9 Conservation Agriculture in Central Asia

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9.1 Introduction

The Central Asia region comprises five independent republics: Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan (Fig. 9.1). The climate in the region is mostly arid and semi-arid and strongly continental, with hot summers and cold winters. Average annual precipitation, which is concentrated in the winter and spring, is about 270 mm, and varies from [illegible] to 800 mm in the mountainous zone and [illegible]–150 mm in the desert regions. The land area of the five Central Asian countries covers about 393 Mha, which is 98% of the total area (Table 9.1). Kazakhstan with 270 Mha is the largest country, comprising almost 68% of the entire area, followed by Turkmenistan and Uzbekistan, while Kyrgyzstan and Tajikistan are two smaller states, which together constitute [illegible]25 Mha (9%).

The Central Asia region includes some of the most sparsely populated areas in the world. In 2010, the estimated population was over 62.5 million with Uzbekistan having the highest population of 29.0 million, followed by Kazakhstan with 15.7 million. The remaining three countries have a combined population of 17.8 million. The population is sparsely settled with a highest density of 65 persons km^{-2} in Uzbekistan to the lowest in Kazakhstan of 6 persons km^{-2}. Cropland amounts to 32.6 Mha. Reported average per capita cropland is 0.45 ha (Table 9.1) with the lowest of 0.11 ha and 0.17 ha in Tajikistan and Uzbekistan, respectively, to the highest of 1.45 ha in Kazakhstan.

Agricultural croplands in Central Asia include rainfed and irrigated areas (Kienzler *et al.*, 2012); and consequently, the adoption and adaptation of Conservation Agriculture (CA) practices should be considered according to farming systems in different agroclimatic zones. For example, raised beds[1] which are suitable in the irrigated systems of Central Asia, are less appropriate in rainfed systems. Thus, to the extent possible, we have reviewed hereafter results pertaining to farming systems by agroclimatic zones.

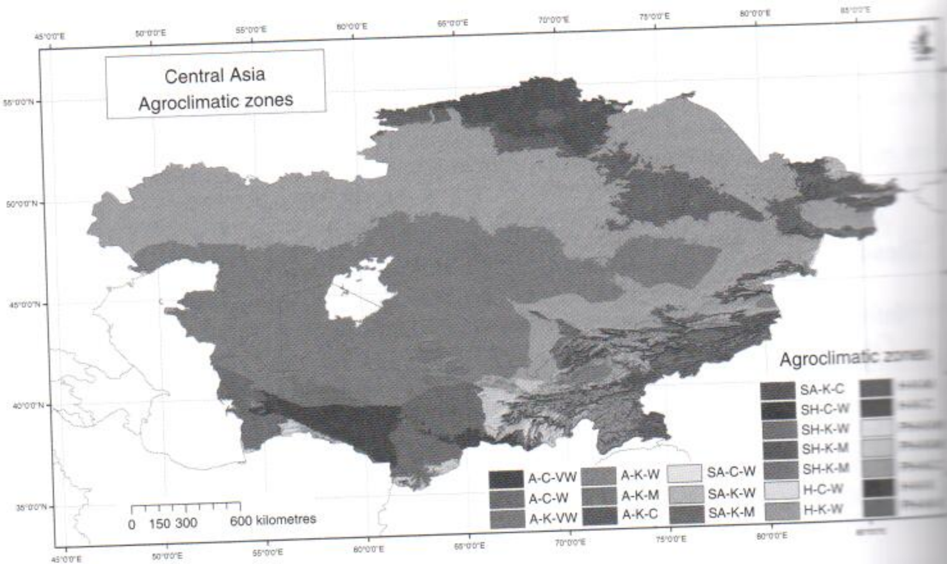

Fig. 9.1. Agroclimatic zones of Central Asia (De Pauw, 2008).

Table 9.1. Land resources and population and agricultural indicators of Central Asia (National [illegible] books of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan, 2010).

Country	Total territory (Mha)	Land area (Mha)	Cropland (Mha)	Cropland (%)	Agric. GDP (%)	Population (million)	Population density (km^{-2})	Rural population (%)	[illegible]
Kazakhstan	272.49	269.7	24.0	8.8	5.3	15.7	6	42.8	[illegible]
Kyrgyzstan	19.99	19.18	1.4	7.0	25.8	5.2	28	63.4	[illegible]
Tajikistan	14.255	13.99	0.9	6.3	19.8	7.4	44	71.4	[illegible]
Turkmenistan	48.81	46.99	1.8	3.7	22.1	5.2	11	72.0	[illegible]
Uzbekistan	44.74	42.54	4.9	10.9	19.4	29.0	65	63.5	[illegible]
Total	400.3	392.7	33	8.3	9.9	62.5	15.1	62.6	[illegible]

9.2 History of Conservation Agriculture in Central Asia

Conservation Agriculture as a term has not been extensively used in Central Asia until the last decade. However, conservation tillage in the rainfed areas and raised bed planting in irrigated areas, formerly researched and applied, could be attributed to be a development towards CA. The development of conservation tillage in rainfed areas of Central Asia was caused by the massive soil erosion occurring at the time when the reclamation of virgin and fallow lands in Kazakhstan became of enormous importance in ensuring food security. In 1954, special surveys by agronomists, soil [illegible] land developers examined vast [illegible] land stocks of Kazakhstan. Those [illegible] identified more than 21 Mha of [illegible] and fallow lands of which more than [illegible] are lands of good to medium [illegible] could be used for agricultural [illegible] marily for planting of cereal [illegible] significant costs (Dvurechenskiy, [illegible]).

Hence, the newly introduced [illegible] farming called 'conservation tillage [illegible] unlike conventional tillage (Conv[illegible]) radically changed the way of land [illegible] steppes of Kazakhstan, and allowed [illegible] in soil degradation on dozens of [illegible] hectares. After development of [illegible] average per annum production of grain in Kazakhstan in the 1961–1965 period increased up to 14.5 Mt (versus 3.9 Mt in the 1949–1953 period), whereas after the introduction of conservation tillage in 1976–1985, per annum production of grain in Kazakhstan increased to 25–27 Mt (Sydyk and Isabekov, 2009a).

During the last decade, the term CA has made its way into research communities of Central Asian countries. For example, since 2006 the Kustanay Research Institute of Agriculture, located in the north-west of Kazakhstan, has gradually moved away from conservation tillage to no-till (NT).[2]

Researchers from the Kustanay Research Institute have achieved complete elimination of mechanical tillage and converted to full CA with all three component practices. At the same time, in the early 20th century the area under irrigation had also been growing rapidly from the 1930s until the 1990s in Central Asia (Fig. 9.2) totalling 8.5 Mha by 1990. This expansion of irrigated farmland combined with poor water management caused a number of environmental problems and devastation of the Aral Sea. After 1990, the growth of irrigated areas slowed significantly in all countries, and during the last 20 years (1990–2010) it increased by only 1 Mha.

The main crop in the irrigated areas in Central Asia during the Soviet era was cotton, covering 80% of the total irrigated area. Some elements of CA such as replacing inversion ploughing in irrigated cotton areas with NT were reported by Kondratjuk (1972). Efforts were made to replace mould-board ploughing with chisel tillage. However, a major factor in assessing the effects was weed control. Ploughing was seen to 'eliminate' weeds in the cotton fields, but chisel tillage on its own did not result in any significant reduction of weeds. A number of studies conducted in different regions and soils reported that weed infestation was substantially higher with NT compared to the ploughed treatments, particularly when lucerne preceded cotton.

Currently, permanent beds and furrow system of soil management practice has received much attention in irrigated areas. Ryzhov *et al.* (1980) reported favourable conditions for the growth of cotton when planted on beds including optimum bulk density, 0.9–3.1°C higher temperatures at the 5 cm depth, and more uniform soil moisture conditions.

