indicates that CA practices may be a suitable alternative to the present intensive soil tillage activities for irrigated cotton production (section 3.3.3). However, benefits are expected not only for the government but also for farmers to whom CA offers a scope for increasing income generation. The highest costs for the farmers are presently caused by machinery use and fuel; they constitute about 33% of the total production cost (Rudenko and Lamers 2006; Tursunov 2009). Hence, similar yields with CA compared to CT practices with concurrent reduced production and operational costs for cotton production results in higher gross margins (Tursunov 2009). Therefore, based on the yield aspect, introducing CA practices should be in the interest of farmers and administrators promoting sustainable cotton production in Uzbekistan.

Also important for farmers in particular and the society as a whole who are concerned about the environment is the N use efficiency during crop cultivation, which under the present conventional practices suffers from N losses via emissions and/or leaching (Scheer et al. 2008; Kienzler 2010). The observed similar cotton yields despite different N levels and tillage methods indicate that during the transition period from CT to CA, the optimum application N level for irrigated cotton does not differ between soil tillage method (section 3.3.3), and obviously depended on the initial soil mineral N content (section 3.3.4). However, the findings show a linear yield response to soil available N until about 200 kg ha^{-1}, which than tapered off with higher N levels. This indicates that every kg of N added above 150 kg N ha^{-1} (assuming about 50 kg N ha^{-1} is residual) does not lead to the same effect as application rates below this threshold figure (Figure 3.3). It may, therefore, not be worthwhile for farmers to invest in more than 150 kg N ha^{-1} during the transition phase from CT to BP practices. Furthermore, in BP, lower amounts of N could be used compared to the recommended amount of ca 180 kg N ha^{-1} with CT in the region. Also, the apparent recovery of applied N in BP was higher than under CT, whereas the physiological N use efficiency (NUE) was lower. Hence, during the transition period, less N is needed, indicating lower production costs for farmers and less pollution of the environment, which is also beneficial to the society as a whole.

Furthermore, due to higher N application levels, there was a linear increase in leaf area and biomass production (Figure 3.2), and a smaller number of open bolls during first picking (Table 3.4); hence, the growth duration of cotton in BP with higher N application levels was extended compared to CT. In case farmers still intend to apply larger amounts of N in BP as they are presently used to, yield benefits from this CA practice can still be captured. In order to do so, farmers would need to advance the cotton seeding time compared to the present seeding time. When considering that for an effective germination of cotton seeds, the soil temperature must be >12 °C, earlier planting dates may be restricted under the agro-climatic conditions in Khorezm. Yet, a recent analysis of weather parameters showed that the present seeding recommendations have become conservative and that site-specific adjustments are viable (Conrad et al. 2011); the authors are thus in favor of this proposed strategy. The analysis showed furthermore that the impact of climate change had not yet resulted in longer frost periods or later spring onsets as previously predicted (Vinogradov and Langford 2001). Obviously, also the introduction of short-duration cotton varieties can be an alternative to reap the potential benefits from permanent raised beds especially when applying higher rates of N fertilizer than needed. Finally, given the increasing costs of inputs such as N fertilizers (Rundenko and Lamers 2006) under virtually similar product prices for cotton, BP with lower levels of N is also advantageous for increasing the farmers' income from the state-ordered cotton production.

Hence, the two main indicators, i.e., yield and N management, show that the introduction of permanent beds is a promising option. However, the findings also show residual soil N losses due to early spring salt leaching (section 3.3.1). These losses can be counterbalanced by introducing a cereal cover crop instead of a winter fallow, thus reducing the groundwater-NO_3 concentration. This in turn can increase the N uptake and NUE for the following summer crop (Gabriel and Quemada 2011; Staver and Brinsfield 1998) such as cotton. Analyses of such a strategy in a cotton mono-crop situation indeed showed an up to 3-fold reduced groundwater-NO_3 concentration in early spring compared to a winter fallow (section 3.3.1). The inclusion of a cereal cover crop in a cotton mono-crop system increased not only N uptake, hence minimized N leaching, but also the carbon input. Findings show that carbon increased by 16% in the top 30 cm soil profile (section 3.3.9) compared to the initial level. This is especially interesting given the on-going carbon losses with conventional cultivation practices.

The combined findings on the effects of CA practices show that introducing CA practices and a winter cover crop in a cotton mono-crop system is a promising option. Yields were similar under the two tillage methods involved in this study, which is of particular interest given the state order quotas. The N use efficiency in the CA practices was higher, which is important given the increasing N prices and the present environmental pollution, and the reduced production costs with BP will result in higher profits. In particular, cotton mono-cropping in BP combined with a winter cover crop and an N application rate of 150 kg N ha^{-1} is a suitable option to increase sustainable cotton production in the salt-affected irrigated drylands in Uzbekistan. It would important to determine whether or not the cultivation and active termination of the winter cover crop with, for example, herbicides is also a financially feasible practice.

7.2.3 Impact of CA practices on water productivity, N use efficiency and soil salinity in a cotton/wheat/maize rotation

Targeted field preparation helped avoiding the usually reported temporary reduction in yields when changing from CT to CA practices (section 4.3.2). Whilst during the first season of CA practices, cotton yields were not affected by soil tillage method, already in the next season the subsequent wheat crop yielded 12% and the next crop maize 41% more with BP than under CT. The observed significant yield increases in both wheat and maize in BP were caused mainly by specific yield-determining components such as higher number of spikes m^{-2} in wheat, and higher number of maize cobs ha^{-1} and grains per cob (section 4.3.2). Furthermore, BP practices lowered irrigation water demands by 12 and 23% during the wheat and maize season, respectively, compared to conventional flood irrigation (section 4.3.2). If such reductions in irrigation water usage are up-scaled, the findings will have considerable importance for Uzbekistan, where both the problem of secondary soil salinization due to excessive water needs through conventional flood irrigation is increasing and the freshwater supply is diminishing. Hence, increasing crop yields while reducing production cost and irrigation water amount in BP is important from the economical as well as food security point of view, as wheat and maize are the major food and feed crops in Uzbekistan. This should be in the interest of the farmers, as production costs can be reduced (section 7.3) and crops could be grown under diminished freshwater supply conditions.

Furthermore, crop yield response to each kg of N applied was higher in BP than under CT in both wheat and maize crops (section 5.3.3). Also, the increased N uptake and use efficiency in BP led to smaller N losses and higher NUE compared to CT (Table 5.3). Options for increasing crop yield per kg N application while reducing N losses can have important implications for both the environment and income generation of farmers under the hot and dry conditions of Central Asia, where up to 40% of applied-N losses occurred in cotton grown under CT (Scheer et al. 2009). Given the higher NUE of a cotton/wheat/maize rotation in irrigated drylands with BP than under CT may therefore reduce production costs for farmers, environmental pollution through greenhouse gas emissions, and groundwater pollution.

The response of the combination of residue retention (RR) and BP to each kg of applied N especially during the maize season exceeded that of all the other treatments even at low N levels (Figure 5.7). As in the case of the cotton/cover-crop/cotton rotation, yield benefits can thus be obtained by applying less N than presently recommended if it is possible to retain crop residues. However, as long as N fertilizer is still affordable, farmers may not feel encouraged to leave crop residues for increasing NUE. Only after CA practices have led to an increased level of organic matter and N content in the soil, may fertilizer N requirements for the crop decrease with CA practices as experienced under rainfed conditions (Karlen 1990 and Salinas-Garcia et al. 2001). Similarly, the higher negative N balance with the combination of RR and N-0 (Figure 5.9) indicates that this practice slowly mines the soil-N resources. Thus, under the present conditions, solely retaining crop residues without N application should be avoided.

In the absence of crop residues, the salinity level in BP increased, while it could be reduced significantly with the retention of crop residues. This increase was even higher than under CT (Figure 6.4), thus complete removal of residues in BP is not recommended. This is particularly important in Uzbekistan, where more than 90% of the area is affected by (secondary) soil salinization.

However, leaving crop residues on the field competes with current farmers' practices, because residues are presently used as animal feed (wheat straw) and also as fuel (cotton stems). To achieve a balanced use of crop residues for improving soil properties and farmers' requirements, it is necessary to conduct further research to determine the optimum level of retained residues and how much can be harvested.

No effect of residues on soil salinity during the (first) cotton season was observed, where only 3 t ha^{-1} wheat residues were applied. However, salinity was decreased after the cotton season, i.e., after the retention of 6 t ha^{-1} cotton residues during the wheat season, and then after the retention of 10 t ha^{-1} wheat residues during the maize season (section 6.3). This indicates that at least more than 3 t ha^{-1} crop residues are needed for reducing soil salinity when introducing CA practices. Although the assessment of an optimal rate of residue retention was beyond the scope of this study, from the present findings it is clear that retaining all residues each time from all crops is unnecessary. Since the irrigated winter wheat crops produced substantial amounts of crop residues (8-10 t ha^{-1}), leaving all these residues as a thick surface layer may reduce seedling emergence and render field operations difficult, i.e., seeding, irrigation, and fertilizer management. According Rawson and Macpherson (2000), a retention of about 4 t ha^{-1} crop residue is the amount to be targeted for to reach better crop growth and management. In a six years of study in CA practices Salinas-Garcia et al. (2001) reported that under the condition of rapidly oxidization of soil organic matter, it is necessary to leave at least 60% of the crop residues. Similarly, after three years of field research in Uzbekistan, Bezborodov et al. (2010) reported that soil salinity levels in cotton fields reduced by 20% with retention of 1.5 t ha^{-1} wheat residues in each season compared to no-residue treatments. Thus, to achieve a balanced use of residues on the degraded croplands, a partial removal of the residues from the fields seems to fit the agronomic and economic demands. However, this needs approval from the administration, which presently recommends the total removal of crop residues.

