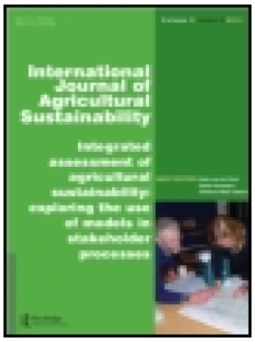

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# Feasibility of conservation agriculture in the Amu Darya River Lowlands, Central Asia

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**ABSTRACT**
Human-driven land degradation threatens economic and environmental sustainability of irrigated agricultural production such as in Central Asia. Many current challenges can be eased by implementing Conservation Agriculture (CA), with however unknown financial consequences under the predominating irrigated conditions. We applied the linear programming to compare costs and benefits of four CA production systems, which are cotton-based rotation systems including (i) cotton-cotton and (ii) cotton-wheat-maize rotations under conventional tillage (CT), as well as (iii) cotton-cover crop-cotton, and (iv) cotton-wheat-maize rotations with mulch cover (crop residue retaining) and both rotations under permanent-bed planting (PB) with minimum tillage. All systems were subjected to six levels of land quality and a series of crop pricing schemes. Data were extracted from empirical research on CA in Uzbekistan, complemented with data on input and output prices from surveys. The findings underpinned the financial advantages of more diversified cropping systems (cotton-wheat-maize) over the crop monoculture (cotton-cotton-based system). Crop cultivation on marginal land was unprofitable under CT. In contrast, crop production under PB could generate profits even on croplands with a lower productivity level considered. It is argued that PB with crop residue retaining and applied in cotton-wheat-maize rotation shows most promise for improving crop yields and income.

**KEYWORDS**
Land degradation; cotton; drylands; permanent-bed planting; crop diversification; price variation; Aral Sea Basin

## 1. Introduction

Irrigated drylands provide about 40% of the global food supply worldwide, yet they have a low natural resilience against anthropogenic pressure (FAO, 2011). Continuous, intensive soil tillage, mismanagement of irrigation water, and growing soil salinity are main drivers of the on-going land degradation in such schemes (Nkonya, Mirzabaev, & von Braun, 2016; Nurbekov et al., 2016). Particularly in Central Asia annual production loss due to land degradation amount to about US$ 2 billion (Mirzabaev et al., 2015) of which about US$ 1 billion is attributed to Uzbekistan (Aw-Hassan et al., 2016; Sutton et al., 2007). In Uzbekistan, which owns more than 50% of the irrigated lands in Central Asia, more than half of its irrigated croplands (i.e. about 885,000 ha) are affected by different degrees of soil salinity (MAWR, 2010). Due to reduced water quality in the lower reaches of the rivers, irrigated areas in downstream regions are more prone to soil salinity and land degradation.

Conservation Agriculture (CA) that comprise minimal tillage, crop residue retention and crop rotations, is reportedly a promising option, also in dryland regions, to tackle land degradation and increase crop yields (Nurbekov et al., 2016), although the financial implications are often less conclusive.

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Several studies pointed out additional economic benefits of CA compared with conventional land use practices (Fileccia, 2009; Knowler, 2003). In the case of drylands, Kassam et al. (2012) argued that financial benefits of CA could be observed but mainly under specific crop rotations. The practice of crop residue retention during the implementation of CA can improve crop yields and profits (Friedrich, Kassam, & Shaxson, 2009). According to Tanwar et al. (2014), a permanent-bed (PB) planting improves water productivity, leaches better salts, and increases crop yields compared with conventional tillage (CT) practices. Also, due to these ecological and economic benefits, the spread of CA keeps on growing and it is reportedly being practiced on more than 155 million ha of land across the world already (Kassam, Friedrich, Derpsch, & Kienzle, 2015).

CA system comprising PB with crop residue retention and diversified crop rotations has been assessed as a promising option in Central Asia because of its positive effects on soil quality and higher nutrient and energy use efficiencies (Jat et al., 2009; Naresh et al., 2014). In Kazakhstan, croplands under CA gradually extended from zero to about 2.1 million ha during the period between 2001 and 2013 (Nurbekov et al., 2016), which, however, is not matched yet in other four Central Asian countries (FAO, 2016). Increasing the presently low adoption rates of CA systems in Uzbekistan cannot be expected, unless flanked with the promotion of more diversified systems and alternative sustainable agricultural practices. The current agricultural policy imposes farmers to cotton and wheat cultivation as part of the state procurement policy. Under this approach, farmers are obliged selling their entire cotton harvest to state-run ginneries and half of their wheat output at state prices (Pomfret, 2008). The state in turn subsidizes agricultural inputs for their strategic crops cotton and wheat (Guadagni, Crole-Rees, & Khidirov, 2005), provides low interest rates for credits (Gilham et al., 1995), and ensures a score of supportive services such as machinery and maintenance of the irrigation infrastructure and drainage networks. These subsidies substantially lower the actual variable costs (e.g. fertilizer, fuel, labour, machinery) (Abdullaev, De Fraiture, Giordano, Yakubov, & Rasulov, 2009) and thus counterbalance in part the low farmgate prices for cotton and winter wheat. However, producing these crops on the marginalized lands often results in economic losses for farmers due to low yields under relative high production costs (Djanibekov, Khamzina, Djanibekov, & Lamers, 2012), while crop yields under different soil tillage practices were obtained for good quality lands (Devkota, 2011). Yet, conditional for farmers and the state alike seem the prospects of financial and environmental profitability of innovative crop rotations with reduced cotton share.