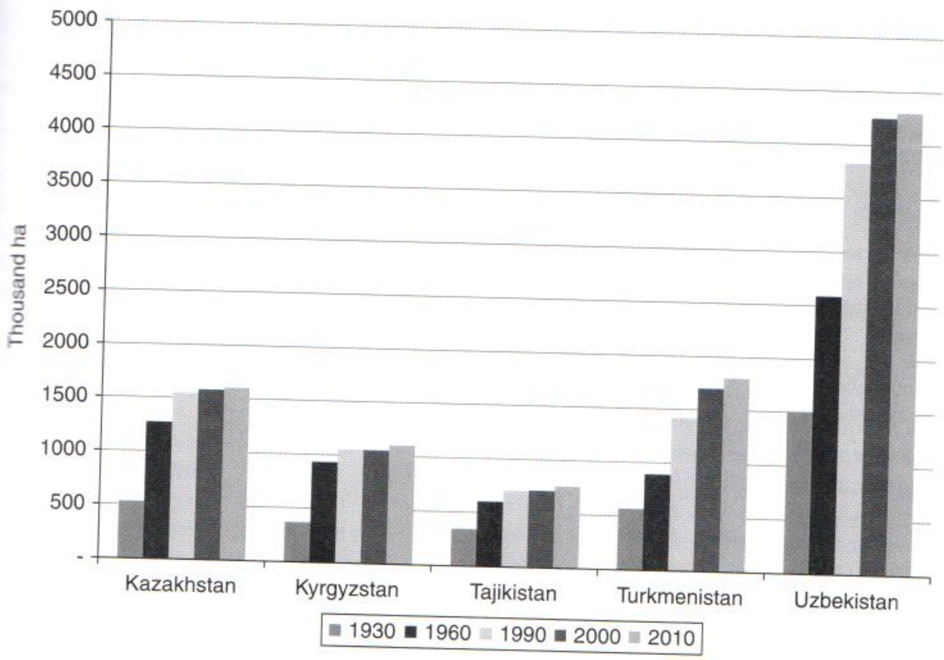

Fig. 9.2. Development of irrigated areas in five countries of Central Asia during 1930–2010.

9.3 Current Status of Conservation Agriculture in the Region

According to the Ministry of Agriculture of Kazakhstan, in 2011, NT and conservation tillage were introduced on an area of 11.7 Mha (Table 9.2), which is 70% of all the area sown to wheat in Kazakhstan (Sydyk *et al.*, 2008). Consequently, in 2011, the country harvested record gross output of grain of 20 Mt corresponding to a yield of 1.7 t ha^{-1} (Sydyk *et al.*, 2008). These results were achieved due to the introduction of CA-related practices, although the area under full CA in Kazakhstan is only 1.7 Mha.

CA is still not widely practised among the farming population in the irrigated areas of the lower half of Central Asia. Current activities are mainly concentrated in research institutes to integrate CA principles and practices into existing production systems.

Over the last 20 years, Uzbekistan has been researching ways of introducing grain crops into existing crop rotation mainly with cotton and lucerne. Earlier, only irrigated cotton or rainfed winter wheat was grown. However, now with well-proven research findings, timely planting of winter wheat in standing cotton has shown promising results. As a result, annual area under planting of winter wheat into standing cotton reached 600,000 ha in Uzbekistan (Qilichev and Khalilov, 2008). In Tajikistan, some elements of CA can be found within several donor-funded projects implemented in the past, but their geographic coverage and number of beneficiaries (mostly farmers) are relatively small. However, there is a claim that direct seeding of winter wheat with minimum soil disturbance after cotton harvest is annually implemented in 25,000–50,000 ha (Hafiz Muminjanov, Ankara, 2012, pers. comm.).

Conservation Agriculture is still not widely practised among the farming population in the irrigated areas of the lower half of Central Asia. However, earlier research on NT bed planting is relevant and useful nowadays as winter wheat has become another strategic crop to provide food security in most countries of the region. The researchers of the South-Western Research Institute for Livestock and Plant Production (Kazakhstan) studied and recommended raised-bed-furrow technology for the cultivation of winter wheat in the central irrigated zone of southern Kazakhstan. Cultivation of winter wheat on raised beds with lowered seeding rate

Table 9.2. Main agroclimatic zones and extent of land area under Conservation Agriculture (Adapted from De Pauw, 2008).

Agroclimatic zones[a]	Total area (ha)	Area planted with elements of CA (ha)	Description of the elements	Source
SA-K-W Semi-arid, cold winter, warm summer	151,387,760	11,700,000	Including 1,700,000 ha of no-tillage, i.e. direct seeding of spring wheat and barley	Ministry of Agriculture of Kazakhstan
A-K-W Arid, cold winter, warm summer	123,027,520	<650,000	Conservation tillage, sowing of winter wheat into standing cotton	Qilichev and Khalilov (2008); H. Muminjanov, Ankara, 2012, pers. comm.
A-C-W Arid, cool winter, warm summer	19,572,560			
SA-C-W Semi-arid, cool winter, warm summer	5,991,600			

[a]For detailed description of the agroclimatic zones, see De Pauw (2008).

between 2.0 and 3.0 million seeds ha^{-1} and application of mineral fertilizers at the rate of $P_{45}N_{90}$ kg ha^{-1} in ridges ensures steady yields of winter wheat with a reduction in production cost.

The demand for food and fodder is expected to continue to grow in countries of Central Asia. A model was proposed by Suleymenov *et al.* (2004, 2006) that grouped the rainfed and irrigated-based zones into three main crop-based production systems: (i) the northern Kazakh steppes; (ii) the warmer foothills of Kyrgyzstan and southern Kazakhstan where a mixture of rainfed and irrigated agriculture is practised; and (iii) Tajikistan, Turkmenistan and Uzbekistan where irrigated bed-and-furrow or basin systems are used (Table 9.3). Wheat, cotton and livestock are the most important commodities in the region. However, with a trend towards diversification, oil crops such as sunflower could also become important (Fig. 9.3). The results of research on adaptive cropping systems and CA conducted since 2003 have been introduced across 230–347 ha in the southern Kazakhstan region.

Several collaborative research and development projects have been implemented to promote CA in Uzbekistan. The projects are demonstrating appropriate management techniques for rehabilitation and improvement of salt-affected and gypsiferous irrigated lands to support food security in the country. Some of the studies and guidelines produced by these projects serve as useful reference materials for other countries in the region. No-till and raised-bed planting practices tested in Karakalpakstan and Tashkent provinces in Uzbekistan proved technically and economically suitable for local conditions and can provide similar or higher crop yields while saving considerable production resources and costs including fuel, seeds and labour. These practices are ready to be disseminated more widely in Uzbekistan.

Some of the striking features of CA experience noted and reported by many farmers in the region include reduction in inputs such as fuel, seed and water and in wear and tear of tractors and machinery. The other benefits include reduced soil erosion due to reduced soil disturbance and soil cover, and enhanced carbon sequestration.

9.4 Research Results Reported in Central Asia

9.4.1 Effect on soil quality under Conservation Agriculture

The impact of CA practices on physical and chemical soil properties has been a subject of many studies in Central Asia. However, most reports are related to different soil properties, CA management and crop rotations. Hence, the numbers of comparable and common research results are too few to make generalizations and further extrapolation to other regions with similar soil and climatic conditions is not yet possible.

Soil physical properties

Egamberdiev (2007) showed that mulching with crop residues improved soil micro-aggregation in the irrigated areas of Uzbekistan. More recently, the impact of tillage and crop residue management on properties of a silt loam soil under irrigation in Uzbekistan was reported stemming from a rotation of winter wheat and maize for 2 years followed by cotton for another 2 years (Ibragimov *et al.*, 2011). This study compared permanent raised beds (PRB) with limited reshaping, and ConvT (mouldboard ploughing). ConvT cotton and maize were superficially tilled (15–17 cm soil depth) two to five times during each season. Both tillage practices were subjected to either 25% (R25) or 100% (R100) retention of crop residues from the previous crops. After four years, PRB+R100 showed significant differences in soil physical properties and organic carbon compared to ConvT. Irrespective of the amount of crop residues retained, with PRB (R25 and R100) soil bulk density and consolidation in the 0.2–0.3 m depth had increased. Furthermore, the findings showed that in the last year of the study under PRB+R100, the amount of water-stable macro-aggregates were greater compared with those under ConvT and PRB+R25 treatments.

Table 9.3. Salient information about dominant cropping systems in the five Central Asian countries according to agroecological zones (Modified after De Pauw, 2008, Gupta *et al.*, 2009 and Kienzler *et al.*, 2012).