Although crop residue retention is a key factor in CA practices such as BP, its application in the irrigated drylands in Uzbekistan needs much more attention. Consent exists that crop residue is a renewable source of soil organic matter, and as such has the potential to improve the soil quality especially in low soil-organic matter conditions (Lal et al. 2007; Sainju et al. 2007). This is particularly important in the irrigated drylands of Uzbekistan, since this region is experiencing soil quality degradation owing to cotton mono-cropping with extensive tillage and crop residue removal that has reached alarming levels (Kienzler 2010). On the other hand, soil organic carbon reportedly only increases slowly, and the process may take several years, depending on temperature, moisture conditions, management practices, and quantity and quality of carbon input and mineral N added (Wang 2006). However, the higher soil organic carbon level at wheat and maize harvest than the pre-experiment level and at cotton harvest in 2008 (Table 5.4; section 3.3.9) indicates that proper crop rotation with residue retention in BP can improve the soil quality at the beginning of CA practices.

The findings combined indicate that BP together with residue retention and crop rotation increases crop yield, saves irrigation water, increases NUE and minimizes N loss, increases soil organic carbon, and reduces the increasing salinity in salt-affected irrigated drylands. The optimal level of crop residue retention, however, needs to be determined.

Although no reduction in crop yield and a high N use efficiency in BP compared to CT under both cotton/cover crop/cotton and cotton/wheat/maize rotations was observed, the latter rotation could be more beneficial from an economic point of view. Here, farmers can harvest three crops in rotation, while with the cotton/cover crop/cotton rotation farmers will get only two cotton crops with, however, extra costs for growing and terminating the winter cover crop. An economic analysis, however, has not been conducted for this system; an economical analysis of a cotton-wheat system under CA in the region by Tursonov (2009) showed that the total gross margin is always higher for the wheat crop than for the cotton. Hence, cotton/wheat/maize rotations under CA practices could be more profitable than cotton/cover crop/cotton rotation in salt affected irrigated lands of Uzbekistan.

7.2.4 Impact of irrigation method on soil salinity management on permanent raised beds

Although residue retention has great potential to reduce the salinity levels in salt-affected irrigated drylands (section 6.3.1), residues may not be available in the quantities and quality needed (section 7.2.1). In the absence of crop residues, the salinity level on top of the raised beds increases (Devkota et al. 2010), and in particular when applying irrigation water from both sides of the furrow, which is presently a common irrigation practice. This can cause salt injury to the growing plants (Brady and

Well 2008) and also demands more irrigation water or the beds need to be destroyed to leach the accumulated salts out from the top of the beds. Hence, the benefits of BP (see Chapter 3, 4 and 5) in the absence of crop residues and with the common farmers' irrigation practice are not sustainable in the long run.

However, permanent skip furrow irrigation (PSFI) in BP did not increase the salinity level on top of the bed (section 6.3.3). Because of the accumulated salt in the dry furrows under PSFI, the salinity level at the irrigated furrow side always remained low. The crops thus enjoyed a more favorable environment, which resulted in significantly higher cotton yields compared to every-furrow (EFI) and alternate skip-furrow irrigation (ASFI) (section 6.3.3). This is particularly beneficial for crops grown on raised beds in salt-affected areas. Use of PSFI in BP can further reduce the amount of irrigation water needed compared to EFI, and thus can minimize secondary soil salinization in saline and shallow groundwater areas. This is particularly important in Uzbekistan, where more than 90% of the area is affected by (secondary) soil salinization. The PSFI practice could further be more beneficial to farmers if, for example, a salt-sensitive crop were to be planted on the side of the irrigated furrow and a salt-tolerant crop on the side of the dry furrow.

After applying similar amounts of leaching water, the salinity level in BP under PSFI remained at <3 dS m^{-1} (below threshold level for most of the crops) compared to 5-6 dS m^{-1} in the EFI and ASFI treatments. This indicates that it is possible not only to leach the salt out efficiently from the bed keeping it permanent, but also to grow crops in permanent raised beds in the absence of crop residues. The accumulated salt on the dry furrow side can be leached efficiently even in the middle of the crop growing season; this practice can ultimately increase crop productivity. This is especially interesting given the decreased crop yield due to increased soil salinity under CT.

These combined findings show that PSFI has win-win opportunities: it supports management of soil salinity and makes it possible to grow crops in salt-affected irrigated drylands while keeping the beds permanent. Thus, should sufficient crop residues not be available, PSFI can be a supplement or alternative management approach to control salt on permanent raised beds. Furthermore, use of crop residues to increase soil organic matter will increase the sustainability of the practice. Leaving a small amount of crop residues together with proper crop rotation and PSFI with BP could be the most sustainable option for crop production in salt-affected and degraded irrigated lands.

7.3 Conclusions and outlook

Conservation agriculture practices with proper N application can be an alternative for sustaining crop production in salt-affected irrigated drylands. A proper application of CA practices leads to short- and long-term economical and environmental benefits that support food security. The results of this study allow the following conclusions:

- **No yield reduction/increasing crop yield**
  There was no significant difference in raw cotton yield between permanent raised beds and conventional tillage in all study years. However, grain yield of wheat and maize grown in a cotton/wheat/maize rotation on permanent raised beds increased by 12% and 42%, respectively, compared to conventional tillage. Hence, intensive soil tillage is deemed unnecessary for growing crops in irrigated drylands, which can reduce cultivation cost and the negative effect associated with intensive soil tillage.

- **Reduction in amount of irrigation water**
  Crops cultivated on permanent raised beds need less irrigation water, i.e., 12% less during the wheat season and 23% less during the maize season, compared to conventional flood irrigation. Given the predictions of diminishing water supply and increasing secondary soil salinization associated with over-irrigation under conventional flood irrigation system, the introduction of permanent raised beds can be a suitable alternative for irrigated saline area with shallow groundwater in the drylands of Uzbekistan.

- **Increase in efficiency of N fertilizer**
  Already after one season of CA practices, apparent N recovery in permanent raised beds was higher in all crops, i.e., 42% higher in cotton, 12% in wheat, and 82% in maize compared to conventional practices. With high-yielding environment (high-N), the apparent positive N balance (N loss) in permanent raised beds remained 71%

lower in the cotton/wheat/maize rotation and 53% lower in the cotton/cover-crop/cotton rotation compared to the conventional practice. The higher NUE is related to increased N availability and N uptake by crops in permanent raised beds than under the conventional system. In the current conventional cropping system in the irrigated lands of Uzbekistan, which are characterized by low N use efficiency and high N loss, permanent raised beds can be a suitable alternative.

- **Reduction in NO_3 concentration in groundwater**
  After inclusion of a winter cereal cover crop in the cotton-cotton rotation, the groundwater-NO_3 concentration during early spring was 3 times lower, i.e., 14 mg l^{-1} at the beginning of the 2008 cotton season and less than 4 mg l^{-1} at the beginning of the cotton season 2009 after inclusion of a cover crop. The reduction in groundwater-NO_3 concentration was related to an N uptake and reduced amount of irrigation water for early spring salt leaching.

- **Minimization of increasing soil salinity**
  When retaining crop residues, the increase in the salinity level on permanent raised beds was reduced by 45% in the top 10 cm and by 18% in the top 90 cm soil profile compared to conditions where all residues had been removed. In salt-affected irrigated drylands where degradation of croplands is increasing due to soil salinity, permanent raised beds with residue retention can therefore be beneficial for decreasing the ongoing rate of soil degradation caused by soil salinity.

- **Increase in soil carbon input**
  Inclusion of cereal crops in the cotton mono-crop system added carbon inputs and hence increases the soil organic carbon. In the top 30 cm soil depth it was 16% higher in the cotton/cover-crop/cotton rotation and 22% higher in the cotton/wheat/maize rotation compared to the initial levels.

The evaluation of different furrow irrigation techniques for salt management in raised beds judged by the salt movement, leaching, and crop performance showed that:

- permanent skip furrow irrigation had advantages for the accumulated salt management, and which resulted in a less saline environment towards the irrigated furrow. In turn plants showed less salt injury compared to conventional irrigation practices such as every-furrow and alternating skip furrow irrigation.
- permanent skip furrow irrigation leached the accumulated salts in the dry furrow properly and hence, the salinity level on the center of the beds was reduced by two-fold compared to every-furrow and alternate skip furrow irrigation.

