Field Crops Research 132 (2012) 95–105

Contents lists available at SciVerse ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Conservation agriculture in Central Asia—What do we know and where do we go from here?

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ARTICLE INFO

Article history:
Received 23 May 2011
Received in revised form 4 December 2011
Accepted 7 December 2011

Keywords:
Sustainable agriculture
Dryland ecosystems
Permanent raised beds
Zero tillage
Conventional tillage
Aral Sea Basin
Water productivity

ABSTRACT

Rainfed and irrigated agricultural systems have supported livelihoods in the five Central Asian countries (CAC) for millennia, but concerns for sustainability and efficient use of land and water resources are long-standing. During the last 50 years, resource conserving technologies were introduced in large parts of the rainfed areas while the irrigated areas were expanded largely without considering resource conservation. In more recent years, the use of conservation agriculture (CA) practices has been reported for the different agricultural production (AP) zones in CAC, albeit centering on a single AP zone or on single factors such as crop yield, implements or selected soil properties. Moreover, conflicting information exists regarding whether the current practices that are referred to as 'CA' can indeed be defined as such. Overall information on an application of CA-based crop management in Central Asia is incomplete. This discussion paper evaluates experimental evidence on the performance of CA and other resource conserving technologies in the three main AP zones of CAC, provides an overview of farmer adoption of production practices related to CA, and outlines technical and non-technical challenges and opportunities for the future dissemination of CA practices in each zone. Agronomic (e.g. implements, crop yields, duration, and crop residues), institutional (e.g. land tenure) and economic (e.g. short vs. long-term profitability) perspectives are considered. At present, adoption of CA-based agronomic practices in the rainfed production zone is limited to partial crop residue retention on the soil surface or sporadically zero tillage for one crop out of the rotation, and hence the use of single CA components but not the full set of CA practices. In the irrigated AP zones, CA is not commonly practiced and many of the pre-conditions that typically encourage the rapid spread of CA practices appear to be absent or limiting. Further, our analysis suggests that given the diversity of institutional, socio-economic and agro-ecological contexts, a geographically differentiated approach to CA dissemination is required in the CAC. Immediate priorities should include a shift in research paradigms (e.g. towards more participatory approaches with farmers), development of commercially available reduced and no-till seeders suitable for smaller-scale farm enterprises, and advocacy so that decision makers understand how different policies may encourage or discourage innovations that lead towards more sustainable agricultural intensification in the CAC.

1. Introduction

The five Central Asian countries (CAC) Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan comprise an area of around 397 million hectares (Mha) (Table 1). Of this, around 20 Mha are cultivated rainfed areas, primarily in northern Kazakhstan, while less than 10 Mha are currently used for irrigated crop production (Table 1). Agricultural productivity and profitability are relatively low across the region, which is mainly due to the prioritization of extensive production rather than of production efficiency, a legacy from the policies of the former Soviet Union (SU) (Gupta et al., 2009). These policies have created ongoing and serious land degradation processes from erosion, nutrient depletion, salinization, water-logging, soil compaction, and desertification which continue despite post-independence land reforms that were

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doi:10.1016/j.fcr.2011.12.008

Table 1
Selected agricultural indicators for Central Asian countries in 2008.

Countries	Total land ($\times 10^3$ ha)	Rainfed ($\times 10^3$ ha)	Irrigated ($\times 10^3$ ha)	Salinized area (% of irrigated land)	Population (million)	Agriculture (% of GDP)
Kazakhstan	272,490	18,994	2082	33.0	15.7	5.3
Kyrgyzstan	19,180	238	1072	11.5	5.2	25.8
Tajikistan	13,996	208	722	16.0	7.4	19.8
Turkmenistan	46,993	400	1800	95.9	6.9	22.1
Uzbekistan	44,410	419	4213	50.1	27.3	19.4
Total/average	392,679	20,259	11,431	48.1	62.6	9.9

Source: National Statistics Committees of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan (2010).

expected to improve land stewardship (Spoor, 1999; Spoor and Visser, 2001). In 2007, the annual costs associated with land degradation were estimated still as high as $1 billion USD for Uzbekistan alone (Sutton et al., 2007), and up to $2.5 billion for all the CAC (ADB, 2006).

During the last 20 years, crop yields in the CAC region have become less predictable owing to an insecure input supply (e.g. fertilizers and implements), irrigation water scarcity (McCarthy et al., 2001; Bates et al., 2008), and the weakening of support services for farmers (e.g. soil laboratories, extension services, and phytosanitary control) (Kuo et al., 2006; Niyazmetov et al., 2011). In some areas, crop productivity significantly declined because increased input prices for fertilizers, pesticides and machinery were not offset by higher agricultural commodity prices (Kandiyoti, 2004). Also, many former trade arrangements and economic linkages for the marketing of farm products were disrupted and are still not fully replaced (Kuo et al., 2006).

Conservation agriculture (CA) is based on three core practices: crop establishment with reduced or no tillage, establishment of permanent soil cover with crop residues retention at the soil surface, and economically viable crop rotations that complement reduced tillage and residue retention by breaking cycles of pests and disease (FAO, 2010). Experimental evidence from many different production environments demonstrate that CA-based management can have both immediate (e.g. reduced production costs, reduced erosion, stabilized crop yield, and improved water productivity) and long-term benefits (e.g. higher soil organic matter contents and improved soil structure), although the magnitude of these benefits tends to be site and year specific and cannot be overly generalized across farming systems (e.g. Derpsch, 2003; Hobbs, 2007; Giller et al., 2009). Current estimates suggest that CA is practiced on an estimated 100 Mha worldwide and across a variety of climatic, soil, and geographic zones (Derpsch and Friedrich, 2009). Most CA systems at present are in rainfed environments, although a growing body of evidence suggests that significant benefits can also be expected under irrigated conditions (Sayre and Hobbs, 2004; Tursunov, 2009) and thus would have relevance to increase productivity and minimize the adverse effects of the current conventional practices in the extensive irrigated systems of the CAC. Based on evidence largely from Africa, Giller et al. (2009) cautioned that CA should not be construed as a "silver bullet" towards achieving the economic, ecological, and social dimensions of sustainable agricultural development (Kassie and Zikhali, 2009), but rather judged on merits in different agro-ecological conditions. Further, the actual practices employed for CA always require a process of refinement and localization; there is no universal template for CA-based management and many production practice adjustments (e.g. fertility, weed control, and pest management) must typically be made to optimize system performance in different environments. Given the wide diversity in agro-ecological and socio-economic conditions as well as political regulations among the CAC, it cannot be expected that a single CA-based management system will be best matched to the diversity of farmer circumstance.