Country/ region	Major production system	Cropping intensity (%)	Growth period (days)	Distinguished features of the agroecology	Production constraints
Kazakhstan (northern parts)	Rainfed spring wheat–fallow systems	60–80, rainfed	210–240	Rainfed cereal systems, steppes, long cold winters	Drought, cold and water stress (precipitation 300–400 mm), soil erosion
Kazakhstan (southern parts)	Extensive cereal–livestock systems Irrigated cotton/ wheat-based systems, rice, rangelands	50–60, rainfed	30–89	Rainfed rangelands with mixed crop–livestock systems, high Mg-soils, saline groundwater	Drought, cold and water stress (precipitation 250–350 mm), 12–14°C, Mg-soil, erosion
Kyrgyzstan (Osh, Chu and Fergana Valley)	Irrigated agriculture on sloped and valley areas	40–60+	60–119	Sloped lands (up to 10%), supplemental irrigation, generally fresh but shallow groundwater table	Drought and heat (precipitation 200–300 mm), saline water use, 16–22°C
Tajikistan (south-west/ north-west)	Irrigated systems (cotton–wheat) Agriculture on sloped land of 5–16%	40–60+	60–150	Pastoral systems/ irrigated agriculture on sloping lands, saline groundwater	Drought (precipitation 250–350 mm), 7–9°C, sloped land mechanization. Water erosion by irrigation, drainage congestion
Uzbekistan (irrigated)	Irrigated cropping systems, cotton–wheat (mostly furrow irrigation)	>60	60–119	Irrigated crop production, drainage water use, soil salinity, long growing season, double cropping	Drought and heat (precipitation 250–500 mm), 16–20°C, salinity, water erosion
Turkmenistan (irrigated)	Rainfed pastoral/cereal production systems (mostly furrow irrigation)	30–60	30–59	Crop–livestock systems, saline groundwater, overgrazing, soil salinity	Drought and heat (precipitation 200–350 mm), 14–18°C, water scarcity, salinity

Soil organic matter dynamics

Soil organic matter (SOM) adds to structural stability and improves soil moisture-holding capacity (Bot and Benites, 2005). Numerous results from the irrigated areas showed that crop residue retention improves SOM and soil N content (e.g. Egamberdiev, 2007; Nurbekov *et al.*, 2012; Pulatov *et al.*, 2012). Egamberdiev (2007) reported from an operational-scale field trial conducted on 2.85 ha under irrigation in north-west Uzbekistan, which involved comparing four tillage practices and two residue management levels. The treatments also included ConvT practice, PRB, intermediate or semi-permanent beds re-shaped every cropping cycle (IT), and NT with planting on flat soil. In each of these tillage systems, the crop residues were either completely removed at harvest (CR–) or retained on the soil surface (CR+). The findings showed that CA practices increased SOM significantly with corresponding

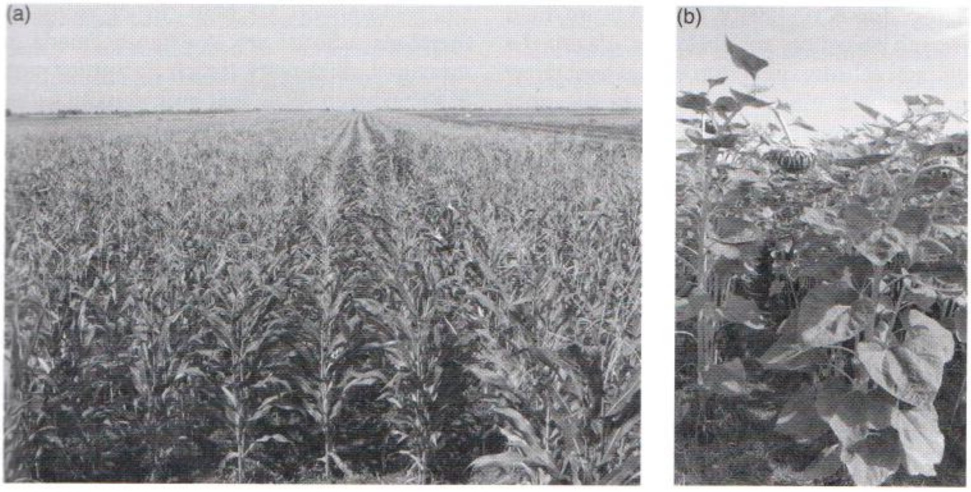

Fig. 9.3. Crop diversification with no-till maize (a) for livestock feed and sunflower (b) for oil extraction; examples are from Kazakhstan and Uzbekistan, respectively.

improvements in soil structure and greater soil moisture-holding capacities (Egamberdiev, 2007; Pulatov *et al.*, 2012). Yet, the significant increase in SOM content from about an initial 0.57% to about 0.75% (i.e. about 32% of increase) after seven cropping cycles in a cotton–winter wheat rotation, represented a moderate absolute increase. In a study by Ibragimov *et al.* (2011), soil organic C in the 0–0.4 m depth increased annually by as much as 0.70 t ha^{-1} with permanent beds and complete residue retention (PRB+R100), whilst this annual increase was not more than 0.48 t ha^{-1} with ConvT+R100. This is due to the temperature/moisture regime, which in arid regions encourages high soil microbial activity and SOM turnover rates (Sanchez *et al.*, 2004). A literature review by Kienzler (2009) showed no reported changes in SOM over a period of around 30 years for conventional farming practices in the north-west of Uzbekistan. In comparison, a wealth of information on CA practices worldwide shows an increase in SOM (e.g. West and Post, 2002; Sanchez *et al.*, 2004; Govaerts *et al.*, 2006; Corsi *et al.*, 2012), and these results were also confirmed by selected studies in the irrigated areas in Central Asia.

Various research experiments have investigated the impact of different tillage systems on crop productivity. Mohanty *et al.* (2007) reported that regression analyses between crop yield and SOM values for tillage and crop residues in rice–wheat systems revealed that both crops showed a positive yield response to increased levels of SOM. There is general agreement that reduced tillage can increase SOM. The overall findings for the irrigated areas in Central Asia can be summarized as follows: the usual low initial SOM contents can be significantly and rapidly boosted by CA practices, but under the prevailing arid and semi-arid agroclimatic conditions in the region, this increase is proportional to the annual amounts of organic matter added.

Soil salinization

Secondary soil salinization, caused by capillary rise of the groundwater, is a major cause of ongoing cropland degradation in the irrigated areas of Central Asia (Akramkhanov *et al.*, 2012; Tischbein *et al.*, 2012). Overall, research results showed a declining rate of soil salinization increase after crop residue retention during a 4-year study on irrigated cotton–winter wheat rotation in Uzbekistan (Egamberdiev, 2007). The differences in soil salinity at the end between conventional practices (0.52%) and NT (0.39%) were significant. After 4 years, NT system had the lowest soil salinity level (Pulatov *et al.*, 2012).

Bezborodov *et al.* (2010), from 3 years' field research on cotton in Uzbekistan, observed a 20% soil salinity reduction with wheat straw mulch of 1.5 t ha^{-1} compared to the non-mulched treatments.

Reduced soil salinity was also reported by Devkota (2011b) under a combination of raised beds and full crop residue retention of up to 45% in the top 10 cm and by 18% in the top 90 cm soil layer compared to a bare soil common under ConvT systems. When comparing three irrigation modes on PRB (Devkota, 2011b), soil salinity on the top of the beds increased significantly with every-furrow and alternative skip-furrow irrigation compared to permanent skip-furrow irrigation (PSFI). Soil salinity management with PSFI resulted in the least saline area and which in addition appeared on the dry furrows only. Recent simulation findings of the soil-water model Hydrus-1D indicated that although water uptake by cotton or wheat would only marginally benefit from a surface mulch layer, it markedly reduced soil evaporation, capillary rise of groundwater and in turn secondary soil salinization (Forkutsa *et al.*, 2009).

Although research findings in the irrigated areas illustrated that soil salinization with CA practices could not be arrested, the observed reductions in soil salinity increase are none the less relevant in the management of irrigated areas of Central Asia that are subject to land degradation caused by soil salinity. It is known that the application of plant biomass helps to ameliorate salinity and sodicity in the soil (for a review of the subject, see Qadir *et al.*, 2007).

In Turkmenistan, trials with raised beds showed differences in soil salinity between top and bottom of the beds. Electric conductivity of soil extracts (EC_e) on the raised-bed was in the range of 3.42–5.47 mS cm^{-1}. At the bottom of the raised bed, in the furrow, EC_e of 1.49–2.86 mS cm^{-1} was considerably lower than in the raised-bed.

Soil bulk density

Soil bulk density is continuously high on the agenda when NT is discussed. A major concern is the perception that without tillage soil compaction will be high. In experiments, therefore, efforts are constantly made to measure bulk density. Data from rainfed areas of Kazakhstan show that bulk density values in regular sierozems before planting (1.29–1.30 g cm^{-3}) and harvesting (1.32–1.37 g cm^{-3}) under conventional technology were comparable to those under conservation tillage and direct planting of winter wheat, 1.26–1.30 g cm^{-3} and 1.29–1.34 g cm^{-3}, respectively (Sydyk *et al.*, 2009).