7.4 Recommendations for management of CA practices

No yield reduction in cotton and increasing grain yields of the following wheat and maize crops while using 12-23% less irrigation water under conservation agriculture practices compared to conventional practices is encouraging evidence for the introduction of permanent raised beds. Reductions in the increase in salinity level with retention of crop residues on permanent raised beds and under permanent skip furrow irrigation further support the importance of CA and other smart practices. Higher yields with lower cultivation costs under permanent raised beds should motivate farmers and administrators in Uzbekistan to accept CA practices. In particular because the present results have been obtained, not from small experimental plots but from operational sized plots i.e., in an area of >3 ha; hence similar results can be expected on farmers' fields with some consideration. Based on the experience of three cropping cycles with CA practices, considering the following aspects further adds to the successful application of CA practices in farmers' fields.

- a proper field preparation, including for instance a laser-guided land leveling is necessary before bed making to facilitate a uniform distribution of irrigation water;
- a suitable bed height, i.e., 10-15 cm height, is needed for efficient salt leaching;
- adequate soil moisture content needs to be ensured during planting to obtain a proper plant stand;
- the use of appropriate herbicides for weed control is advantageous;
- the use of appropriate machinery to drill seed and fertilizer at the proper depth is compulsory;
- a reshaping of beds during planting, if necessary;
- the use of short-maturing crop varieties is advantageous.

8 REFERENCES

Abdullaev C (2003) Republic of Uzbekistan. Land degradation assessment in dry lands (LADA). State Design and Research Institute (Uzgip), Tashkent

Abdullaev I and Molden D (2004) Spatial and temporal variability of water productivity in the Syr Darya Basin, Central Asia. Water Resources Research 40, doi:10.1029/2003WR002364

Ahmad IM, Qubal B, Ahmad G and Shah NH (2009) Maize yield, plant tissue and residual soil N as affected by nitrogen management and tillage system. Journal of Agriculture and Biological Sciences 1(1):19–29

Ahmad N, Rashid M and Vaes AG (1996) Fertilizer and their use in Pakistan. NFDC publication No. 4/96, 2nd edition, Islamabad, Pakistan, p 274

Akbar G, Hamilton G, Hussain Z and Yasin M (2007) Problems and potentials of permanent raised bed cropping systems in Pakistan. Pakistan Journal of Water Resources 11(1):11–21

Akramkhanov A, Ibrakhimov M and Lamers JPA (2010) Managing soil salinity in the lower reaches of the Amudarya delta: How to break the vicious circle? Case Study No. 8-7. In: Per Pinstrup-Andersen and Fuzhi Cheng (eds.), Food Policy for Developing Countries: Case Studies, p 13

Akramkhanov A, Lamers JPA, and Martius C (2010) Conversion factors to estimate soil salinity based on electrical conductivity for soils in Khorezm region, Uzbekistan. In: Qadir M, Wichelns D, Oster J, Jacobsen SE, Basra SMA and Choukr-Allah R (eds.): Sustainable management of saline waters and salt-affected soils for agriculture. Proceedings of the Second Bridging Workshop, 15-18 November 2009, Aleppo, Syria

Anga´s P, Lampurlanes J and Cantero-Martinez C (2006) Tillage and N fertilization Effects on N dynamics and Barley yield under semiarid Mediterranean conditions. Soil and Tillage Research 87:59–71

Ayers R S and Westcot D W (1985) Water quality for agriculture. FAO Irrigation and Drainage paper 29, Rev.1. FAO, Rome, pp 1–174

Bakker DM, Hamilton GJ, Hetherington R and Spann C (2010) Salinity dynamics and the potential for improvement of water logged and saline land in a Mediterranean climate using permanent raised beds. Soil and Tillage Research 110(1):8–24

Beare MH, Pohland BR, Wright DH and Coleman DC (1993) Residue placement and fungicide effects on fungal communities in conventional and no-tillage soils. Soil Sci Soc Am J 57:392–399

Bekchanov M, Karimov A and Lamers JPA (2010) Impact of water availability on land and water productivity: A temporal and spatial analysis of the case study region Khorezm, Uzbekistan. Water 2:668–684

Bezborodov GA, Shadmanov DK, Mirhashimov RT, Yuldashev T, Qureshi AS, Noble AD and Qadir M (2010) Mulching and water quality effects on soil salinity and sodicity dynamics and cotton productivity in Central Asia. Agriculture, Ecosystems and Environment 138:95–102

Blevins RL and Frye WW (1993) Conservation tillage: an ecological approach to soil management. Advances in Agronomy 51:33-78

Boquet D, Robert J, Hutchinson L and Breitenbeck GA (2004) Long-term tillage, cover crop, and nitrogen rate effects on cotton: Yield and fiber properties. Agron J 96:1436–1142

Bordovsky JP, Lyle WM and Keeling JW (1994) Crop rotation and tillage effects on soil water and cotton yield. Agron J 86:1–6

Brady NC and Weil RR (2008) The Nature and Properties of Soils. 14th edition, Pearson-Prentice Hall, Upper Saddle River, NJ, p 990

Braim MA, Chaney K and Hodgson DR (1992) Effects of simplified cultivation on the growth and yield of spring barley on a sandy loam soil. 2. Soil physical properties and root growth; root: shoot relationships, inflow rates of nitrogen; water use. Soil and Tillage Research 22:173–187

Bremen Cotton Report (2010) Cotton Report No.25/26. http://www.baumwollboerse.de Cited 02 July 2010

Bremner JM and Mulvaney CS (1982) Nitrogen-total. In: Page AL (ed) Methods of soil analysis: Part 2. Chemical and microbiological properties. Agron Monograph Number 9, ASA and SSSA, Madison, WI, pp 595–624

Bronson KF, Onken AB, Keeling JW, Booker JD and Torbert HA (2001) Nitrogen response in cotton as affected by tillage system and irrigation level. Soil Sci Soc Am J 65:1153–1163

Campbell CA, Zentner RP, Selles F, McConkey BG and Dyck FB (1993) Nitrogen management for spring wheat grown annually on zero-tillage: Yields and nitrogen use efficiency. Agron J 85:107–114

Campbell RB, Karlen DL and Sojka RE (1984) Conservation tillage for maize production in the U.S. Southeastern coastal plain. Soil and Tillage Research 4:511–529

Cantero-Martınez CP, Angas and Lampurlanes J (2003) Growth, yield and water productivity of barley (*Hordeum vulgare* L.) affected by tillage and N fertilization in Mediterranean semiarid, rainfed conditions of Spain. Field Crops Research 84:341–357

Cardon GE, Davis JG, Bauder TA and Waskom RM (2010) Managing Saline soils. http://www.ext.colostate.edu/pubs/crops/00503.htm. Cited 27 Aug 2010

Carefoot JM and Janzen HH (1997) Effect of straw management, tillage timing and timing of fertilizer nitrogen application on the crop utilization of fertilizer and soil nitrogen in an irrigated cereal rotation. Soil and Tillage Research 44(3-4):195–210

Carter MR (1991) Evaluation of shallow tillage for spring cereals on a sandy loam. 1. Growth and yield components, N accumulation and tillage economics. Soil and Tillage Research 21:23–35

Carter MR and Rennie DA (1984) Crop utilization of placed and broadcast 15N urea fertilizer under zero and conventional tillage. Canadian Journal of Soil Science 64:563–570

Cassman KG, Dobermann A and Walters DT (2002) Agro-ecosystems, nitrogen-use efficiency, and nitrogen management. AMBIO 31:132–140

Chaudhry MR and Guitchonouts A (2003) Cotton Facts. Technical paper No. 25 of the common fund for commodities. International Cotton Advisory Committee, p 158

Choudhary MR, Munir A and Mahmood S (2008) Field soil salinity distribution under furrow-bed and furrow-ridge during wheat production in irrigated environment. Pakistan Journal of Water Resources 12 (2):33–40

Christmann S, Martius C, Bedoshvili D, Bobojonov I, Carli C, Devkota K, Ibragimov Z, Khalikulov Z, Kienzler K, Manthrithilake H, Mavlyanova R, Mirzabaev A, Nishanov N, Sharma RC, Tashpulatova B, Toderich K and Turdieva M (2009) Food Security and Climate Change in Central Asia and the Caucasus, Tashkent, Uzbekistan. CGIAR-PFU, ICARDA Tashkent, p 39

Chua TT, Bronson KF, Booker JD, Keeling JW, Mosier AR, Bordovsky JP Lascano RJ, Green CJ and Segarra E (2003) In-season nitrogen status sensing in irrigated cotton: I. Yields and nitrogen-15 recovery. Soil Sci Soc Am J 67:1428–1438

CIA Factbook (2010) Central Intelligence Agency. Central Asia, Uzbekistan. https://www.cia.gov/library/publications/the-worldfactbook/geos/uz Cited 28 Dec 2010

Conrad C, Fritsch S, Zeidler J, Rücker G and Dech S (2010) Per-field irrigated crop classification in arid Central Asia using SPOT and ASTER data. Remote Sensing *2*(4):1035–1056

Conrad C, Schorcht G, Tischbein B, Davletov S, Sultonov M, Lamers JPA (2011) Agro-meteorological trends of recent climate development in Khorezm and implications for crop production. In: Martius C, Rudenko I, Lamers JPA, and Vlek PLG (eds.) Cotton, water, salts and Soums - economic and ecological restructuring in Khorezm, Uzbekistan