In Central Asia, research findings on CA have been reviewed previously but were either limited to a single agricultural production (AP) zone (e.g. Wall et al., 2007; Gan et al., 2008) or addressed a few aspects only such as yields, implement development or selected soil parameters (e.g. Pulatov, 2002). Furthermore, research has been conducted in the rainfed systems of the North and the irrigated systems in the South of Central Asia, but few studies have looked at CA in the rainfed foothills in the South. Finally, inconsistent standards and terminology have been used internationally as well as in the CAC for describing CA-based systems and other resource conserving production technologies (e.g. Suleimenov et al., 2004). Mitchell et al. (2009) provide some common definitions for resource conservation technologies (RCT) related to crop establishment which are presented in Table 2 along with examples from the CAC. Confusion related to terminology has also been caused by inaccurate translations into Russian and local languages.[1]

In summary, to assess the present status of CA in Central Asia and to determine research gaps and future needs, experimental information were compiled and analyzed. To organize the analysis, research findings were grouped according to the three main AP zones while considering their duration (long- or short-term), the crops and crop rotations examined, the studied parameters and conclusions. Thereafter, the near-term prospects for expansion of CA-based management practices were assessed according to the prevailing agronomic, socio-economic and political conditions in different parts of the CAC.

2. The Central Asian setting

Although the perception of Central Asia as being a uniform area was (indirectly) promoted during the SU era, ecologically this region is very heterogeneous (Fig. 1). Similar in size to India or the European Union, large differences exist between mean annual temperature, rainfall, duration of the growing period, soil types, slopes, etc. (Table 3) that subsequently impact the farming systems (Table 4) and determine land use.

From an agro-ecological perspective, the region can be divided into four different zones (Gupta et al., 2009): (i) the irrigated areas (i.e. Turkmenistan, Uzbekistan, Kyrgyzstan and Tajikistan, and southern Kazakhstan), where a large share of the irrigated cropland relies on water diverted from the rivers Syrdarya and Amudarya, (ii) the rainfed areas which are mainly in northern Kazakhstan but smaller areas exist in the mountain regions of Kyrgyzstan, Tajikistan, and Uzbekistan, (iii) rangeland and pastures, and (iv) small-scale subsistence agriculture in the mountain

[1] The term "conservation agriculture" (Russian: сберегающее земледелие) is frequently translated and considered synonymously as either "resource conserving agriculture" (Russian: ресурсо-сберегающее земледелие), "no-tillage/zero-tillage" (Russian: нулевая обработКа), "reduced tillage" (Russian: щадящая/поверхностная обработКа) or "minimum tillage" (Russian: минимальная обработКа). Wall et al. (2007) postulated that crop residue retention on the soil surface is the main characteristic used to define 'CA' in Central Asia, but this conclusion is not universally accepted (Gan et al., 2008).

Table 2
Definitions of resource-conserving crop establishment practices according to Mitchell et al. (2009) in comparison to crop management in three agricultural systems of Central Asia (Suleimenov et al., 2004, 2006).

Term	Land management	Crop production practices in the warm irrigated areas of Tajikistan, Turkmenistan and Uzbekistan	Crop production practices in the warm rainfed and irrigated foothill areas of Kazakhstan (south) and Kyrgyzstan	Crop production practices in the cold rainfed areas of Kazakhstan (north)
Reduced tillage	15–30% residues preserved	Winter wheat planted into standing cotton resulting in 60% tillage reduction; wheat planted into rice stubbles	Unknown	Spring wheat (with adequate N fertilizer) with some soil tillage to allow for water infiltration in heavy-textured soils; residues as snow-traps during winter
Conservation tillage	>30% residues preserved; reduced soil disturbance	Unknown	Unknown	Spring wheat (with adequate N fertilizer)
No tillage/direct seeding	Soil disturbance only at planting; weed control via herbicides	Surface seeding or broadcasting winter wheat into rice resulting in 100% tillage reduction (most of household farms in lowland Amu Darya)	Unknown	Spring wheat (with adequate N fertilizer)
Strip tillage	Seed row is tilled; one pass combining strip tillage and seeding	Short duration maize as a summer crop planted after winter wheat (Fergana Valley)	Unknown	Unknown
Ridge tillage	Seed row is tilled; fertilizer injection; weed control via herbicides	Unknown	Unknown	Unknown
Mulch tillage	>30% residues preserved; limited passes across the field (only 1–3 passes)	30% residues preserved; fodder crops planted after winter wheat	Unknown	Spring wheat (with adequate N fertilizer)
Stale seedbed	<30% residues preserved; weed control via herbicides; conventional land preparation	Cotton production in general; reshaping of beds by moving soil from beds to furrows and thus forming new beds (Fergana Valley)	Unknown	Unknown
Minimum tillage	Reduced tillage passes by 40%	Winter wheat planted after fodder crops resulting in 30% tillage reduction	Unknown	Spring wheat (with adequate N fertilizer) with some soil movement to allow for water infiltration in heavy-textured soils; residues as snow-traps during winter

regions (mainly in the higher altitudes of Kyrgyzstan and Tajikistan and in parts of the other countries (Fig. 1). An alternative model was proposed by Suleimenov et al. (2004, 2006) that groups the rainfed and irrigated-based zones into three main crop-based production systems: (1) the northern Kazakh steppes; (2) the warmer foothills of Kyrgyzstan and southern Kazakhstan where a mixture of rainfed and irrigated agriculture is practiced and (3) Tajikistan, Turkmenistan and Uzbekistan where irrigated bed-and-furrow or basin systems are used (Table 3). Our analysis uses this three-part AP classification to assess CA-based crop management in the CAC.