Overall, the studies indicated that winter wheat grown in cotton–maize rotation and retaining winter wheat residues positively impacted soil bulk density (ρb, Mg m^{-3}) irrespective of the tillage modes, while in one study it was concluded that cotton cropping without tillage resulted in increased soil compaction (Ibragimov *et al.*, 2011).

9.4.2 Carbon sequestration, climate change adaptation and mitigation

Given the relatively short history of CA in Central Asia, evaluation of the effects on carbon sequestration is limited to few short-term trials. In rainfed areas, the biggest problem is with the fallow period when multiple passes of regular tillage are conducted to control weeds, causing substantial erosion of the topsoil. Under such conditions, results from CKARI (Central Kazakh Agricultural Research Institute) over the 4-year trial period showed that there was on average about 0.2% more SOM in the treatments without tillage during fallow and with direct seeding of the wheat crop with narrow seeder shoes (as opposed to the sweeps used on the conventional equipment; Murat Karabayev, Astana, 2012, pers. comms). This translates into approximately 400 kg C ha^{-1} $year^{-1}$, a level which is consistent with the review of Six *et al.* (2002), who reported an average increase in SOC, under CA practices, at a rate of 325±113 kg C ha^{-1} $year^{-1}$ under a wide range of temperate and tropical conditions.

Climate change poses a major threat to the agricultural production potential of Central Asian countries (IPCC, 2007). Burman and Roy (2011) reported that increased temperature in the future is likely to reduce fertilizer use efficiency. This could lead to increased fertilizer requirement for meeting future food production demands, and may also increase greenhouse gas (GHG) emissions.

Overall, CA systems have a higher adaptability to climate change because of the higher effective rainfall due to higher infiltration and therefore reduced surface runoff and soil erosion as well as greater soil moisture-holding capacity (Saturnino and Landers, 2002; Jat *et al.*, 2012). Thus crop growth under CA systems can continue towards maturity for longer than those under ConvT (Stewart, 2007).

In the northern Kazakhstan region, where much of the annual precipitation is in the form of snow in the winter, CA provides a way of trapping snow evenly on the field which may otherwise move away; and this further permits snow to melt evenly into the soil. In the dry areas of continental Eurasia, one-third or more of the precipitation is not effectively used in tillage-based systems, forcing farmers to leave land fallow to 'conserve' soil moisture, leading to extensive wind erosion of the topsoil from exposed fallow land and to dust emissions and transport over large distances (Brimili, 2008). Under CA, more soil moisture can be conserved than by leaving the land fallow; this allows the introduction of additional crops including legume cover crops into the system (Blackshaw *et al.*, 2007; Gan *et al.*, 2008).

No-till farming also reduces the unnecessarily rapid oxidation of soil organic matter to CO_2 induced by tillage (Reicosky, 2008; Nelson *et al.*, 2009). Together with the addition of mulch as a result of saving crop residues, there is a reversal from net loss to net gain of carbon in the soil, and the commencement of a long-term process of carbon sequestration (West and Post, 2002; CTIC/FAO, 2008; Baig and Gamache, 2009). Expanded across a wide area, CA has the potential to slow/reverse the rate of emissions of CO_2 and other GHG by agriculture (Lal, 2002, 2008). However, there are exceptions to such results but in general there is an increase in soil carbon content under CA systems, as shown from the global meta-analyses by West and Post (2002) and Corsi *et al.* (2012).

With CA, reduced use of tractors and other powered farm equipment results in lower CO_2 emissions. Up to 70% in fuel savings have been reported (FAO, 2008). CA systems can also help reduce the emissions of other relevant GHG such as methane and nitrous oxides, if combined with complementary techniques. Both methane and nitrous oxide emissions result from poorly aerated soils, from severely compacted soils, or from heavy poorly drained soils. CA soil management favours the multiplication of methane-oxidizing bacteria, leading to reduced methane emission (Ceja-Navarro *et al.*, 2010).

The soil is a dominant source of atmospheric N_2O (Houghton *et al.*, 1997). The rate of production and emission of N_2O depends primarily on the availability of a mineral N source. Addition of fertilizer N, therefore, directly results in extra N_2O formation. Nitrogen leaching and nitrogen runoff are minimal under CA systems, and over the longer term CA generally reduces the need for mineral N by 30–50% (Derpsch, 2008; Crabtree, 2010). Thus overall, CA has the potential to lower N_2O emissions as reported by Parkin and Kaspar (2006) and Baig and Gamache (2009).

Although detailed studies are needed to provide additional evidence in the local environment, one can expect similar benefits from reducing GHG emissions when promoting CA practices in Central Asia. Thus, the incentive programme launched by Kazakhstan to promote CA could be seen as initial step to promote carbon sequestration by farmers and reduce GHG emissions. However, for its wider application in the region, government incentive programmes are needed across the region in each country.

9.4.3 Crop yields

Using NT raised-beds, yields of the cotton–wheat system in Uzbekistan did not differ significantly from that under ConvT (Suleymenov *et al.*, 2004, 2006). In the Chu Valley in Kyrgyzstan, yields of irrigated winter wheat varieties 'Manas', 'Intensive' and 'Asyl' were at least equal if not higher under NT raised-bed planting compared to conventional practices from the first year of experimentation (Kienzler *et al.*, 2009b). In addition to this yield response, NT raised-bed planting improved seed germination, and hence the seeding rate could be reduced by 50% (Kienzler *et al.*, 2009b). Winter wheat development was advanced by 2–4 days for each growth stage in raised beds, which advanced ripening by 8–10 days with NT and raised beds (Kienzler *et al.*, 2009b). Irrigated maize on raised beds in southern and south-eastern Kazakhstan was harvested 3–5 days earlier than on conventional flat beds (Ospanbaev and Karabayev, 2009).

Although yields of cotton and winter wheat were equal at the onset of studies in north-western Uzbekistan, the use of NT PRB also showed higher yields than conventional practices in the longer run (Egamberdiev, 2007; Tursunov, 2009). When comparing yields of crops in a cotton–wheat–third crop rotation (Fig. 9.4) on permanent beds and conventional land preparation over three cropping cycles, Devkota (2011b) noted that cotton yield and its yield components were unaffected by both tillage practices immediately after the conversion of conventional to CA practices. But the subsequent rainfed wheat crop yielded 12% more with NT PRB than with ConvT, and the following irrigated maize crop yielded 14% higher grain under permanent beds.

No-till mungbean was successfully grown as a catch crop after winter wheat in the irrigated conditions of Uzbekistan and provided 3.3% yield advantage compared to traditional tillage practice, which was not significantly different. Even without significant differences in crop yields the NT system has an advantage in reduced costs of production (Nurbekov, 2007).

Kurvantaev *et al.* (2004) reported results from raised bed system trials involving planting on preformed raised beds, with and without tillage, in Tashkent region. Tillage treatments were combined with maximum (250:175:125) and minimum (150:125:50) NPK fertilizer rates. Direct drilling on beds with maximum fertilizer rates resulted in higher yields (3.89 t ha^{-1}) compared to that under beds with tillage preparations and maximum fertilizer rates (3.65 t ha^{-1}). Minimum fertilizer rates on direct drilled beds yielded 3.45 t ha^{-1} of cotton, whereas under tilled beds the yield was 3.33 t ha^{-1}. Research conducted in 2002–2004 demonstrated that permanent beds can be implemented without yield penalty in the initial years of switching to NT.

Recent results from Kyrgyzstan show that wheat yields were 29–41% higher on NT raised beds compared to traditional tilled fields. In addition to yield increases, seeding rates can also be reduced by 50%. Similar trials need to be established to adapt the NT technology including seeding depth and weed control in various soils (Pozharskiy and Akimaliev, 2002).

Nurbekov (2007) reported that the rate of nitrogen had no significant effect on the winter wheat yields in either of the two tillage systems, NT and ConvT. The 120 kg ha^{-1} rate was as good as the 140 kg ha^{-1} in traditional tillage with mouldboard ploughs, while NT slightly increased grain yield with higher nitrogen rate. Nurbekov *et al.* (2012) reported that winter wheat yield was higher in the treatment involving NT compared to other treatments.

Sydyk *et al.* (2009) studied the possibility of direct seeding and the ways of reducing tillage in cultivating winter wheat. They showed that it was possible to produce winter wheat in rainfed areas of southern Kazakhstan through NT direct seeding with mandatory application of mineral fertilizers and herbicides. Several varieties proved to be most suitable for direct seeding in rainfed areas of southern Kazakhstan (Sydyk and Isabekov, 2009b).