Constable GA, Rochester IJ and Daniells IG (1992) Cotton yield and nitrogen requirement is modified by crop rotation and tillage method. Soil and Tillage Research 23:41–59

Cotton Research Institute (1977) Methods of agrochemical analyses for soil and plants of Central Asia (in Russian). 5th edition Tashkent, Uzbekistan Cotton Research Institute, p 187

Cox WJ, Zobel RW, van Es HM and Otis DJ (1990) Tillage effects on some soil physical and corn physiological characteristics. Agron J 82:806–812

Daniel JB, Abaye AO, Alley MM, Adcock CW and Matland JC (1999) Winter annual cover crops in a Virginia no-till cotton production system. II. Cover crop and tillage effects on soil moisture, cotton yield and cotton quality. Journal of Cotton Science 3:84–91

Davidson DJ and Chevalier PM (1992) Storage and remobilization water soluble carbohydrates in stems of spring wheat. Crop Sci 32:186–190

De Wit CT (1992) Resource use efficiency in agriculture. Agricultural Systems 40 121–151

Deng L, Chen M, Liu Z, Shen Q, Wang H and Wang J (2003) Effects of different ground covers on soil physical properties and crop growth on saline-alkaline soil. Chinese Journal of Soil Science 34 (2):93–97

Derpsch R and Friedrich T (2009) Global overview of conservation agriculture no-till adoption. In 4th World Congress on Conservation Agriculture New Delhi, India, 4-7 February. http://www.fao.org/ag/ca/doc/Global-overview-CA-adoption-Derpsch comp2.pdf. Cited 12 Oct 2010

Devkota MK, Martius C, Sayre KD, Egamberdiev O, Devkota KP, Gupta RK, Manschadi AM and Lamers JPA (2010) Performance of maize under conservation agriculture on salt-affected irrigated croplands of Uzbekistan, Central Asia. http://wwwtropentagde/2010/abstracts/full/1022pdf. Cited 22 Nov 2010

Dilz K (1988) Efficiency of uptake and utilization of fertilizer nitrogen by plants. In: Jenkinson DS and Smith KA (eds) Nitrogen efficiency in agricultural soils. Elsevier Applied Science, London, pp 1–26

Ding G, Novak JM, Amarasiriwardena D, Hunt PG and Xing B (2002) Soil organic matter characteristics as affected by tillage management. Soil Sci Soc Am J 66:421–429

Ditsch DC, Alley MM, Kelly KR and Lei YZ (1993) Effectiveness of winter rye for accumulating residual fertilizer N following corn. Journal of Soil and Water Conservation 48:125–132

Djumaniyazova Y, Sommer R, Ibragimov N, Ruzimov J, Lamers J and Vlek P (2010) Simulating water use and N response of winter wheat in the irrigated floodplains of Northwest Uzbekistan. Field Crops Research 116: 239–251

Dobermann A, Dawe D, Roetter RP and Cassman KG (2000) Reversal of rice yield decline in a long-term continuous cropping experiment. Agron J 92:633–643

Dong H, Li W, Tang W and Zhong D (2008) Furrow seeding with plastic mulching increases stand establishment and lint yield of cotton in saline field. Agron J 100:1640–1646

Doran JW, Elliott ET and Paustian K (1998) Soil microbial activity, nitrogen cycling, and long-term changes in organic carbon pools as related to fallow tillage management. Soil and Tillage Research 49:3–18

Durynina EP and Egorov VS (1998) Agrochemical analysis of soil, plants and fertilizer. Moscow, Moscow University (MGU), p 113

Egamberdiev O (2007) Dynamics of irrigated alluvial meadow soil properties under the influence of resource saving and soil protective technologies in the Khorezm region. Dissertation, National University of Uzbekistan

Eijkelkamp (2002) Eijkelkamp catalogue. Eijkelkamp Agrisearch Equipment, the Netherlands

Elbehar JW (1991) Producing quality cotton in 1991: Plant nutrition management. In: Herber DJ and Richter DA (eds.) Proceedings of Beltwide Cotton Conference San Antonio, TX. 8–12 January National Cotton Council of America Memphis, TN, pp 55–58

Elmi AA, Madramootoo C, Egeh M, Liu A and Hamel C (2002) Environmental and agronomic implications of water table and nitrogen fertilization management. J Environ Qual 31:1858–1867

El-Swaify SA (2000) Soil and water supply. In: Silva JA and Uchida R (ed.) Plant nutrient management in Hawaii’s soils: Approaches for tropical and subtropical agriculture. http://www.ctahr.hawaii.edu/oc/freepubs/pdf/. University of Hawaii, Manoa

Engelstad OP (1985) Fertilizer technology and use. Soil Science Society of America, Inc, Mdison, WI, p 633

Erenstein O, Sayre K, Wall P, Dixon J and Hellin J (2008) Adapting no-tillage agriculture to the conditions of smallholder maize and wheat farmers in the tropics and sub-tropics. In:Goddard T, Zoebisch M, Gan Y, Ellis W, Waston A and Sombatpanit S (eds.) No-till farming systems. Special publication 3:253-278. World Association of Soil and Water Conservation (WASWC), Bangkok

Etana A, Hakansson I, Zagal E and Bucas S (1999) Effect of tillage depth on organic carbon content and physical properties in five Swedish soils. Soil and Tillage Research 52:129–139

Fageria NK and Baligar VC (2005) Enhancing nitrogen use efficiency in crop plants. Advances in Agronomy 88:97–185

Fanong W, Xuqing W and Sayre K (2004) Comparison of conventional, flood irrigated, flat planting with furrow irrigated, raised bed planting for winter wheat in China. Field Crops Research 87:35–42

FAO (2000) Crops and drops. Land and Water Division of the food and agriculture organization. FAO, Rome, Italy

FAO (2002) The salt of the earth: hazardous for food production. Cited 10 Sept 2010

FAO (2002) Uzbekistan country report FAO. Cited 30 Oct 2008

FAOSTAT (2010) Agriculture data, agricultural production. http://faostat.fao.org/, Cited 28 July 2010

Fischer RA, Santiveri F and Vidal IR (2002) Crop rotation, tillage and crop residue management for wheat and maize in the sub-humid tropical highlands: II. Maize and system performance. Field Crops Research 79 (2-3):123–137

Forkutsa I (2006) Modelling water and salt dynamics under irrigated cotton with shallow groundwater in the Khorezm region of Uzbekistan. Dissertation, ZEF/Rheinische Friedrich-Wilhelms-Universität Bonn

Forkutsa I, Sommer R, Shirokova Y, Lamers JPA, Kienzler K, Tischbein B, Martius C, and Vlek PLG (2009) Modeling irrigated cotton with shallow groundwater in the Aral Sea Basin of Uzbekistan: I. Water dynamics. Irrigation Sci 27(4):331–346

Fowler DB, Limin AE, and Ritchie JT (1999) Low-temperature tolerance in cereals: Model and genetic interpretation. Crop Sci 39:626–633

Francis GS and Knight TL (1993) Long-term effects of conventional and no-tillage on selected soil properties and crop yields in Canterbury, New Zealand. Soil and Tillage Research 26 (3):193–210

Franzluebbers AJ, Hons FM and Zuberer DA (1995) Soil organic carbon, microbial biomass, and mineralizable carbon and nitrogen in sorghum. Soil Sci Soc Am J 59:460–466

Fredrick JR and JJ Camberato (1995) Water and nitrogen effects on winter wheat in the southeastern central plain: I. Grain yield and kernel traits. Agron J 87:521–526

Frye WW, Smith WG and Williams RJ (1985) Economics of winter cover crops as a source of nitrogen in no-till corn. Journal of Soil and Water Conservation 40:246–249

Gabriel JL and Quemada M (2011) Replacing bare fallow with cover crops in a maize cropping system: Yield, N uptake and fertilizer fate. European Jourrrnal of Agronomy DOI 10.1016/j.eja.2010.11.006

Gant CA, Gauer LE and Bailey LD (1992) Tillage and soil physical quality. In: www.mandakzerotill.org/books/proceddings/proceeding%201992/cynt Cited 10 Oct 2010

Gardner CMK, Robinson D, Blyth K and Cooper JD (2001) Soil water content. In: Smidth KA and Mullins CE (eds.) Soil and environmental analysis: physical methods. Marcel Deccer Inc, New York, USA, pp 1–65

Garten RW and Widders IE (1990) N and P preconditioning of small seedlings influences growth and yield processing tomatoes. Hort Science 25:655–657

Gastal F and Lemaire G (2002) N uptake and distribution in crops: an agronomical and ecophysiological perspective. Journal of Experimental Botany 53 (370):789–799

Govaerts B, Sayre KD and Deckers J (2005) Stable high yields with zero tillage and permanent bed planting? Field Crops Research 94:33–42

Guadagni M, Raiser M, Crole-Rees A and Khidirov D (2005) Cotton taxation in Uzbekistan: Opportunities for reform. ECSSD Working Paper No 41, Europe and Central Asia Region. World Bank, Washington DC, p 29