Table 3
Salient information about the dominant cropping systems in the five Central Asia countries according to identified agro-ecological zones.

Country/region	Major production system	Cropping intensity (%)	Growth period (days)	Distinguished features of the agro-ecology	Production constraints
Kazakhstan (northern parts)	Rainfed spring wheat–fallow systems	40–60, 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	40–60, 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% or more	60–119	Sloped lands (up to 10%), supplemental irrigation, generally fresh but shallow groundwater table	Drought (precipitation 250–350 mm), 7–9 °C, sloped land, mechanization Water erosion by irrigation, drainage congestion
Tajikistan (South west/NW)	Irrigated systems (cotton–wheat) Agric. on sloped land of 5–16%	40–60% or more	60–150	Pastoral systems/irrigated agriculture on sloping lands, saline groundwater	Drought and heat (precipitation 250–500 mm), 16–20 °C, salinity, water erosion
Uzbekistan (irrigated)	Irrigated cropping systems, cotton–wheat (mostly raised-bed)	More than 60%	60–119	Irrigated crop production, drainage water use, soil salinity, long growing season, double cropping	Drought and heat (precipitation 200–350 mm), 14–18 °C, water scarcity, salinity
Turkmenistan (irrigated)	Rainfed pastoral/cereal production systems (mostly raised-bed)	30–60%	30–59	Crop–livestock systems, saline groundwater, overgrazing, soil salinity	Drought and heat (precipitation 200–300 mm), saline water use, 16–22 °C

Source: Modified after Gupta et al. (2009) and De Pauw (2008).

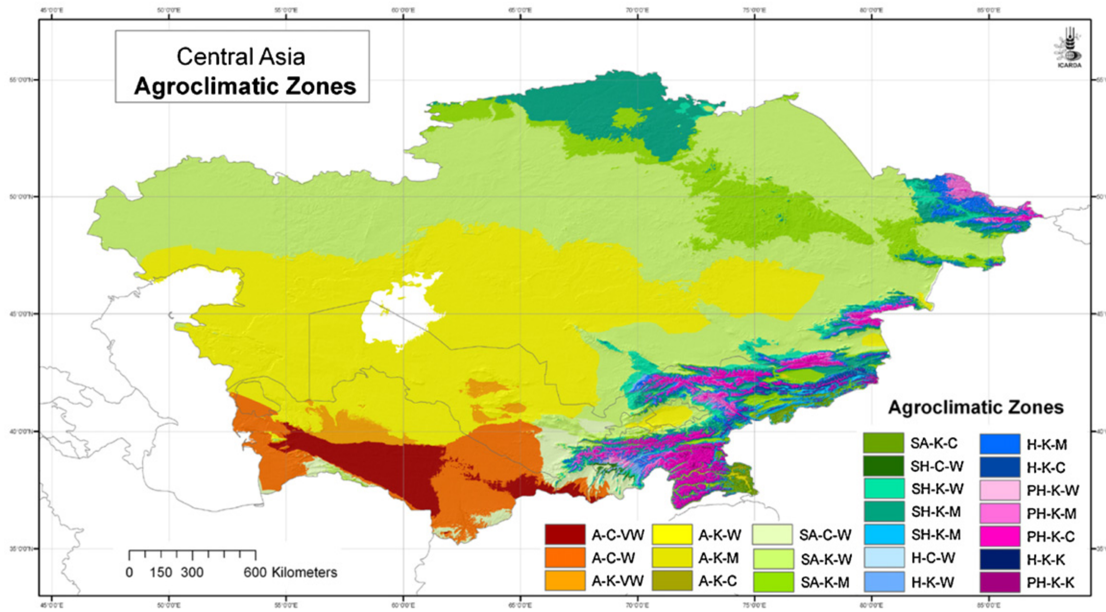

Fig. 1. Agro-climatic zones in Central Asia. Details of the legend are given below. *Source*: De Pauw (2008).

Agroclimatic zone	Description	Aridity index	Temp. range coldest month	Temp. range warmest month	% of total
SA-K-W	Semi-arid, cold winter, warm summer	0.2–0.5	≤0 °C	20–30 °C	37.9
A-K-W	Arid, cold winter, warm summer	0.03–0.2	≤0 °C	20–30 °C	30.8
SA-K-M	Semi-arid, cold winter	0.2–0.5	≤0 °C	10–20 °C	6.6
SH-K-M	Sub-humid, cold winter	0.5–0.75	≤0 °C	10–20 °C	5.9
A-C-W	Arid, cool winter, warm summer	0.03–0.2	0–10 °C	20–30 °C	4 9
A-C-VW	Arid, cool winter, very warm summer	0.03–0.2	0–10 °C	>30 °C	2.9
PH-K-C	Per-humid, cold winter, cool summer	>1	≤0 °C	0–10 °C	2.0
H-K-M	Humid, cold winter, mild simmer	0.75–1	≤0 °C	10–20 °C	1.6
SA-C-W	Semi-arid, cool winter, warm summer	0.2–0.5	0–10 °C	20–30 °C	1.5
SH-K-W	Sub-humid, cold winter, warm summer	0.5–0.75	≤0 °C	20–30 °C	1.4
A-K-VW	Arid, cold winter, very warm summer	0.03–0.2	≤0 °C	>30 °C	1.2
PH-K-M	Per-humid, cold winter	>1	≤0 °C	10–20 °C	1.2
SH-K-C	Sub-humid, cold winter, cool summer	0.5–0.75	≤0 °C	0–10 °C	0.5
SA-K-C	Semi-arid, cold winter, cool summer	0.2–0.5	≤0 °C	0–10 °C	0.5
H-K-C	Humid, cold winter, cool summer	0.75–1	≤0 °C	0–10 °C	0.5
H-K-W	Humid, cold winter, warm summer	0.75–1	≤0 °C	20–30 °C	0.2
SH-C-W	Sub-humid, cold winter, warm summer	0.5–0.75	0–10 °C	20–30 °C	0.1
A-K-M	Arid, cold winter, mild summer	0.03–0.2	≤0 °C	10–20 °C	0.1
PH-K-K	Per-humid, cold winter, cold summer	>1	≤0 °C	≤0 °C	0.1
PH-K-W	Per-humid, cold winter, warm summer	>1	≤0 °C	20–30 °C	0.0
A-K-C	Arid, cold winter, cool summer	0.03–0.2	≤0 °C	0–10 °C	0.0

The ratio of the mean annual precipitation over the mean annual potential evapotranspiration.