Research on planting of winter wheat before harvest of cotton crop has been carried out in Yavan and Gozimalik districts of Tajikistan. The results of the field observation on wheat growth and development suggest that the proposed technology has some advantages in making savings in seed quantity and increased yield (Sanginov and Khamikov, 2003).

Overall, reported yield responses to CA practices for the region vary, apparently depending on the crop, and land preparation is necessary to ensure a smooth conversion from conventional to CA practices (e.g. Devkota, 2011b). It has been demonstrated that proper field preparation, including

Fig. 9.4. (a) No-till winter wheat in rainfed areas of Kazakhstan and (b) mung bean grown as a catch crop with retention of surface residues in irrigated areas of Uzbekistan.

levelling to advance the implementation of CA practices after years of ConvT use, was conducive in bypassing the often observed yield reduction when changing from conventional to conservation practices. In many studies it was not mentioned whether or not such preparations had been taken into account (Devkota, 2011b).

9.4.4 Runoff, infiltration, soil water content and soil conservation

Soil moisture in the rainfed areas is highly influenced by snow cover during winter periods. At the same time, despite minor slopes of the fields in the northern Kazakhstan the size of the fields is large, leading to melting snow-water accumulation and runoff that causes considerable soil erosion. Residues retained on the soil surface can protect against erosion. The difference in erosion between the tilled fallow plots and the untilled plots was extremely marked: erosion in plots without fallow tillage was only 12% of that measured on the tilled plots (Murat Karabayev, Astana, 2012, pers. comms).

The effects of NT on soil moisture accumulation in the rainfed areas of northern Kazakhstan were also studied in the research farm of the North-West Research Institute (Zarechnoe) (Sydyk *et al.*, 2008). Moisture accumulation in 1 m layer was 160 mm in traditional fallow and 239 mm in treatment with 'coulisse' fallow, the field that is planted with a cover crop instead of leaving it bare. Treatment with tillage using flat sweeps that leaves standing stubble accumulated only 73 mm of soil moisture reserves, while standing stubble without any tillage accumulated 127 mm. Accordingly, under minimum winter precipitation, coulisse fallow and high stubble allowed maximum accumulation of snow cover and uniform snow-melt: on coulisse fallow, the height of the snow reached a highest value of 40 cm, on stubble 33 cm, on traditional fallow 8 cm and fallow tillage with flat sweeps only 3 cm.

9.4.5 Insect pest and disease dynamics

Although weed and pest management have always been given high attention in the Soviet period, little research has been directed so far on these aspects for CA systems in Central Asia. Some authors and farmers reported recurring problems with weed infestations, particularly with NT practices, but a closer look recurrently showed that herbicides have either not been used sufficiently or inappropriate herbicides were used. The preliminary results of testing different herbicides and application rates for rainfed maize (Kienzler *et al.*, 2009b) indicate an efficient weed management with the broad spectrum herbicide Stomp (pendimethaline) at 5 l ha^{-1} before germination and the systemic herbicide Dialen (2,4-D and dicamba) at 1 l ha^{-1} during the vegetative period. This double treatment increased application efficiency to around 83%. This research certainly deserves more attention given the reoccurring shortages in availability of suitable herbicides at the local markets as well as the high costs that discourage farmers to use appropriate herbicides (Murat Karabayev, Astana, 2012, pers. comms).

9.4.6 Nutrient use efficiency

Preliminary findings in Uzbekistan (Egamberdiev, 2007) on the dynamics of soil nitrogen content suggest that crop residue retention must be complemented with nitrogen (N) fertilizer application. This seems particularly true at the onset of conversion from conventional to CA practices to counterbalance any N immobilization caused by residue retention (Hickmann, 2006; Sommer *et al.*, 2007). Yet, few studies in the irrigated areas have addressed this aspect. Devkota (2011b) compared over the course of three cropping cycles, the impact of ConvT versus PRB. In each cycle two crop residue management treatments were included, namely complete retention of residues and complete removal of residues. In addition, he compared the effects of three N application rates for the different crops, which obviously differed according to crops: for example, no application or N-0 was compared to low-N, which in the case of cotton amounted to 125 kg N ha^{-1} but in maize and wheat to 100 kg N ha^{-1}. The high-N treatments for cotton were 250 kg N ha^{-1}, but for maize and wheat were 200 kg N ha^{-1}. The findings illustrated that N application significantly increased crop yields at each cycle with both tillage practices, but resulted in higher nitrogen use efficiency with NT permanent beds compared to ConvT practices for cotton (42%), wheat (12%) and maize (82%). Furthermore, when using the wet and dry irrigation (WAD)-mode, N losses occurred irrespective of the crop retention level. After three cropping cycles, which involved two times rice and one time wheat, cumulative N losses amounted to more than 350 kg N ha^{-1} even when all residues were retained, owing to both leaching and denitrification. However, these N losses for a major part occurred during the two seasons of flooded rice cultivation.

Overall, an appropriate N management seems to be of paramount importance in the irrigated areas of Central Asia for both conventional and CA practices since high N_2O emissions occur with conventional cotton, wheat and rice cultivation, which in all crops peaked when mineral N applications were immediately followed by irrigation (Scheer *et al.*, 2008).

As tillage is reduced or avoided altogether, there is less mineralization of N, often one of the apparent major 'benefits' of intensive tillage. Especially in soils that have low levels of available N, this may result in moderate to severe N deficiency in crops grown without tillage, particularly where considerable levels of crop residues remain on the surface. This N shortage is generally overcome with the application of approximately 20–30 kg ha^{-1} of N fertilizer for a few years, until SOM levels increase and a new level of SOM turnover and N mineralization is established (Murat Karabayev, Astana, 2012, pers. comms).

While NO_3-N levels were adequate in the tilled treatments, P levels were very low in all treatments. Phosphorus fertilizer (60 kg ha^{-1} P_2O_5) was applied to the conventionally tilled fallow and the reduced tillage fallow in the autumn of the fallow season, but even so P levels were low in these treatments. In the other three treatments with untilled fallows, P fertilizer was applied at a rate of 20 kg ha^{-1} P_2O_5 at seeding, after the samples had been taken for the analyses. Previous research had shown that 60 kg ha^{-1} P_2O_5 in the fallow year was sufficient for the whole of the 4-year rotation, and so this common practice and recommendation continued. However, after Perestroika (Independence), the unfavourable economic conditions resulted in little fertilizer use, even on the Central Experimental Base of the research institutes, and this in turn resulted in low soil P levels. This fact underscores one of the big problems affecting research in Kazakhstan. The country has a rich history of very good and meticulous agricultural research. However, the focus of this research, and the recommendations that emanated from it, were oriented towards a very different philosophy of agricultural production and economic circumstances. Consequently, it will require considerable effort in revisiting the past research results and reinterpret them, or repeat much of the research to develop new recommendations (Murat Karabayev, Astana, 2012, pers. comms).

9.4.7 Crop rotation

To diversify the rainfed steppe zones of northern Kazakhstan, recommendations were developed for the four- to five-field crop rotations with different sequences of agricultural crops, which avoids the traditional fallow year in an otherwise wheat monocropping system:

1. Canola for fodder–wheat–pea–wheat.
2. Sudan grass–wheat–chickpea–wheat.
3. Pea–wheat–oilseed rape–wheat.
4. Fallow (coulisse)–wheat–maize for grain–wheat.
5. Fallow (coulisse)–buckwheat–rape for fodder–wheat.
6. Fallow (coulisse)–oilseed rape–wheat–sunflower–wheat.
7. Fallow (coulisse)–wheat–barley–wheat–oats.

In these crop rotation systems monocropping of wheat is interrupted by leguminous and oilseed crops. It is difficult to overestimate the importance of crops such as oilseed rape, safflower, linen, sunflower and soybean for the northern region. The demand for such products for both the domestic and export markets is favourable. Besides, the grain growers benefit from them not only economically but also from the viewpoint of disease and weed management. Their use significantly increases the productivity of each hectare of arable land due to production of diverse products from raw crops to spring wheat. Most of those crops are good predecessors for the main crop – spring wheat.

For example, research on the introduction of safflower showed good potential in diversifying crops to fit into the spring-wheat production system. The best preceding crops for safflower were winter and spring crops, leguminous, raw and industrial crops, as well as annual and perennial grasses. In direct planting, the cultivation of safflower after winter wheat, as the second crop after fallow, is recommended.