Gupta R, Kienzler K, Martius C, Mirzabaev A, Oweis T, de Pauw E, Qadir M, Shideed K, Sommer R, Thomas R, Sayre K, Carli C, Saparov A, Bekenov M, Sanginov S, Nepesov M and Ikramov R (2009) Research Prospectus: A Vision for Sustainable Land Management Research in Central Asia. ICARDA Central Asia and Caucasus Program. Sustainable Agriculture in Central Asia and the Caucasus Series No.1. CGIAR-PFU, Tashkent, Uzbekistan

Gürsoy S, Sessiz A and Malhi SS (2010) Short-term effects of tillage and residue management following cotton on grain yield and quality of wheat. Field Crops Research 119:260–268

Habtegebrial K, Singh BR and Haile M (2007) Impact of tillage and nitrogen fertilization on yield, nitrogen use efficiency of tef (Eragrostis tef (Zucc.) Trotter) and soil properties. Soil and Tillage Research 94:55–63

Haper HJ (1924) The accurate determination of nitrates in soils. Journal of Industrial and Engineering Chemistry 16:180-183

Harris BL and JH Krishna (1989) Furrow diking to conserve moisture. Journal of Soil and Water Conservation 44:271–273

Hassan I, Hussain Z and Akbar G (2005) Effect of permanent raised beds on water productivity for irrigated maize–wheat cropping system. In: Roth CH, Fischer RA and Meisner CA (eds.) Evaluation and performance of permanent raised bed cropping systems in Asia, Australia and Mexico. ACIAR Proceeding No. 121

Hicks SK, Wendt CW, Gannaway JR and Baker RB (1989) Allelopathic effects of wheat straw on cotton germination, emergence, and yield. Crop Sci 29:1057–1061

Hirel B, Le Gouis J, Ney B and Gallais A (2007) The challenge of improving nitrogen use efficiency in crop plants: Towards a more central role for genetic variability and quantitative genetics within integrated approaches. Journal of Experimental Botany 58 (9):2369–2387

Holanda FSR, Mengel DB, Paula MB, Carvaho JG and Bertoni JC (1998) Influence of crop rotations and tillage systems on phosphorus and potassium stratification and root distribution in the soil profile. Communications in Soil Science and Plant Analysis 29 (15-16):2383–2394

Holland JE, White RE and Edis R (2007) The relation between soil structure and solute transport under raised bed cropping and conventional cultivation in south-western Victoria. Australian Journal of Soil Research 45:577–585

Holland JM (2004) The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. Agriculture, Ecosystems and Environment 103:1–25

Huang Q, Yin Z and Tian C (2001) Effect of two different straw mulching methods on soil solute salt concentration. Arid Land Geography 24:52–56.

Huang YL, Chen LD, Fu BJ, Huang, ZL and Gong E (2005) The wheat yields and water-use efficiency in the Loess Plateau: straw mulch and irrigation effects. Agricultural Water Management 72 (3):209–222

Huntington TG, Grove JH and Frye WW (1985) Release and recovery of nitrogen from winter annual cover crops in no-till corn production. Communications in Soil Science and Plant Analysis 16:193–211

Ibragimov NM (2007) Ways of increasing the nitrogen fertilizer efficiency on cotton in the belt with irrigated sierozem soils (Habilitation, in Russian). Dissertation, Uzbekistan Cotton Research Institute

Ibrakhimov M, Khamzina A, Forkutsa I, Paluasheva G, Lamers JPA, Tischbein B, Vlek PLG and Martius C (2007) Groundwater table and salinity: Spatial and temporal distribution and influence on soil salinization in Khorezm region, Uzbekistan, Aral Sea Basin. Irrigation and Drainage Systems 21 (3-4):219–236

Ibrakhimov M, Park SJ and Vlek PLG (2004) Development of groundwater salinity in a region of the lower Amu-Darya River, Khorezm, Uzbekistan Agriculture in Central Asia: Research for Development Proceedings of a Symposium held at the American Society of Agronomy Annual Meeting at Indianapolis, Indiana, USA, 10-14 Nov International Centre for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria, pp 56-75

Isfan D (1990) Nitrogen physiological efficiency index in some selected spring barley cultivars. Journal of Plant Nutrition 13:907–914

Ishaq M, Ibrahim M and Lal R (2001) Tillage effect on nutrient uptake by wheat and cotton as influenced by fertilizer rate. Soil and Tillage Research 62:41–53

Jalota SK and Arora VK (2002) Model-based assessment of water balance components under different cropping systems in North-West India. Agricultural Water Management 57:75–87

Jat ML, Chandna P, Gupta R, Sharma SK and Gill MA (2006) Laser land leveling: A precursor technology for resource conservation Rice-wheat consortium technical bulletin series 7 New Delhi, India: Rice-Wheat Consortium for the Indo-Gangetic Plains, p 48

Jat ML, Pal SS, Subba Rao AVM and Sharma SK (2003) Improving resource use efficiency in wheat through laser land leveling in an ustochrept of Indo-Gangetic plain. In: National Seminar on Developments in Soil Science, 68th Annual Convention of the Indian Society of Soil Science, November 4-8, CSAUAT, Kanpur (UP)

Jaynes DB, Colvin TS, Karlen DL, Gambardella CA and Meek DW (2001) Nitrate loss in sub-surface drainage as affected by nitrogen fertilizer rate. J Environ Qual 30: 1305–1314

Karlen RL (1990) Conservation tillage research needs. Journal of Soil and Water Conservation 45:365–369

Keeling WJ, Segarra E and Abernathy JR (1989) Evaluation of conservation tillage systems for cotton on the Texas Southern High Plains. Journal of Production Agriculture 2:269–273

Khadjiyev TK (1998) Fertilizer-nitrogen transformation and ecological basics of increasing its efficiency in irrigated soils of sierozem belt (Habilitation, in Russian) Extended abstract Dissertation, Uzbekistan Committee on Soil Resources, Cadaster and Bonitet, p 49

Khaleque M, Paul N and Meisner C (2008) Yield and N use efficiency of wheat as influenced by bed planting and N application Bangladesh. Journal of Agricultural Research 33(3):439–448

Khamzina A (2006) The assessment of tree species and irrigation techniques for afforestation of degraded agricultural landscapes in Khorezm, Uzbekistan, Aral Sea Basin Dissertation, ZEF/Rheinische Friedrich-Wilhelms-Universität Bonn

Khorezm Regional Department of Statistics (2009) Agricultural Indicators for Khorezm Oblast, OblStat: Urgench, Uzbekistan

Kienzler K (2010) Improving the nitrogen use efficiency and crop quality in the Khorezm region, Uzbekistan Dissertation, ZEF/Rheinische Friedrich-Wilhelms-Universität Bonn

Kottek M, Grieser J, Beck C, Rudolf B and Rubel F (2006) World map of Köppen Geiger climate classification. http://koeppen-geigervu-wienacat/. Cited 22 Sept 2009

Kraatz DF and Mahajan JK (1975) Small hydraulic structures FAO irrigation and drainage paper 26/2 FAO, Rome, p 198

Krupnik TJ, Six J, Ladha JK, Paine MJ and van Kessel C (2004) An assessment of fertilizer nitrogen recovery efficiency by grain crops. In: Mosier AR, Syres JK and Freney JR (eds) Agriculture and nitrogen cycle Assessing the impact of fertilizer use on food production and the environment SCOPE, Island Press, Washington, Covelo, London, pp 193–207

Lal R, Reicosky DC and Hanson JD (2007) Evolution of the plow over 10,000 years and the rationale for no-till farming. Soil and Tillage Research 93 (1):1–12

Latiri-Souki K, Nortcliff S and DW Lawlor (1998) Nitrogen fertilizer can increase dry matter, grain production and radiation and water use efficiencies for durum wheat under semi-arid conditions. European Journal of Agronomy 9:21–34

Li X and Zhang Z (1999) Effect of straw mulching on soil water and salt movement. Chinese Journal of Soil Science 30:257–258

Li X, Zhang Z, Liu X and Li Y (2000) Effect of straw mulching on soil water and salt moving. Journal of Shandong Agricultural University 31 (1):38–40

Limon-Ortega A, Sayre KD and Francis CA (2000) Wheat and maize yields in response to straw management and nitrogen under a bed planting system. Agron J 92:295–302

Limon-Ortega A, Sayre KD and Francis CA (2000) Wheat nitrogen use efficiency in a bed planting system in Northwest Mexico. Agron J 92:303–308

Liu X, Ju X, Zhang F, Pan J and Christie P (2003) Nitrogen dynamics and budgets in a winter wheat–maize cropping system in the North China Plain. Field Crops Research 83:111–124

Lopez MV, Sabre M, Gracia R, Arrue JL and Gomes L (1998) Tillage effects on soil surface conditions and dust emission by wind erosion in semiarid Aragon NE Spain. Soil and Tillage Research 45:91–105

Lopez-Bellido L, Fuentes M, Castillo J E, Lopez-Garrido FJ and Fernandez EJ (1996) Long-term tillage, crop rotation, and nitrogen fertilizer effects on wheat yield under rainfed Mediterranean conditions. Agron J 88:783–791