3. Evidence from the three major agricultural production systems in Central Asia

The research findings for the different AP systems of Central Asia are inconsistent (Table 5). Most of the readily accessible research results on CA in the rainfed North date from recent years, although various citations make reference to previous experiments (Suleimenov et al., 2004; Wall et al., 2007; Karabayev et al., 2009; Kaskarbayev, 2009a,b). Furthermore, recent research for this AP zone primarily considers the advantages of minimal tillage practices compared to conventional practices. The CA-systems practiced involve deep tillage by a chisel plow in autumn (as to improve the water infiltration from snow melt) followed by harrowing in spring prior to seeding (to conserve accumulated soil moisture) (Wall et al., 2007). Furthermore, the crops considered were almost always spring wheat with a few cases of winter rye. Much research in the recent past was directed towards the development of suitable agricultural implements for minimum tillage (e.g. seeders with different openers for different soil types). Also, fallows managed with herbicides rather than tillage were assessed (Suleimenov et al., 2005).

In the warm foothills of the rainfed areas of southern Kazakhstan and northern Kyrgyzstan, cropping patterns are dominated by winter wheat-based rotations with supplemental irrigation present in some locations. The sparse experimental evidence available from this AP zone (Table 5) focuses on a limited number of parameters, the trials were conducted for a few years only but sporadically included information on production costs and financial returns (e.g. Medeubaev, 2003, 2009; Kienzler et al., 2009). However, research on CA practices in this AP zone is increasing, as preliminary findings point at a high potential of CA. Pender et al. (2009) reported for instance financial benefits of direct seeding and no-till with conventional practices for rainfed winter wheat, barley and safflower in southern Kazakhstan. Mainly owing to reduced expenses for fuel and labor, the six-year averaged net benefit for direct seeding increased by 32%. Suleimenov et al. (2004), Medeubaev (2009) and Pender et al. (2009) documented insignificant yield differences for winter wheat, safflower, winter chickpea and winter barley between minimal and no tillage practices. But net benefits increased under minimal and no tillage while also higher soil moisture contents were monitored during the growing season with the CA practices examined. This is particularly relevant given the

Table 4
Overview of farm types and major characteristics in four of the five Central Asian countries (as of 2011).

Country	Farm type	Ownership	Number of owners	Land area
Kazakhstan	Household plots	Private land ownership with the right of inheritance	1 family	Small plots below 1 ha
	Peasant farms (individual farms)	Private land ownership on a long-term rent base from 5 to 49 years	2–3 families, or the largest up to 7 families	Small from 7 ha and large up to 250 ha
	Agricultural cooperation	Private land ownership on a long-term rent base from 49 to 99 years including limited liability and joint-stock companies	Large number up to 200 members	2000 to up to half a million ha of total land
Kyrgyzstan	Family farms (small-scale individual farms)	Private land ownership	Single family farms. Mainly livestock production	Minimum 1 ha irrigated land in mountainous, and 5 ha in non-mountainous areas
	Peasant farms: medium scale individual farms	Private land ownership	Several families. Importance of crops increases	Land area varying from 5 to 150 ha
	Agricultural cooperatives	Private land ownership	Several households or family farms that are cooperative members	Land size varying from 5000 to 87,000 ha
Turkmenistan	Household plots	Private land ownership	1 family	Small plots of about 1/4 ha and around 15 heads of sheep
	Family farms	Private land ownership	1 family	Variable ranging from 3 ha to 150 ha
	Private (peasant) livestock producers	Mainly sheep and camel producers	2–3 families	No arable land, no land property rights, rely on sandy used as common rangelands
	Agricultural cooperatives	Practically similar to old collective farms	Cooperative membership	Large farming units operating on vertical integration
Uzbekistan	*Dehqon* farms	Private ownership	1 family	0.25–1 ha within the irrigated area
	Cotton and wheat production farms	Lease contracts for a maximum of 50 years	1 family	Since land consolidation reforms in January 2011, ca. 100-ha in size
	Orchards and vineyards farms	Lease contracts for a maximum of 50 years	1 family	Minimum 1 ha
	Livestock farms	Livestock and poultry	1 family	Size depends on the animal stock but at least 10 ha (based on 0.33 ha per cattle unit with a minimum of 30 heads of cattle equivalents)

Source: Updated after Lamers et al. (2009).

unreliable rainfall which became pronounced during the unusually dry year 2008 in southern Kazakhstan. Experiments with zero-tillage in the rainfed areas showed that yield of wheat can be increased by 0.46 t ha^{-1} (Karabayev et al., 2009).

Most experimental evidence from the *irrigated South* comes from shorter-term experiments (a maximum of 5 seasons) and for a few locations only (Table 5). Reported are mostly the impact of CA practices on selected aspects, e.g. either implements, yield response, crop growth and development, soil organic matter and nitrogen, soil salinization, water productivity, options for crop rotation and crop diversification, or crop residue management. The experiments have been predominantly conducted on research stations, on non-degraded land (e.g. non-saline) and often with sufficient access to irrigation water which does not reflect farmers' reality in many areas of the region. Furthermore, research was rarely conducted with farmers' participation even when addressing the development of CA equipment (Tursunov, 2009). Implement research centered further on adapting imported seeders and tested for raised beds and zero-tillage as CA practices only (Pulatov, 2002; Egamberdiev, 2007; Tursunov, 2009).