9.4.8 Economic returns

Although the findings from the research on CA for the irrigated areas in Central Asia are encouraging, there are few reports on the economic aspects of CA. This is particularly important since the economic profitability of CA practices varies over time and, like any production system, can be site-specific, which necessitates site-specific analyses (Knowler *et al.*, 2001). Furthermore, CA practices regularly require long-term investments (e.g. in direct seeders and planters), but it is unrealistic to expect that capital investments for increasing the efficiency of natural resources use will alone be sufficient for convincing farmers to switch from tillage-based agriculture to CA (Knowler *et al.*, 2001).

Although no significant effects of reduced soil disturbance on cotton or wheat yields had been observed for instance in Uzbekistan, the initial yield loss that allegedly occurs when introducing CA was also not observed, while savings in operational costs were achieved immediately (Egamberdiev, 2007; Tursunov, 2009). The values were highest under CA with crop residue retention, which amounted to UZS1,288,000 (ca. US$1075) per ha accumulated over 3 years. While using the results of three consecutive growing seasons, a dominance analysis showed that CA had much higher potential than the conventional practices owing to higher total variable costs and lower gross margins (GM). Cumulative gross margin analysis showed higher GM in all CA practices tested as compared to ConvT. Dominance analysis further revealed the advantage of the CA practices over ConvT because of the lower total variable cost and higher GM (Tursunov, 2009). Thus, adopting CA practices on the irrigated soils of Central Asia can improve the sustainability in agricultural production, provide benefits to farmers and reduce the threat of food insecurity. The financial analyses from Devkota (2011a) over four seasons of a rice-winter wheat rotation subject to a change from flood-irrigated to water-saving irrigation methods, showed a reduction in overall production, GM and benefit:cost ratio, which were highest with ConvT combined with continuous flood irrigation and lowest with permanent-bed and zero-till plantings while retaining all crop residues. Devkota (2011a) concluded that as long as irrigation water cost was not charged to farmers, it is unlikely that an economically-driven change in attitude will occur.

Introduction of CA technologies has been shown to lower production cost, raise profitability of winter wheat production and accordingly facilitate sustainable development of agriculture in different forms of agricultural entities in the south of Kazakhstan (Sydyk *et al.*, 2009). It has been found that in south Kazakhstan direct planting of winter wheat provides cost reduction by 28–44%. According to Fileccia (2009), considering both the cost savings and the yield gains, the economic efficiency of wheat production with NT technology resulted in an average improved net profit per hectare of over 50% in Kazakhstan. Meanwhile, the application of mineral fertilizers at the rate of $P_{30}N_{50}$ and the treatment of crops by herbicides facilitate the growth of conventional net income by 85.2% and reduces the production cost (Sydyk *et al.*, 2009).

In calculating energy efficiency in cultivating wheat in rainfed areas, Sydyk *et al.* (2008) determined the cost of aggregate energy directly associated with fulfilment of field operations described in 'technology maps' based on energy equivalents. It was found that about 7–22% energy expense was for soil treatment and planting; 3–4% for application of mineral fertilizers, 4–5% for application of herbicides, 40–45% for harvesting and transportation of crop and 34–36% for postharvest treatment of grain (Sydyk *et al.*, 2008).

It was determined that application of mineral fertilizers and herbicides, in South Kazakhstan province, did not require significant energy expenditure, but gave highest payback of energy resources, where energy efficiency ratios were 1.31 and 1.52 (Sydyk *et al.*, 2008).

It was revealed that under an irrigated farming system of southern Kazakhstan, raised-bed NT direct planting of winter wheat is a promising technology of CA. Significant reduction in cost for production of grain can increase the amount of conventional net income almost 1.4 times (Sydyk and Isabekov, 2009a).

9.5 Challenges Encountered in Scaling Conservation Agriculture in Central Asia

Several challenges that hinder the spread of CA in Central Asia can be recognized. They are elaborated in the following sections.

9.5.1 Government policies and institutional support

Preceding sections indicate that the governments in Central Asia do not have clear-cut policies on which kind of agricultural paradigm they wish to support to meet their future needs for food security, ecosystem services, climate change adaptability and mitigation as well as to respond to higher costs of energy and production inputs, and environmental degradation. The current status is to continue with tillage-based agriculture as much as possible. Only Kazakhstan took a policy decision to promote and support NT farming for rainfed production through subsidy on equipment (see Box 9.1). However, its policies towards CA and CA-based ecosystem management have some way to go. While there are research institutions or some researchers in some institutions who have been active in CA-related research, by and large research institutions do not explicitly implement a comprehensive CA-based research programme.

The Central Asian and Caucasus Association of Agricultural Research Institutes (CACAARI) in its statement on regional research priorities recognizes the need for capacity development in research and extension in the area of CA; but it is one topic amongst several, reflecting perhaps that CA is an option amongst several other technologies rather than an approach that involves a paradigm change in the way farming is carried out, and the mainstreaming of CA research to generate new knowledge on the

Box 9.1. Support for Conservation Agriculture in Kazakhstan – Subsidy and research

In the Republic of Kazakhstan, the state policy is oriented to the expansion of sowing areas under Conservation Agriculture. Moreover, in agricultural research, the priority area of study is resource and water-saving technology (Conservation Agriculture) of cultivation of agricultural crops in all regions of the country.

In compliance with the Resolutions of the Government of the Republic of Kazakhstan No.221 dated 4 March 2011 and No.938 dated 22 August 2011, the Ministry of Agriculture identified a flexible strategy of subsidizing farmers.

The amount of subsidies in case of using Conservation Agriculture is significantly higher (3–4 times) versus conventional technology. Government subsidies for adopting CA practices also have accelerated adoption. For example in 2011, the Government subsidies for adopting no-till practices were slightly over US\$6 ha^{-1} Kazakhstan (Kazakhstan Farmers Union, 2011, Kienzler *et al.*, 2012).

Regrettably, in irrigated farmlands in southern Kazakhstan, CA technologies are being introduced slowly. It is believed that the main reasons are lack of planting machines and a lack of knowledge by the farmers of no-till technologies.

Respectively, agricultural researchers for the last years often (two or three times a year) are organizing Farmers' Days, training workshops and scientific-practical conferences with the invitation of foreign scientists.

different aspects of CA management as well as the benefits that are possible from CA at the farm, community and landscape level. Research is one amongst several institutional responsibilities that need to be aligned towards generating new knowledge regarding CA so that the full potential of CA can be harnessed with locally formulated practices to suit the diversity of ecological and socio-economic contexts. Others involve extension, input suppliers including machinery and equipment, and output value chain and market access. In addition, several other institutions exist to address issues related to agriculture such as irrigation and water resource management, natural resource management and land degradation, livestock, climate change adaptability and mitigation. In general, public institutions are expected to operate within the policy environment of governments, and similarly private institutions have to align themselves to government strategies. Given the almost complete lack of official policy on CA in the Central Asia region, public and private institutions can by and large decide independently on what kind of agriculture to promote and support, resulting in confusion and wastage of human and financial resources.

An enabling government policy and institutional environment is needed to promote the mainstreaming of CA. This in practice requires that all the stakeholders must become engaged in the management of production and of the natural resource base in a sustainable manner. However, it is also necessary for the government to create an enabling environment to promote farmers' interest in undertaking sustainable soil and production management as well as the maintenance of ecosystem services. For this, farmers must be assisted to empower themselves by forming associations so that farmers can work together in testing CA practices and sharing experiences and results as well as in articulating their needs for equipment, information, advice and incentives. Also, there should be effective integrated development planning and policies backed up by relevant research and advisory/extension systems, and the mobilization of private sector stakeholders, for both rainfed and irrigated systems (Kassam *et al.*, 2012, unpublished results).

Providing policy and institutional support to farmers for CA adoption is an important necessary step in establishing ecological sustainability of production systems. When CA can be adopted over large areas such as watersheds and provinces, landscape-level benefits can be harnessed through appropriate schemes. Such schemes could be for carbon offset trading, e.g. in Alberta, Canada, or for water-related services in the Paraná Basin III, Brazil, or for erosion control, e.g. in olive groves in Andalucía, Spain (Kassam *et al.*, 2013).

9.5.2 Changing the tillage mindset

One of the biggest challenges to the widespread adoption of CA in northern Kazakhstan is that of changing the tillage mindset. This has been the case in all other countries where CA has spread, and we believe Kazakhstan will be no different. However, there is clear evidence that the system works under the conditions of the region; and there are some hard-working enlightened individuals who see that the principles of CA are not only functional, but important to halt the marked, albeit slow, soil and land degradation in the region. There are currently some 13.5 Mha of CA in Canada (Friedrich *et al.*, 2012), much of it under conditions similar to that in northern Kazakhstan and elsewhere in Central Asia. Thus farmers in the region can benefit from both the positive experiences and lessons learned by their Canadian counterparts (Karabayev *et al.*, 2012).