Lopez-Bellido RJ and Lopez-Bellido L (2001) Efficiency of nitrogen in wheat under Mediterranen conditions: effect of tillage, crop rotation and N fertilization. Field Crop Research 71:31–46

Maas EV and Grattan SR (1999) Crop yields as affected by salinity. In: Skaggs RW and van Schilfgaarde J (eds) Agricultural Drainage. Agron Monograph 38 ASA, CSSA, SSA, Madison, pp 55–108

Mahmood T, Ali R, Iqbal J and Robab U (2008) Nitrous oxide emission from an irrigated cotton field under semiarid subtropical conditions. Biology and Fertility of Soils 44 (5):773–781

Mallik RK, Yadav A and Singh S (2005) Resource conservation technologies in rice-wheat cropping system of Indo-Gangetic plains. In: Abrol IP, Gupta RK and Malik RK (eds) Conservation agriculture: Status and prospects Centre for advancement of sustainable agriculture, New Delhi, pp 13–23

Malpassi RN, Kaspar TC, Parkin TB, Cambardella CA and Nubel NA (2000) Oat and rye root decomposition effects on nitrogen mineralization. Soil Sci Soc Am J 64:208–215

Mann RA, Ramzan M and Munir A (2008) Improving the sustainability of wheat production in irrigated areas of Punjab, Pakistan through conservation tillage technology. International Journal of Agriculture and Biology 10 (3):249–254

MAWR (2000) Agrotechnology of cereal production in irrigated and non-irrigated areas (in Russian). HAYOT, Andijan, Uzbekistan, p 46

McConkey BG, Curtin D, Campbell CA, Brandt SA and Selles F (2002) Crop and soil nitrogen status of tilled and no-tillage systems in semi-arid regions of Saskatchewan. Canadian Journal of Soil Science 82:489-498

McFarland ML, Hons FM and Saladino VA (1991) Effects of furrow diking and tillage on corn grain yield and nitrogen accumulation. Agron J 83:382–386

Meiri A and Plaut Z (1985) Crop production and management under saline conditions. Plant and Soil 89:253–271

Metha SL and Bandyopadnyay A (2004) Sustainable agriculture farming system and natural resources. In: Sundaram KV, Moni M, and Jha M (eds) Natural resource management and livelihood security survival strategies and sustainable polices Bhoovigyan Vikas Foundation Ashok Kumar Mittal, concept publishing company, A/15-16, commercial Block Mohan Garden, p 210

Minhas PS (1996) Saline water management for irrigation in India. Agricultural Water Management 30:1–2

Minhas PS (1998) Crop production in saline soils. In: Tyagi NK and Minhas PS (eds) Agricultural Salinity Management in India. Central Soil Salinity Research Institute (CSSRI), Karnal, India, pp 325–350

Müller M (2006) A general equilibrium approach to modeling water and land use reforms in Uzbekistan. Dissertation, ZEF/Rheinische Friedrich-Wilhelms-Universität Bonn

Mulumba LN and Lal R (2008) Mulching effects on selected soil physical properties. Soil and Tillage Research 98:106–111

Nakaseko K, Gotoh K and Sato H (1978) Physiological studies on prolificacy in maize III. The relationships between expression of second ear and some physio-ecological characteristics. Japanese Journal of Crop Science 47 (2):212–220

Nelson DW and Sommers LE (1982) Total carbon, organic carbon and organic matter. In: Page AL (ed) Methods of soil analysis: Part 2 Chemical and microbiological properties. Agron Monograph No 9, ASA and SSSA, Madison, WI, p539–579

Norton ER and Silvertooth JC (2007) Evaluation of added nitrogen interaction effects on recovery efficiency in irrigated cotton. Soil Science 172 (12):983–991

Novoa R and Loomis RS (1981) Nitrogen and plant production. Plant and Soil 58:177–204

Nyakatawa EZ and Reddy KC (2000) Tillage, cover cropping, and poultry litter effects on cotton: germination and seedling growth. Agron J 92:992–999

Nyakatawa EZ, Reddy KC and Mays DA (2000) Tillage, cover cropping, and poultry litter effects on cotton II Growth and yield parameters. Agron J 92: 1000–1007

Ochs WJ and Smedema LK (1996) Planning for drainage development in the Aral Sea basin. In: Bos MG (ed) The inter-relationship between irrigation, drainage and the environment in the Aral Sea Basin. Proceedings of the NATO advanced research workshop on drainage and development in arid zones. Kluwer Academic Publisher, the Netherlands, pp 28-29

Olsen SR and Sommers LE (1982) Phosphorus. In: Page AL (ed) Methods of soil analysis: Part 2 Chemical and microbiological properties. 2nd edition, Agron Monograph Number 9, ASA and SSSA, Madison, WI, p 403–430

Omonode RA, Gal A, Stott DE, Abney TS and Vyn TJ (2006) Short-term versus continuous chisel and no-till effects on soil carbon and nitrogen. Soil Sci Soc Am J 70:419–425

Palta JA and Fillery RP (1995) N application enhances remobilization and reduces losses of pre-anthesis N in wheat grown on a duplex soil. Australian Journal of Agricultural Research 46:519–531

Pang H (1999) The effect of straw mulching on the soil environment and wheat yield traits. Chinese Journal of Soil Science 30:174–175

Pang H and Xu F (1998) Study on the tillage methods under straw mulching in Weibei Arid Area. Res Agric Mod 19:249–251

Pang HC, Li YY, Yang JS and Liang YS (2009) Effect of brackish water irrigation and straw mulching on soil salinity and crop yields under monsoonal climatic conditions. Agricultural Water Management 97 (12-15):1971–1977

Patni NK, Masse L and Jui PY (1998) Groundwater quality under conventional and no-tillage: I Nitrate, electrical conductivity, and pH. J Environ Qual 27:869–877

Paxton KW, Boquet DJ and Hutchinson RL (2001) An economic analysis of best management practice adoption by Louisiana cotton producers. In: Proceedings of the Beltwide Cotton Conference, Anaheim, CA, January 9–13 National Cotton Council, Memphis, TN, pp 193–195

Peng S and Cassman KG (1998) Upper tresholds of nitrogen uptake rates and associated N fertilizer efficiencies in irrigated rice. Agron J 90:178–185

Pettigrew WT and Jones MA (2001) Cotton growth under no-till production in the lower Mississippi River Valley alluvial flood plain. Agron J 93:1398–1404

Power JF and Peterson GA (1998) Nitrogen transformations, utilization, and conservation as affected by fallow tillage method. Soil and Tillage Research 49:37–47

Qiao H, Liu X, Li W, Huang W, Li C and Li Z (2006) Effect of deep straw mulching on soil water and salt movement and wheat growth. Chinese Journal of Soil Science 37 (5):885–889

Randall GW and Bandel VA (1991) Overview of nitrogen management for conservation tillage systems: An overview. In: Logan et al (ed) Effects of conservation tillage on groundwater quality, nitrogen and pesticides. Lewis Publication Chelsea, MI, pp 39–63

Raun WR and Johnson GV (1999) Improving nitrogen use efficiency for cereal production. Agron J 91 (3):357–363

Rautaray SK (2005) Machinery for conservation agriculture: Progress and Needs. In: Abrol IP, Gupta RK and Malik RK (eds) Conservation agriculture: Status and prospects Centre for Advancement of Sustainable Agriculture, New Delhi, p 43

Rawson, HM and Macpherson H G (2000). Irrigated Wheat: Managing your crop. Rome: FAO

Razzouk S and Whittington WJ (1991) Effects of salinity on cotton yield and quality. Field Crops Research 26(3-4):305–314

Reeves DW, Wood CW and Touchton JT (1993) Timing nitrogen applications for corn in a winter legume conservation-tillage system. Agron J 85:98–106

Reiter MS, Reeves DW, Burmester CH and Torbert HA (2008) Cotton nitrogen management in a high-residue conservation system: cover crop fertilization. Soil Sci Soc Am J 72:1321–1329

Rhoades JD (1999) Use of saline drainage water for irrigation. In: Skaggs RW and van Schilfgaarde J (eds) Agricultural Drainage American Society of Agronomy (ASA)–Crop Science Society of America (CSSA)–Soil Science Society of America (SSSA), Madison, Wisconsin, USA, pp 615–657

Rhoades JD, Chanduvi F and Lesch S (1999) Soil salinity assessment: Methods and interpretation of electrical conductivity measurements. FAO, Irrigation and Drainage Paper 57 FAO, Rome

Rhoades JD, Kandiah A, Mashali AM (1992) The use of saline waters for crop production. In: FAO Irrigation and Drainage Paper No 48 FAO, Rome

Rice CW and Smith MS (1982) Denitrification in no-till and plowed soils. Soil Sci Soc Am J 46:1168-1173

Rochester IJ, Constable GA and Saffigna PG (1997) Retention of cotton stubble enhances N fertilizer recovery and lint yield of irrigated cotton. Soil and Tillage Research 41:75-86

Rochester IJ, Peoples MB, Hulugalle NR, Gault RR and Constable GA (2001) Using legumes to enhance nitrogen fertility and improve soil condition in cotton cropping systems. Field Crops Research 70:27–41