Yield responses to permanent raised beds and zero till, the two CA practices chiefly examined in the irrigated AP systems, are inconsistent and dependent on factors such as crop type, land preparation during the conversion to CA, or the "type" of CA practice tested (e.g. Devkota, 2011b). Devkota (2011b) reported that proper field preparation advancing the implementation of CA practices helped bypass the expected yield reductions observed elsewhere (e.g. Ishaq et al., 2001; Pettigrew and Jones, 2001) when changing from conventional to conservation practices. As the crop portfolio in this AP zone is dominated by cotton and winter wheat, the majority of experimental evidence is from cotton-based systems, and only sporadically includes other crop rotations. The few available findings with CA-based management on other crops illustrated a potential for mungbean, common bean, maize, buckwheat, chickpea and field pea, sugar beet and maize (Suleimenov et al., 2004). Double-cropping for instance after winter wheat was one way of increasing crop diversification.

The impact of CA practices on selected physical and chemical soil properties was part of virtually all reported studies in the irrigated AP zone. However, as each publication is related to different soil property parameters, CA management and crop rotations, comparable and common findings for each of the chemical and physical parameters are still few in number and therefore difficult to verify. For example, based on his findings on the dynamics of soil N content Egamberdiev (2007) suggests that crop residue retention must be complemented with additional N fertilizer applications particularly at the onset of a conversion from conventional to CA practices as to counterbalance N immobilization, even though limited when not incorporated, caused by residue retention on the soil surface (Hickmann, 2006; Sommer et al., 2007). Research findings by Egamberdiev (2007) suggest further that secondary soil salinization could not be completely arrested with CA practices such as permanent raised beds and zero till, but the rate of soil salinization increase declined with crop residue retention.

Given the urgency of addressing water use efficiencies, Kalashnikov (2009) reported up to 22–32% reduced water demand with fresh raised-bed systems without residue retention compared to the conventional practices during wheat production in Southern Kazakhstan. Although partial economic returns were not commonly calculated, those available still indicated that the use of for example permanent raised beds, but not for zero till, in the irrigated AP zones can be profitable and can improve the sustainability in agricultural production (Tursunov, 2009).

Table 5
Compilation of experimental evidence of resource conserving crop management practices in the three agricultural production zones of the CAC.

Country and year	Crop	Resource-conserving practice	Parameters investigated	Results/conclusions	Authors
Rainfed agro-ecology: the cold North					
KAZ, 2 years	SW	CT, RT, NT	Yield	Yields were higher with CT in 2005, but higher with NT in 2006, due to different weather conditions in these years	Pender et al. (2009)
KAZ	SF	CT, NT	Yield	Equal yields for CT and NT, although weed infestation was greatest for NT	Pender et al. (2009)
UZB, 4 years	WW, F	CT, RT, NT	Yield	Average yield was similar for NT and CT, but 14 to 18% lower with RT. Fallow provided a yield advantage in dry years but not in wet years.	Pender et al. (2009)
KAZ, 6 years	WW, B, SF	CT, NT	Financial benefits	Average net benefits were 32% higher with NT due to lower costs	Pender et al. (2009)
KAZ, 2 years	SW	RT, NT, CT	Yield	Equal yields under RT and CT; continuous NT decreased yield in heavy textured soils;	Suleimenov et al. (2004, 2005)
			Soil erosion	Decreased wind and water erosion under weedy fallow	
KAZ, 5 years	SW, F	CT, sub-tillage	Yield	Yields for sub-tillage were always higher for all years	Wall et al. (2007)
KAZ, 2 years	SW	NT	Yield	Yields increase under NT for 0.46 t ha^{-1} (25%) compared CT	Karabayev and Suleimenov (2009)
KAZ, 5 years	SW	NT, RT, CT	Yield	Equals yields under NT, RT and CT; continuous (>3 years) NT decreased yield in the cereal-fallow cropping system	Kaskarbayev (2009a)
KAZ, 3 years	P	RT, NT	Yield	Equal yields under RT and NT	Kaskarbayev (2009b)
KAZ, 3 years	–	RT, NT	SOM, BD	Increased SOM and BD under NT compared to RT	Djalankuzov and Saparov (2009)
Rainfed South (also supplemental irrigation)					
KAZ, 6 years	WW, B, SF	NT, CT	Financial benefits	Reduced expenses for fuel and labor. The six-year averaged net benefit for direct seeding increased by 32%	Pender et al. (2009)
KAZ, 3 years	WW, B, CHP,SF	NT, RT, CT	Yield	Equal yields of WW and B under NT, RT and CT; equal yield of CHP under CT and RT, but yield decreased for 23% under NT; equal yields of SF under CT and RT, but yield increased for 8% under NT	Medeubaev (2003, 2009)
KAZ, 2 years	WW	NT, RT	Soil BD, N, weeds and yield	Yield decrease in low-rainfall areas due to soil compaction; reduced availability of nitrates: provoked weedy environment; in areas with higher rainfall, RT increased yields	Suleimenov et al. (2004, 2006)
KYR, 1 year	WW	RB, CT	Yield	Yields at least equal if not higher than with RB compared to CT	Kienzler et al. (2009)
			Seeding rate Crop growth	Improved germination and reduced seeding rate by 50%; advanced by 2–4 days for each growth stage in RB, with advanced ripening by 8–10 days by RB	
CAC	C, WW, R	CA	Water use efficiency	CA increased irrigated water use efficiency from 0.1 US$ m^{-3} for cotton to 0.5 US$ m^{-3}	Aldaya et al. (2010)
Irrigated agro-ecology					
TAJ, 5 years	C, WW	NT	Yield, financial benefits	Average wheat yields were 22–24% higher with NT, resulting in substantially greater net benefits from wheat production	Pender et al. (2009)
TAJ	C, WW	NT, RT	Yield	Yields did not differ for NT or RT treatments for cotton or wheat	Pender et al. (2009)
UZB, TAJ, TUR, 2 years	C, WW	RT	Yield	Moldboard plowing with RT reduced C, not WW yields; recommended: maintain use of moldboard plow for C, but use RT for WW	Suleimenov et al. (2004, 2006)
UZB, 3 years	WW, M, C	ZT, PB, IT, CT	Seeders and financial benefits	Highest operational costs with IT; lower total variable cost and higher gross margin with PB as determined through dominance analysis	Tursunov (2009)
UZB, 3 years	WW, M, C	ZT, PB, IT, CT	Crop residue, SOM, soil N-total and salinity	Crop residues increased SOM, soil micro-aggregate and soil N contents; reduced rate of soil salinization increase with NT and PB	Egamberdiev (2007)
KAZ, 3 years	WW	RB, CT	Seeding rate, yield	Reduced seeding rate up to 70%, grain yield increased with ca. 25% compared with CT	Karabayev and Suleimenov (2009)
KAZ, 2 years	WW, M, SB	RB, CT	Yield	Equal WW yields, but M and SB yields increased with ca. 12% and 15% under RB compared to CT	Ospanbaev and Karabayev (2009)
UZB, 1 years	WW	ZT, RB, CT	Germination, weeds, yield	Savings in time and labor under RB and NT systems; equal yields under CT and NT, but yield increased for 11% under RB	Pulatov (2002)
UZB, TUR, TAJ, KAZ, 1–2 years	C, M, L	RB	Intercropping, financial benefits	Profitability increased for farmers of C and M intercropped with legumes, and sainfoin with barley	Kienzler et al. (2009)
UZB, 3 years	C, WW	RB, CT	Yield	RB increased yield of C.	