9.5.3 Skills required to operate Conservation Agriculture equipment

In addition to the change in mindset, all the skills that are required under ConvT management are also required for management of CA systems. The major differences are the operations of NT seed drills and herbicide sprayers.

Operation of NT seed drills requires the knowledge of the variety of the openers and coulters and their effects on the groove shape and seed placement. Groove shape and seed placement play important roles in seed germination under moist soil conditions. To master such skills, the operator must have deeper knowledge of different soil types, whereas in a ConvT system field preparations for sowing are uniform in terms of the use of machinery. Depending on the surface residue levels, the operator should be able to select the appropriate coulter types and make necessary adjustments to seed the NT crop.

Traditionally, herbicide application in Central Asia is done largely with air-blast sprayers, therefore there is limited knowledge of other types of sprayers such as rotary plate, boom and ultralow volume that produce different sizes of droplets. In CA, boom sprayers are widely used, which are fitted with different types of nozzles to target leaves. Exploitation of boom sprayers requires good understanding of nozzle types, angles produced by nozzles to ensure good coverage, pressure, preparation of solutions amongst other factors. There is also a need for improving legislation and developing the national capacity on pesticide application equipment registration, inspection and operator licensing.

9.5.4 Availability and accessibility to suitable implements

Numerous experiments with locally made and imported seeders have been conducted and seeders have been tested for the common raised-bed systems as well as flat seeding. In irrigated cotton–wheat systems, the replacement of mouldboard ploughing with conservation tillage reduced cotton yield, but not of wheat (Suleymenov *et al.*, 2004). Hence, a modified system was suggested: the use of the mouldboard plough for cotton and the use of conservation tillage for wheat. Prior to introducing CA practices, seeding equipment was adapted in Uzbekistan (Egamberdiev, 2007; Tursunov, 2009). As a first step, seedbed preparation and planting/seeding was tested in north-western Uzbekistan (Tursunov, 2009). The modifications in an imported Indian NT seeder included the introduction of a seeding-depth regulator, appropriate soil openers for planting into the hard and mulched soil, the seeding blade that now is suitable for various crops, and an adoption of the row distance regulator. The modified seeder became suitable for planting cotton and wheat on permanent beds (Tursunov, 2009).

In a 5-year study, Ospanbaev and Karabayev (2009) concluded that the use of a raised-bed seeder advanced the possibilities of crop planting by up to 30 days compared to conventional systems, which is a substantial encouragement for the spread of CA practices. In another joint farmer-researcher managed trial in Uzbekistan, implements for the bed-and-furrow system (BFS) typical for local cotton production and NT technologies were compared (Pulatov *et al.*, 2001). The research focused on the performance of NT and BFS planters and the effects of sowing with NT drill, BFS planter and ConvT on crop yield, irrigation and income. Findings from NT and BFS planting showed that savings in time and labour as well as the user-friendly machine construction and the simple technology appealed to farmers and researchers. The use of implements suitable for CA practices increased yields through an earlier establishment of the crops and decreased crop establishment costs through a reduction in tillage costs, which was underlined by the participating farmers (Pulatov *et al.*, 2001).

Evidence worldwide shows that a widespread adoption of CA practices is unlikely if the suitable equipment is not readily available at acceptable costs (e.g. Knowler *et al.*, 2001; Friedrich and Kassam, 2009). Although national policies in Central Asian countries prioritize agriculture, the necessity to increase the accessibility and affordability of locally made CA implements suitable for seeding in untilled and mulched soils and in the presence of stubbles and/or a cover crop is still underestimated. Moreover, practices such as land levelling and NT raised bed planting can provide employment opportunities to jobless rural youths and employment in small-scale manufacturing and transport-related sectors as shown in other countries (Gupta and Sayre, 2008).

The 'Matyushkov' seeding shoes still cause considerable soil movement and longer (front to back), narrower shoes which cause less lateral soil velocity would be an improvement. Recently, chisel points from India have been imported into Kazakhstan, and a new modification to the standard seeding shoes has been made by Dr Dvurechenskiy. Manufacture of these was tried at both the Agromash factory in Astana, Kazakhstan, and a factory in Omsk, Siberia, with the latter giving better results because of the hardness of the steel used and therefore the extended life of the shoes (Karabayev *et al.*, 2012).

9.5.5 Residue supply and management

In virtually the entire Central Asian region, crop stubbles, essential for CA, are either burned due to a lack of suitable, powerful tractors for ploughing or, more commonly, residues are removed and fed to livestock. Some of the Central Asia nations such as Uzbekistan still have tillage regulations at present that limit the possibility for farmers to leave crop residues on the field. Studies thus far have therefore compared mainly the cases of 100% crop residue retention or no retention (e.g. Egamberdiev, 2007; Kienzler *et al.*, 2009a; Tursunov, 2009; Devkota, 2011a, b; Ibragimov *et al.*, 2011). Research on intermediate levels, rates and residue management practices have been usually beyond the scope of these initial studies. Only Devkota (2011b) concluded from her findings in a cotton–wheat–maize rotation that the retention of all crop residues after each cropping cycle is unnecessary to improve soil quality. The mulch layer from a retention of 8–10 t ha^{-1} wheat straw obstructed seeding, irrigation and fertilizer management in a cotton–winter wheat rotation. The retention of 14 t ha^{-1} standing residues on permanent beds for rice reduced soil temperature and resulted in a delayed germination and reduced yields (Devkota, 2011a). Previous studies outside Central Asia (FAO, 2000) indicated that the retention of 4 t ha^{-1} crop residues was sufficient for CA practices. However, given the scarcity of findings, additional research is needed to clarify this component. Research should in this case concentrate on identifying suitable and manageable levels of partial residue retention and residue management so as to achieve the expected agronomic benefits and consider the alternative demands from farmers.

After independence in 1991 from the Soviet Union, Uzbekistan and Turkmenistan maintained the notion of strategic crops under a state order system, while in the rest of the Central Asian states, the order was abolished or replaced by other crops. Turkmenistan and Uzbekistan still regulate and own the majority of the economic and land resources, while Kyrgyzstan, Kazakhstan and Tajikistan have introduced a certain level of land privatization. Nevertheless, after almost two decades since the changes were introduced, the knowledge, design and equipment available in the different countries in many aspects still 'mimic' the former Soviet agricultural system. The most common crop rotations in Central Asia such as cotton–wheat, wheat–fallow or wheat–rice rotations (Gupta *et al.*, 2009) thus leave little scope for diversifying the system especially under the current agricultural legislation prevalent in some Central Asian nations, thereby failing to harness the benefits of crop rotations, which is an important component of CA practices. Also, in the absence of private land tenure, farmers for instance in Uzbekistan and Turkmenistan refrain from CA practices for a longer timespan, although after only few years typical environmental benefits of CA emerge such as an increase in SOM (Egamberdiev, 2007; Funakawa *et al.*, 2007; Sommer and De Pauw, 2010).

9.5.6 Weed management

Weed infestation is not only common in CA, but rather CA causes a change in the dynamics of weed growth that are already present in traditional production systems. Effects of crop rotation on weeds have been intensively studied in cotton-growing areas during the period 1975–1984 (Tursunkhodjaev and Bolkunov, 1981; Ismailov, 2004) with different combinations of cotton–lucerne–wheat rotations. The principles still hold true that crop rotation helps to suppress weeds and appropriate strategy is needed for CA as well.

Weed control is one of the principal reasons for soil tillage, and when tillage is reduced or avoided, weed control is one of the major management challenges that must be tackled. As CA became more readily possible with the advent of herbicides one can expect that in most instances, in the first years of CA, the use of chemicals for weed control may increase. However, the principal herbicide used for weed control in the growing crop or prior to crop establishment is glyphosate – a herbicide for the total control of weeds. Glyphosate is relatively benign environmentally: it has very low mammalian and invertebrate toxicity; it is tightly bound to clay particles in the soil and so is not leached; and is broken down by soil microbes, generally within about 3 months. As soil erosion is drastically reduced under CA, the chance of glyphosate getting into waterways from CA fields is very low, and even then it is so tightly bound to the clay particles that it is not released into the water. However, one concern is the widespread use of glyphosate in CA systems and the appearance of glyphosate-resistant weeds: populations of 11 weeds resistant to glyphosate have been reported worldwide (International Survey of Herbicide Resistant Weeds, 2006).