Rudenko I, Lamer JPA (2006) The comparative advantages of the present and future payment structure for agricultural producers in Uzbekistan. Central Asian Journal of Management, Economics and Social Research 2(1-2):106-125

Sainju UM, Lenssen AW, Caesar-TonThat T and Evans RG (2009) Dryland crop yields and soil organic matter as Influenced by long-term tillage and cropping sequence. Agron J 101(2):243–251

Sainju UM, Schomberg HH, Singh BP, Whitehead WF, Tillman PG and Lachnicht-Weyers SL (2007) Cover crop effect on soil carbon fractions under conservation tillage cotton. Soil and Tillage Research 96:205–218

Sainju UM, Singh BP and Whitehead WF (2005) Tillage, cover crops, and nitrogen fertilization effects on cotton and sorghum root biomass, carbon, and nitrogen. Agron J 97:1279–1290

Sainju UM, Singh BP, Whitehead WF and Wang S (2006) Carbon supply and storage in tilled and non-tilled soils as influenced by cover crops and nitrogen fertilization. J Environ Qual 35:1507–1517

Salinas-Garcia JR, Baez-Gonzalez AD, Tiscareno-Lopem M and Rosales-Robles C (2001) Residue removal and tillage interaction effects on soil properties under rain-fed corn production in Central Mexico. Soil and Tillage Research 59:67-79

Sauer TJ, Hatfield JL and Prueger JH (1996) Corn residue age and placement effects on evaporation and thermal regime. Soil Sci Soc Am J 60:1558–1564

Sayre K (2007) Conservation agriculture for irrigated agriculture in Asia. In: Lal et al. (eds) Climate change and terrestrial carbon sequestration in central Asia. Taylor and Francis/Balkema, the Netherlands pp 211-242

Sayre K and Hobbs P (2004) The raised-bed system of cultivation for irrigated production conditions. In: Lal R, Hobbs P, Uphoff N and Hansen DO (eds) Sustainable agriculture and the Rice-Wheat system. Ohio State University, Columbia, Ohio, USA, pp 337-355

Sayre KD (2004) Raised-bed cultivation. In: Lal R (ed) Encyclopedia of Soil Science. Marcel Dekker Inc, (eBook Site Online publication). Cited 03 March 2008

Scheer C (2008) Biosphere-atmosphere-exchange of C and N trace gases and microbial N turnover processes in irrigated agricultural systems of the Aral Sea Basin, Uzbekistan. Dissertation, ZEF/Rheinische Friedrich-Wilhelms-Universität Bonn

Scheer C, Wassmann R, Kinzler K, Ibragimov N and Eschanov R (2008) Nitrous oxide emissions from fertilized, irrigated cotton (*Gossypium hirsutum* L.) in the Aral Sea Basin, Uzbekistan: Influence of nitrogen applications and irrigation practices. Soil Biology and Biochemistry 40:290–301

Scheer C, Wassmann R, Butterbach-Bahl K, Lamers JPA and Martius C (2009) The relationship between N_2O, NO, and N_2 fluxes from fertilized and irrigated dryland soils of the Aral Sea basin, Uzbekistan. Plant and Soil 324:273–283

Schertz D L and Kemper WD (1994) Report on field review of no-till cotton. Huntsville, AL, 22–23 Sept, USDA/ARS/NRCS/Auburn University/Alabama A and M University, Normal, AL

Schwab EB, Reeves DW, Burmester CH and Raper RL (2002) Conservation tillage systems for cotton in the Tennessee Valley. Soil Sci Soc Am J 66:569–577

Scotter DR (1978) Preferential solute movement through larger soil voids I Some computations using simple theory. Australian Journal of Soil Research 16:257–267

Shennan C (1992) Cover crops, N cycling and soil properties in semi-irrigated vegetable production systems. Hort Science 27:749–754

Shipley PR, Meisinger JJ and Decker AM (1992) Conserving residual corn fertilizer nitrogen with winter cover crops. Agron J 84:869–876

Silber J (1913) Die kolorimetrische Bestimmung der Salpetersäure in Wasser. Zeitschr. f.Untersuchung d. Nahr.-u. Genußmittel: 282-286

Smart JR and Bradford JM (1999) Conservation tillage with roundup can decrease cotton production costs. In: Proceedings of the Beltwide Cotton Conference, Orlando, FL, and January 3–7 National Cotton Council, Memphis, TN, pp 735–738

Staver KW and Brinsfield RB (1998) Using cereal grain winter cover crops to reduce groundwater nitrate contamination in the mid-Atlantic coastal plain. Journal of Soil and Water Conservation 53(3):230–240

Tian K and Lei Y (1994) Integrated effect of water, fertilize and salinity on the wheat yield in desalinized fluvo-aquic soil in Heilonggang Region. Res Agric Mod 15:364–368

Timsina J, Singh U, Badaruddin M, Meisner C and Amin MR (2001) Cultivar, nitrogen, and water effects on productivity, and nitrogen use efficiency and balance for rice-wheat sequences of Bangladesh. Field Crops Research 72:143–161

Toderich K, Ismail S, Massino I, Wilhelm M, Yusupov S, Kuliev T and Ruziev S (2009). Extent of salt-affected land in Central Asia: Biosaline agriculture and utilization of the salt-affected resources. In: Advances in assessment and monitoring of salinization and status of biosaline agriculture. Reports of expert consultation held in Dubai, United Arab Emirates, 26-29 Nov. 2007. World Soil Resources Reports No. 104, FAO, Rome, pp 315–342

Torbert HA and Reeves DW (1994) Fertilizer nitrogen requirements for cotton production as affected by tillage and traffic. Soil Sci Soc Am J 58:1416–1423

Torbert HA, Potter KN and Morrison JE (2001) Tillage system, fertilizer nitrogen rate, and timing effect on corn yields in the Texas Blackland Prairie. Agron J 93:1119–1124

Touchton JT, Reeves DW and Wood CW (1995) Fertilizer management In GW Langdale and WC Moldenhauer (eds) Crop residue management to reduce erosion and improve soil quality. USDA Conservation Research Report 39:13–15

Triplett G B, Dabney SM and Siefker JH (1996) Tillage systems for cotton on silty upland soils. Agron J 88:507–512

Tursunov M (2009) Potential of conservation agriculture for irrigated cotton and winter wheat production in Khorezm, Aral Sea Basin. Dissertation, ZEF/Rheinische Friedrich-Wilhelms-Universität Bonn

Tyagi N K (1984) Effect of land surface uniformity on irrigation quality and economic parameters in sodic soils under reclamation. Irrigation Sci 5:151-166

Unger PW, Stewart BA, Parr JF and Singh RP (1991) Crop residue management and tillage methods for conserving soil and water in semi-arid regions. Soil and Tillage Research 20:219-240

Uri N D (1999) Factors affecting the use of conservation tillage in the United States. Water, Air and Soil Pollution 116:621–638

Verachtert E, Govaerts B, Lichter K, Sayre K, Ceballos-Ramirez J, Luna-Guido M, Deckers J and Dendooven L (2009) Short term changes in dynamics of C and N in soil when crops are cultivated on permanent raised beds. Plant and Soil 320 (1):281–293

Verhulst N, Govaerts B, Nelissen V, Sayre KD, Crossa J, Raes D and Deckers J (2011) The effect of tillage, crop rotation and residue management on maize and wheat growth and development evaluated with an optical sensor. Field Crops Research, 120 (1):58-67

Vinogradov S and Langford VPE (2001) Managing trans-boundary water resources in the Aral Sea Basin: In search of a solution. International Journal of Global Environmental Issues 1(3-4):345–362

Vita P De, Di Paolo E, Fecondo G, Di Fonzo N and Pisante M (2007) No-tillage and conventional tillage effects on durum wheat yield, grain quality and soil moisture content in Southern Italy. Soil and Tillage Research 92:69–78

Vlek PLG and Byrnes BH (1986) The Efficacy and Loss of Fertilizer N in Lowland Rice. In: De Datta SK and Patrick WH (eds), Nitrogen Economy in Flooded Rice Soils Martinus Nijhoff Publishers, Dordrecht, the Netherlands, pp 131–148

Vlek PLG and Uzo Mokwunye A (1989) Soil Fertility Problems in the Semiarid Tropics of Africa. In: Christianson CB (ed) Soil Technology and Fertilizer Management in Semi-Arid Tropical India. IFDC Special Publication - 11 Muscle Shoals, Al 35662, USA

Vlek PLG, Fillery IRP and Burford JR (1981) Accession, transformation, and loss of nitrogen in soils of the arid region. Plant and Soil 58 (1-3):133–175

Vlek PLG, Martius C, Wehrheim P, Schoeller-Schletter A and Lamers JPA (2001) Economic restructuring of land and water use in the Region Khorezm (Uzbekistan) (Project Proposal for Phase I). ZEF Work Papers for Sustainable Development in Central Asia, 1 [Online] http://www.khorezm.unibonn.de/downloads/WPs/ZEF-UZ-WP01_proposal.pdf 75 pp