Table 5 (*Continued*)

Country and year	Crop	Resource-conserving practice	Parameters investigated	Results/conclusions	Authors
UZB, 2 years	WW, R	RB, CT	Yield	Anaerobic grown R unsuitable for RB practices; retention of 14 t ha^{-1} standing residues on RB reduced soil temperatures and in turn delayed germination and finally R yields	Devkota (2011a)
UZB, 2 years	C, WW, M	RB, CT, CR	Yield, soil quality	Equal C yields immediately after the conversion of CT to RB; consequent WW and M yielded 12% and 14% more with PB than CT; retention of all crop residues after each cropping cycle is unnecessary to improve soil quality. Optimal amount un-determined	Devkota (2011b)
UZB, 4 years	WW, M, C	RB, CT	BD, WSMA, SOC, yield, WUE	Soil compaction under RB but also increased WSMA and SOC; improved WUE and yield in three years after PB establishment	Ibragimov et al. (2011)
UZB, 3 years	C	CR	WUE, yield	WW residue retention improved WUE and yield of C	Bezborodov et al. (2010)
KAZ, 1 years	WW	RB	Seeding rate, irrigation norms, yield	With RB water savings of 22–32%, yield increase of 24–32% using reduced (50%) seeding rates with RB	Kalashnikov (2009)
UZB, 2 years	WW	NT, RB, CT	Plant density,	10% less plants in NT, but no yield differences between NT and CT during two years of the experiment	Nurbekov (2008)
	S		Yield	Grain yield increased with ca. 12% with PB compared to CT	

Legend: CAC – Central Asian Countries, KAZ – Kazakhstan, KYR – Kyrgyzstan, UZB – Uzbekistan, TAD – Tajikistan, TUR – Turkmenistan.
Crop: SW – spring wheat, WW – winter wheat, C – cotton, M – maize, S – sorghum, B – barley, R – rice, L – legumes, SF – safflower, P – pea, SB – soybean, CHP – chick-pea.
Tillage mode: CA – conservation agriculture, NT – no till, RB – raised beds, RT – reduced till, IT – intermediate till, CT – conventional till (including CP – chisel plow, H – harrowing), F – fallow, CR – crop residue mulched.
Soil parameters: SOC – soil organic carbon, SOM – soil organic matter, BD – bulk density, N – nitrogen, WSMA – water stable macro-aggregation.
Water: WUE – water use efficiency, GW – ground water.

4. Overall discussion

The rainfed AP zone in the cold North of Kazakhstan with its relatively flat land, scarce rainfall and high erosion potential is particularly well-suited for CA practices. More so, resource conserving practices have become a common farmers' practice since the 1960s, since the widespread effort for reducing the prevailing wind and water erosion at that time (Suleimenov et al., 2004). Research findings from this region (Table 5) support the applicability and value of CA-based approaches in this environment. The research has focused mainly on spring wheat, which is the major crop cultivated in northern Kazakhstan and makes up about a quarter of the value of agricultural production in Kazakhstan (National Statistics Committee of Kazakhstan, 2010). It is further one of the main agricultural export goods of Kazakhstan (National Statistics Committee of Kazakhstan, 2011). Due to the dissemination of research results and Government subsidies, more than 1 Mha spring wheat is annually planted under CA-based management in this AP (Derpsch and Friedrich, 2009). Since this is still less than 10% of the total agricultural area of Kazakhstan (Pender et al., 2009), and since the effect of resource conserving technologies and CA-based management practices is widely promoted owing to successes of early adopters and strong Government support (Derpsch and Friedrich, 2009), it is forecasted that the area under conservation agriculture will continue to increase rapidly in the near future (Gan et al., 2008). Currently, Kazakhstan is among the top 10 countries with the largest areas under no-tillage in the world (Derpsch and Friedrich, 2009).