The effect of different types of herbicides on productivity of NT winter wheat was studied by Nurbekov (2007) in Karakalpakstan, Uzbekistan. The overall weed infestation observed in conventionally tilled wheat with application of Puma Super in spring was essentially equal to that found in NT wheat with Dafosat applied in the autumn followed by spring-applied Puma Super. Some recommendations on herbicide applications to control specific weeds have already been developed for Kazakhstan. In northern regions of Kazakhstan, during the early growth of wild oats (usually when soils warm up to 10–12°), it is recommended that glyphosate (which has uniform impact) should be applied before planting of cereals. Herbicides could be applied at minimum dose – up to 1.0 l ha^{-1}. Favourable environment, such as mass sprouting of wild oats, cool weather, sufficient soil moisture, provides highly efficient suppression of this weed.

Meanwhile, application of these herbicides in minimum dose costs 2.0–2.7 times less than the use of counter-wild oats herbicides, and is 1.6 times cheaper compared to crop management activities aimed at control (Sydyk *et al.*, 2008). Moreover, since this method does not require large number of machines, practically any farmer can afford it.

When the herbicide Target was applied at the rate of 1 l ha^{-1} in NT directly seeded winter wheat, high yield of 4.0–4.4 t ha^{-1} was achieved in the rainfed areas in high rainfall years, whereas in medium rainfall years the yield was in the range 2.6–3.2 t ha^{-1}. In 2006–2008, the application of herbicide Aroma (50% emulsifiable concentrate) at 1.5 and 2.0 l ha^{-1} with direct seeding, demonstrated greater efficiency. Treatment at the rate of 1.5 l ha^{-1} reduced the number of weeds down to 24.8 plants m^{-2} from the initial number of 124 plants m^{-2}, while under the higher rate these numbers were 21.6 plants m^{-2} and 128.2 plants m^{-2}, respectively. Reduction of fresh biomass of weeds compared to control fluctuated within 74.0–74.6%, depending on the rates of herbicide treatments.

In safflower, preplanting treatment by the herbicides Dual Gold 960 emulsifiable concentrate at a rate of 1.5 l ha^{-1} allowed reduction of number of weeds by 93% and biomass by 96%, providing high yield of oilseeds (1.45 t ha^{-1}) (Sydyk and Isabekov, 2009b). It was found that the treatment of safflower crop by herbicide Dual Gold 960 emulsifiable concentrate (1.5 l ha^{-1}) resulted in increase of thousand kernel weight (TKW) by 4.7 g or 14.5%. Thus, under direct planting at the rate of 1.0 l ha^{-1}, productivity of safflower increased by 0.46 t ha^{-1}; in raising the herbicide rate to 1.5 l ha^{-1}, productivity of safflower comprised 1.18 t ha^{-1} and productivity increased by 0.6 t ha^{-1}. The highest yield of safflower, 1.35 t ha^{-1}, was obtained in treatment with herbicide Pivot (10%) at a rate of 0.8 l ha^{-1} at the sprouting stage, a yield increase of 0.77 t ha^{-1} (Sydyk *et al.*, 2009). Application of Pivot (10%) at 0.5 l ha^{-1} resulted in the average yield of 1.08 t ha^{-1} and the yield increased by 0.5 t ha^{-1}.

The other two principles of CA, NT and maintenance of soil cover, also contribute to suppressing weeds in CA systems that promote integrated weed management. Not tilling the soil promotes the rotting of the weed seed bank in the soil over time, and avoids the burying of weed seeds into the soil, which can protect them. Similarly, mulch cover can suppress weeds and also helps to kill weed seeds with humic acids that are released from the decomposing organic residues. Little work has been done in the region on integrated weed management, and should be encouraged in the future.

In should be noted that the quality control and certification of chemicals, including herbicides, is still not fully in place. Thus, very often low-quality and hazardous herbicides are used by the farmers. On the other hand, the prices for herbicides are high and not all farmers, especially small-scale farmers, can afford their application.

9.6 Prospects for Conservation Agriculture in Central Asia

Conservation Agriculture is one of the most promising agricultural land use options that have been developed in our time. Conservation Agriculture is more an approach to sustainable agroecosystem management than a production technology because it offers a way to produce more with less while at the same time preserves and enhances many of the ecological functions a natural soil has to offer in a natural ecosystem. Conservation Agriculture also offers economic benefits to farmers who apply it. Generally, an immediate cost reduction due to reduced cultivation and machinery operations can be felt right after the introduction of CA. There are a number of challenges that CA faces throughout the largely agricultural region of Central Asia including the lack of: crop and farming system diversification on small-size farming areas; knowledge about CA systems among extension and technical staff; knowledge about CA at decision-making levels; farmers' ability to decide on diversified crop rotations; and implements needed for use in CA. Nevertheless, farmers in the region of Central Asia are now becoming increasingly aware of CA as a new, promising farming paradigm. Awareness comes in the form of accepting NT as a viable system in growing crops as opposed to the earlier total rejection of agriculture without tillage. Particularly for irrigated areas, large programmes by different institutions need to be carried out to adapt CA to local conditions and to generate research results to advise farmers accordingly. For example, in Uzbekistan and Kazakhstan, the governments provide research grants to institutions, and they have approved a number of applications from different research groups for addressing water and crop issues in CA systems.

Only Kazakhstan has managed to implement supportive policies for CA, and as a result the area under CA-based practices increased from 0 ha in 2000 to 1.6 Mha in 2011 with continued expansion according to a recent assessment conducted by CIMMYT (FAO, 2012). Usually manufacturers, importers and dealers are proactive with the objective of increasing the demand for CA implements. Yet, the present political systems in Central Asia indicate that the public rather than the private sector is now being called upon to initiate and lead such efforts.

Agriculture in the region is diverse, and has a great potential to revitalize the withered economies of the Central Asian countries via improved productivity (efficiency) and higher total output through CA-based agricultural development. After independence in 1991, the production of fodder crops such as maize and lucerne sharply decreased along with reduction in area under rice and vegetables (melon). Conservation Agriculture will have to shoulder the largest burden of making sustainable intensification of production systems a reality for food, fodder and fibre crops and livestock in Central Asian countries.

The demand for food and fodder production will continue to grow in Central Asian countries. Wheat, cotton and livestock are the most important agricultural commodities in the region, and with a trend to diversification, oil crops such as rapeseed, sunflower, safflower and soybeans could likewise become important commodities, similar to the Canadian model.

The evidence from Central Asian countries shows that CA practices are suitable for the existing major cropping systems. However, most of the results come from collaborative projects largely initiated and funded by international organizations. Conservation Agriculture is not a single or uniform technology that can be immediately applied anywhere in a standard manner. Rather it represents a set of principles that encourage the formulation of locally adapted practices, approaches and methods, which need to be tested, evaluated and then adopted or implemented under various biophysical and socio-economic conditions. Further research is necessary, for example, to study in detail the effects of various CA crop rotations and mulch cover on weed management, nutrient, pest and water management, on residue levels, sowing depth, dates, density, and on fertilizer and irrigation rates; and impact assessment on livelihoods and environmental conditions including the potential of integrating trees and livestock into CA farming systems, particularly with small-scale farmers. To make results applicable on a wider scale, state programmes should become more active in conducting research, training and extension.

Considerable knowledge has been generated about CA practices in the Central Asian region, first in rainfed areas and, more recently, in irrigated areas. In fact, the potential of CA for sustainable agricultural development has been demonstrated in the region. Building the technical and scientific capacity of national partners will be essential for moving to widespread CA adoption and uptake. Researchers, extension workers and farmers will continue exchanging experience and knowledge about the new CA methods. Consequently, for the foreseeable future, facilitating national development strategies for up-scaling of CA, conducting training courses with national partners for capacity development, promoting farmer associations and facilitating stakeholder engagement through national and regional platforms in supporting CA adoption and uptake should remain a high priority in the efforts undertaken by FAO, ICARDA, CIMMYT and other international organizations such as IFAD, ADB, EU and national donors, to promote CA in the region.

Notes

[1] We define permanent raised beds as raised beds that were prepared and used during a previous season but subsequently used also for growing the next crop on the same beds. Therefore, we differentiate between raised beds that are not permanent (fresh beds prepared every season) and those that are permanent.

[2] No-till consisting of direct drilling as the only mechanical operation disturbing the soil surface. All other operations usually employed under 'conservation tillage' in the rainfed areas of Kazakhstan, such as sweep tillage, discing and harrowing, are thus not included.

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