Walter H and Leith H (1967) Klimadiagramm-Weltatlas. 3rd edition Jena, VEB Gustav-Fischer-Verlag

Wang FH, Wang XQ and Sayre KD (2004) Comparison of conventional, flood irrigated, flat planting with furrow irrigated, raised bed planting for winter wheat in China. Field Crops Research 87:35–42

Wang X (2006) Conservation tillage and nutrient management in dryland farming in China. Dissertation, Wageningen University

Wang XB, Cai DX, Hoogmoed WB, Oenema O and Perdok UD (2007) Developments in conservation tillage in rainfed regions of North China. Soil and Tillage Research 93:239–250

Wehrheim P and Martius C (2008) Farmers, cotton, water, and models Introduction and overview. In: Wehrheim P, Schoeller-Schletter A and Martius C (eds) Continuity and change: Land and water use reforms in rural Uzbekistan Socio-economic and legal analyses for the region Khorezm. IAMO, Halle/Saale pp 1-16

Weinert TL, Pan WL, Moneymaker MR, Santo GS, and Stevens RG (2002) Nitrogen recycling by non-leguminous winter cover crops to reduce leaching in potato rotations. Agron J 94:365–372

Weston LA and Zandstra BH (1989) Transplant age and N and P nutrition effects on growth and yield of tomatoes. Hort Science 24:88–90

Wiatrak PJ, Wright DL, Marois JJ, Koziara W and Pudelko JA (2005) Tillage and nitrogen application impact on cotton following wheat lysimeter results. Agron J 97:288–293

Wright DL, Reed S, Roads FM, and Wiatrak P (1998) Fate of nitrogen on cotton following winter fallow, small grains and legumes in conventional and conservation tillage systems. NFREC Res Rep 98–11 Univ of Florida, Gainesville, FL

Yau SK, Sidahmed M and Haidar M (2010) Conservation versus conventional tillage on performance of three different crops. Agron J 102:269–276

Yuen SH and Pollard AG (1952) The determination of nitrogen in agricultural materials by the Nessler reagent. I: Preparation of the reagent. Journal of the Science of Food and Agriculture 3:441-447

Yuen SH and Pollard AG (1954) Determination of nitrogen in agricultural materials by the Nessler reagent.II: Micro-determinations in plant tissue and in soil extracts. Journal of the Science of Food and Agriculture 5:364-396

Yusuf AA, Iwuafor ENO, Abaidoo RC, Olufajo OO, and Sanginga N (2009) Effect of crop rotation and nitrogen fertilization on yield and nitrogen efficiency in maize in the northern Guinea savanna of Nigeria. African Journal of Agricultural Research 4 (10):913–921

Zadoks JC, Chang TT and CF Zonzak (1974) A decimal code for the growth stages of cereals. Weed Research 56:309-314

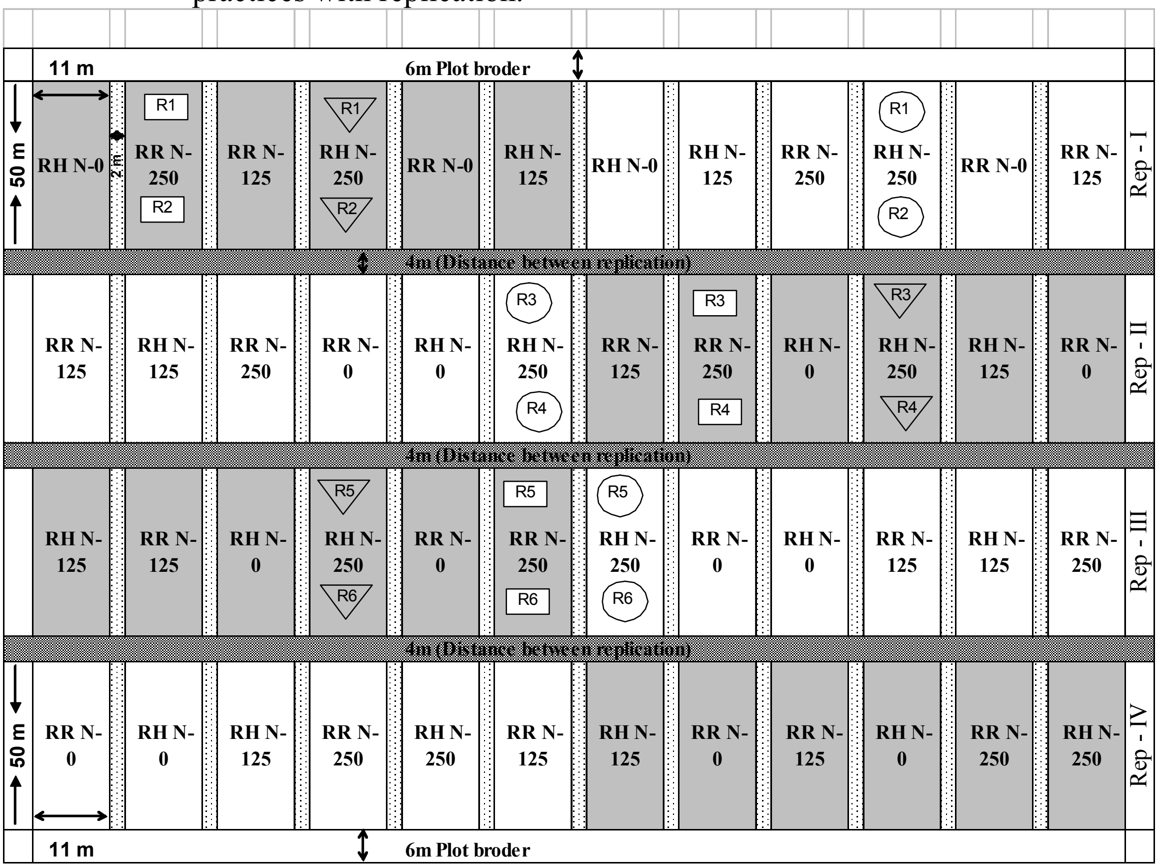
ZEF (2001) Project proposal Economic and ecological restructuring of land- and water use in the region Khorezm (Uzbekistan): A pilot project in development research Bonn, Germany, Center for Development Research (ZEF)

Zhang HJ, Dong HZ, Shi YJ, Chen SY and Zhu YH (2007) Transformation of cotton (*Gossypium hirsutum*) with AbCMO gene and the expression of salinity tolerance. Acta Agronomica Sinica 33:1073–1078

Zhu JK (2001) Over expression of a delta-pyrroline-5-carboxylate synthetase gene and analysis of tolerance to water and salt stress in transgenic rice. Trends in Plant Science 6:66–72

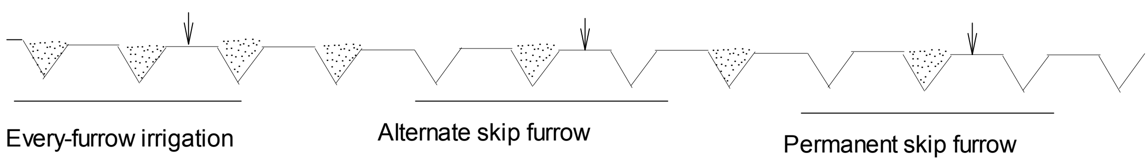
9 APPENDICES

Appendix 9.1: Field layout cotton/wheat/maize system showing the sampling points for salinity dynamics under conventional and conservation agriculture practices with replication.



Note: Shaded area represents the bed planting area. RR-Residue retention, RH-residue harvest, shaded area represents bed planting. Bed planting with RR (▼), bed planting with RH (□) and conventional practice (○)

Appendix 9.2: Irrigation treatments allocated in each replication in raised beds. The arrows denote the bed where soil samples were taken and also the dotted furrow denotes the irrigated furrow.



Appendix 9.3: Analysis of variance of soil salinity distribution before leaching as affected by irrigation method, position of the beds during 2008 and 2009.

Source of variation	df	15 cm	30 cm	45 cm	60 cm	75 cm	90 cm
		2008					
Treatment	2	<.001	0.2	<.001	<.001	<.001	<.001
position	6	0.01	0.1	0.008	0.2	0.004	0.4
Position x treatment	12	<.001	0.5	0.6	0.5	0.4	0.5
		2009					
Treatment	2	<.001	0.3	<.001	<.001	<.001	<.001
position	6	0.01	0.3	0.008	0.2	0.004	0.7
Position x treatment	12	<.001	0.7	0.9	0.9	0.6	0.8

Appendix 9.4: Analysis of variance of soil salinity distribution after leaching as affected by irrigation method, position of the beds during 2008 and 2009.

Source of variation	df	15 cm	30 cm	45 cm	60 cm	75 cm	90 cm
		2008					
Treatment	2	0.04	0.9	0.5	0.5	0.03	0.4
position	6	0.003	0.5	0.2	0.2	0.5	0.9
Position x treatment	12	0.01	0.3	0.7	0.8	0.9	0.8
		2009					
Treatment	2	0.01	0.04	0.7	0.1	0.2	0.01
position	6	0.1	0.7	0.3	0.09	0.03	0.1
Position x treatment	12	0.1	0.7	0.03	0.5	0.3	0.6

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