Irrigated agriculture dominates the warm regions of Southern Kazakhstan, Kyrgyzstan, and southern Tajikistan, Turkmenistan and Uzbekistan. In Turkmenistan only irrigated agricultural is possible whereas in Uzbekistan, Kyrgyzstan, and Tajikistan, the irrigated areas produce around 75% of all agricultural production (Bucknall et al., 2003). Yet, since the total available amount of irrigation water limits area expansion, production increase must focus on increasing productivity (Pender et al., 2009). Due in part perhaps to the short history of research in this AP zone, reported *crop yields* with different resource conserving practices in the irrigated systems are inconsistent. Some evidence indicates that immediately after the conversion from conventional systems, permanent raised beds or zero till, yields do not exceed conventional practices and in cases were lower. Overall, current findings suggest that cotton production in these environments is not favored by zero-till (Tursunov, 2009; Devkota, 2011b), although yield reductions can be clearly attributed to insufficient land preparations, inadequate seeders and lack of knowledge about the most suitable management of crop residue retention, and would thus presently not justify any widespread promotional campaign of implementing zero-till. On the other hand, most CA research in this AP zone used to start with irrigated cotton as the transition crop, but hardly any research has been conducted over several cropping cycles and hence more research is needed before a final conclusion can be drawn. Furthermore, Devkota (2011b) showed that yield dips could be avoided with an appropriate field preparation including laser-guided land leveling following deep plowing, which confirms research evidence from elsewhere (Daniel et al., 1999; Nyakatawa et al., 2000; Govaerts et al., 2005; Gürsoy et al., 2010). The short history of CA experiments points also to potentially high yield gains with permanent raised-bed plantings for irrigated winter wheat but not for zero-till (Egamberdiev, 2007; Tursunov, 2009; Devkota, 2011a,b; Rücker et al., 2011). These results are in line to findings in irrigated wheat production in Mexico, where the financial benefits from CA are very substantial due to the use of permanent raised beds compared to fresh beds but only with crop residue retention (Ekboir, 2002; Govaerts et al., 2006). Overall, the evidence point to a more positive picture for the scope of expansion of permanent raised-bed in this

AP and the very necessary and common aspect of technology 'fine tuning' as major innovations in production practices are introduced to new areas.

Seeders (with or without simultaneous fertilizers applications) suitable for CA practices in the irrigated AP zone were tested predominantly in Uzbekistan. Yet, the seeders successfully developed for untilled soils and for raised-bed planting are not commercially available in contrast to the situation in the rainfed areas of Kazakhstan where efforts have been made to make these accessible to farmers (Kienzler et al., 2009). This deficiency in the irrigated AP zone is presently bridged through the import of equipment, an approach which could be expanded to overcome machinery bottlenecks while efforts are made to simulate the development of locally made machinery suitable for implementing CA. Although national policies in the CAC prioritize agriculture, the necessity to increase the accessibility of high-quality and affordable CA implements still is under-appreciated with respect to the extent that it hampers the successful introduction and dissemination of CA practices in the CAC. The present political and institutional setup in the CAC makes it easier for the public rather than the private sector to undertake such efforts first. Relying exclusively on the import of CA equipment seems a short-term solution but may not be the most appropriate option in the long run. Experience has shown that imported equipment in most cases needed to be adapted to local conditions (e.g. Kienzler et al., 2009; Tursunov, 2009), spare parts for foreign machinery can be expensive and often unavailable at local markets, and the banking system regulations can hamper the import of goods by individuals (Müller, 2006). With targeted policy advocacy, decision-makers may become more supportive in promoting the national manufacture of implements given the employment generating opportunities to the jobless rural population that can be created when promoting small-scale manufacturing as has been shown in India (Gupta and Sayre, 2008).

Overall evidence illustrates a favorable impact of CA on different *physical and chemical soil properties* in the CAC, which is consistent with evidence from other production environments. A rapid increase in soil organic matter (SOM) is consistently reported in experiments (Egamberdiev, 2007; Tursunov, 2009; Devkota, 2011a,b; Ibragimov et al., 2011; Pulatov et al., 2011) leading to improvements in soil structure and greater soil moisture holding capacities. These reports are consistent with a wealth of information on CA practices worldwide (e.g. Sanchez et al., 2004; Govaerts et al., 2006). A close look at the experimental evidence reveals that significant increases in SOM in the CAC are not surprising given the low initial SOM values. Moreover, the SOM increases observed in the arid and semi-arid agro-climatic conditions in the CAC were roughly proportional to the annual amounts of SOM added irrespective of the ways of application, i.e. as surface mulch or residues incorporated in the soil. This raises the question of how to manage *crop residue* best due to the present high dependence of farmers on crop residues as fodder for livestock and income generation (Djanibekov, 2008). Although in general the hurdles of introducing CA practice in regions with a strong interdependence of crop–livestock systems have been mentioned previously (Iñiguez et al., 2005), not much research has specifically addressed the issue of critical residue return rates that are required to achieve the benefits of CA-based management. Devkota (2011b) speculated that the retention of all residues from the previous crops is not needed under permanent raised beds, but the evidence base for making such judgments in the entire CAC is low. Overall, crop residue management remains a particular challenge. Research topics related to crop residue management should thus look into options for an expansion of fodder crops as to reduce farmers' dependence on crop residues for feed. Furthermore research could address if it is sufficiently profitable to transfer crop residue from production sites at a close distance to the CA sites and while minimizing transportation costs and that irrigation water availability is adequate.

The accumulated positive effects of CA practices on soil physical and chemical parameters were mirrored in the increasing irrigation *water use efficiency* with for instance permanent raised-bed. This is quite relevant given the drastic decrease in water productivity in the irrigated AP in the past decades, which is about 0.37 kg m^{-3} in the Syrdarya basin, approximately 40% less than the world average of 0.60 kg m^{-3} (Abdullaev and Molden, 2004). In addition, predicted water scarcity in the irrigated areas in Central Asia due to climate change, population growth, and an increase in use of water in upstream regions (Gupta et al., 2009) demands immediate efforts to increase water use efficiencies in agriculture which constitutes more than three quarters of all water resource use in the CAC at present (Abdullaev and Molden, 2004).

Given the wide-spread damage of *soil salinity* and the limited options presently available to arrest a further increase (Gupta et al., 2009), CA practices such as permanent raised beds showed significant positive results although CA alone will have to be combined with other best practices to resolve this important and damaging problem (Egamberdiev, 2007; Devkota, 2011a,b). These findings are thus an important signal to promote action since secondary soil salinization, caused by capillary rise of the ground water, is a major cause of the on-going cropland degradation in the irrigated areas of Central Asia (Akramkhanov et al., 2011; Tischbein et al., 2011).

Adjustments to basic agronomic practices for CA-based systems (e.g. optimal fertilizer management and crop rotations) have hardly been addressed yet by research in the CAC. Certain studies have addressed appropriate N management, which is of paramount importance in the irrigated AP zones since high N losses to the environment occur with conventional cotton, wheat and rice cultivation, especially when N applications are immediately followed by irrigation (Scheer et al., 2008). The state policy mandates for specific crop rotations in the irrigated AP zone such as cotton–wheat, wheat–fallow or wheat–rice rotations (Gupta et al., 2009) leave little scope for farmers to diversify their crop rotation systems, one of the main principles of CA practices. On the other hand, evidence for the performance of CA-based management for crops other than cotton and wheat is still limited although few evidence indicate a high potential for maize or sunflower (Ospanbaev and Karabayev, 2009) but not for rice (Devkota, 2011a). At this stage, CA-based recommendations for these crops are less relevant to farmers since seed availability is a constraining issue (Gupta et al., 2009). Also, evaluating and promoting the right food legumes and fodder crops is challenging because of distinct regional preferences and dietary habits in the CAC (Kienzler et al., 2009).

The few *financial assessments* conducted support the promotion of CA practices mainly because of similar yield levels for CA and conventional practices but with lower production costs for CA (Tursunov, 2009; Devkota, 2011a). Yet, even in case of profits, the recurrent observed yield reductions in cotton (even if only initially), makes CA practices more difficult to promote among policy-makers and farmers, because any new crop management that bears the risk of potential yield reductions and particularly of the strategic crops is unlikely to find spontaneous support at the higher administration levels in the CAC. As best practices for CA-based management continue to be improved and disseminated, this will become less of an issue.

CA and other resource conserving crop management practices are not yet commonly used by farmers in CAC. One of the reasons is that, despite the present volume of research findings and benefits associated with certain CA practices such as raised-bed (Table 5), *doubts* about the technical viability and performance of resource conserving technologies still dominate the mindsets of Central Asian authorities. Contributing to these doubts is the present lack of clarity about different technology types and their potential role for addressing land degradation, increasing profitability, and stagnating or declining crop yields. Thus research on the potential of CA practices is only slowly being added to the research and development agendas. Skepticism or lack of interest is also fueled by the findings of resource conserving practices as they addressed only at a few crops in the rotation or only single aspects of crop production. For example in the rainfed North (Kazakhstan), the dominant 'CA' practice involves deep tillage by a chisel plow in autumn and harrowing in spring prior to seeding to conserve accumulated soil moisture (Wall et al., 2007). Although commonly referred to as CA, this practice is best defined as a resource conserving technology as it is not based on full CA including minimal soil disturbance and residue retention at the soil surface although residues are sometimes left standing. Also farmer practices in the irrigated AP zones include no-till seeding of winter wheat into the standing stubble of cotton which is sometimes denoted as 'conservation agriculture' (Pulatov, 2002), even though this practice does not include retention of residue on the soil surface.

Agricultural policies greatly influence the adoption rate and dissemination of CA-based management practices. Although it has been suggested that, in the absence of private land tenure, farmers in Uzbekistan and Turkmenistan are reluctant to invest in any conservation-related practices (Egamberdiev, 2007; Funakawa et al., 2007; Sommer and De Pauw, 2010), the lack of adoption of CA practices in Kyrgyzstan for instance, where farmers have gained private ownership about a decade ago, suggests that land tenure by itself does not automatically lead to an adoption of new cropping practices including CA. The rapid spread of CA practices in northern Kazakhstan was made possible by the concentration of large land areas under agricultural joint-stock companies, which are the main adopters of CA practices (Kazakhstan Farmers Union, 2011). 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 6 US Dollars per hectare in Kazakhstan (Kazakhstan Farmers Union, 2011). But even though a limited amount, when coupled with additional cost-savings emanating from CA practices and economies of scale enjoyed by large agricultural joint-stock companies, considerable aggregated gains have been made. Similar targeted subsidy programs do not exist in the other CAC. But due to the strong influence of the Government in the CAC, wide-spread dissemination of any innovative practices including CA cannot be expected without strong Government support coupled with progressive policy reforms of pricing resources, specifically water, and the increasing security of private tenure which indeed may deter farmers from making long-term investments in arresting or reversing land degradation (Djanibekov et al., 2011). Hence as long as farmers and governments are not convinced of the positive effects of CA-based crop management systems, its adoption rates will remain low. It is in the interest of the Governments, however, to motivate farmers to engage in resource conserving and even CA-based practices through e.g. subsidies and education on sustainable resource use by environment-friendly regulations.

5. Conclusions and recommendations

Given the long-standing issue with land degradation and physical water scarcity in Central Asia, there is a certain scope for the expansion of CA-based crop management and other resource conserving technologies (RCT). However, the promotion of any practice must be evidence-based and geographically differentiated; for example, any advantages associated with CA-based systems are unlikely to be the same in rainfed and irrigated production environments. The communication of benefits to policy makers and farmers can be strengthened by more consistent and accurate use of terminology; all RCTs are not the same, and the details do matter. Moreover, efforts to expand CA-based and other innovative agronomic practices must be cognizant of the different socio-economic, institutional and policy environments across the CAC.

At present, the evidence base is still too limited to justify a broad-scale promotion of CA-based crop management and other innovative agronomic practices that may ensure high yields in the CAC while improving land resources and water productivity. More efforts are required not only to validate performance of CA-based systems, but also to implement the type of technology 'fine tuning' through adaptive research that is always required to optimize the performance of innovative practices in new environments. Fine-tuning must be done with respect to biophysical conditions, but also reflect differences in farmer circumstances, machine availability, and other factors of production that govern the success of new approaches. Encouraging participatory approaches to technology evaluation and refinement will be essential to future progress.

Particularly critical are enabling agricultural policies backed by national administrations and centering on providing incentives or alleviating bottlenecks that will encourage farmers to adopt CA practices. Increased land tenure security, more liberalized input and output markets, more optimal pricing of scarce water resources, and targeted subsidies may help, but still are insufficient when implemented as isolated measures. To achieve adoption of CA practices would need an increased information dissemination, awareness, and learning among farmers and policy makers about the benefits of CA. This demands the support of extension services for awareness creation among agricultural producers and improving links among farmers, markets and service organizations which however are not yet available.

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