Previous research on CA in Central Asia focused on the cultivation of rice and wheat, and studies that considered cotton, even when cultivated on degraded lands, remained limited (Kienzler et al., 2012). Studies that considered the economic effects of CA under various crop rotations in the irrigated drylands of Central Asia are even less known. The linear programming model at farm-level was developed using the case of Uzbekistan to assess and compare the optimal cropland allocations and crop production benefits for both conventional and CA systems, and to determine the most economically efficient crop rotations and cultivation practices under different land fertility levels without conducting a score of field trials over many years. A series of scenarios were designed and analysed for a comparison of the yield and income effects of CA and CT practices under conventional and innovative cotton-based crop rotations. Given the current state crop procurement policy, crop price liberalization scenarios were considered. The necessary agro-physical data were collected from experimental results on CA systems (Devkota, 2011), while socio-economic data were collected through surveys (Djanibekov et al., 2012). The data combined permitted the economic feasibility analyses of CA systems and comparing various rotation systems on different cropland fertility classes.

## 2. Methods

### *2.1. Description of the study area*

The Khorezm region (60°40′44″ N and 41°32′12″ E, 100 m a.s.l.) in Uzbekistan is characterized by an arid climate, with hot and dry summers and cold winters. Precipitation is about 100 mm per annum, most of which falls outside the growing season (April–October). Evaporation is about 1200 mm per annum and thus crop production is possible with irrigation only. Irrigated agriculture accounts for about 35% of the regional GDP and occupies about 88% of the arable area in the region (State Statistical Committee of Uzbekistan, 2010). About 20–30% of the arable lands are classified as marginal with low productivity levels (MAWR, 2010). The low inherent soil fertility requires elevated levels of fertilizer applications to keep up crop production (Kienzler, Djanibekov, & Lamers, 2011).

Cotton and wheat are the major crops due to the imposed state crop procurement system while maize is a preferred crop by farmers for fodder and grain production (MAWR, 2010). The resulting cotton-wheat-third crop (often maize) rotation, therefore, is presently a most typical rotation applied on more than 70%–80% of the irrigated cropland in the region (Ibragimov et al., 2011). Cotton production is imposed by authorities to generate cash revenues for the state, while winter wheat is imposed for meeting domestic food demand (MacDonald, 2012). In addition to the cultivation area and production quantity, the purchasing prices (i.e. state procurement price [SPP]) for these two crops are set by state organizations (Abdullaev et al., 2009; Mori, Bhaduri, & Djanibekov, 2014), which usually are lower than the market prices (MPs; see, e.g. Figure 1 for information on SPP and MP of the crops analyzed over 2001–2009).

Production or crop yield targets for a farm are imposed by government authorities considering cropland quality (Rahmatullaev, Huneau, Coustumer, & Mikael, 2012). Land quality or soil fertility indexation and classification are based on bonitet scores (BSs), which are assessed by integrating various short- and long-term parameters such as weather, irrigation, soil cover, soil density, soil humidity and soil nitrogen absorption capacity, soil salinity, groundwater depth, and soil organic matter (Karmanov, 1980). State Land Cadastre conducts cropland quality assessments and BS measurements in each ten years. BS is considered within the range of 1–100, where 100 indicates the land with the highest quality and soil fertility, and with the potential of generating the highest crop yield (Rahmatullaev et al., 2012). When calculating potential crop yield from the cropland considering its BS, 0.04 tons of cotton yield or 0.06 tons of wheat yield is considered per 1 BS (Rahmatullaev et al., 2012). The BSs are grouped into 10 classes, each class including equal number of elements. For example, Bonitet Class I (BtC 1) considering the range of BSs from 1 to 10, Class II (BtC 2) considering BSs varying between 11 and 20, etc.

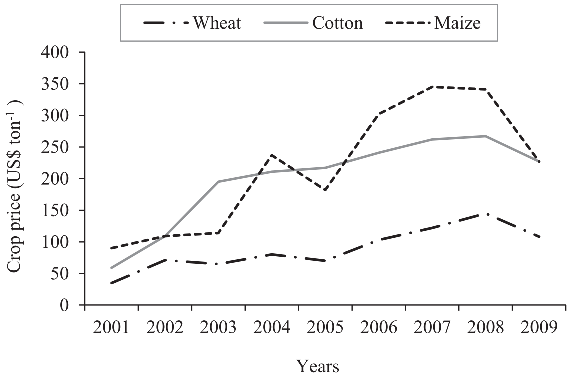


**Figure 1.** Dynamics of cotton, wheat, and maize prices over time. Source: MAWR (2010); State Statistical Committee of Uzbekistan (2010).

In Khorezm, cotton and wheat production areas with a BtC of 1, 8, 9, and 10 do not exist (Table A1) and hence are excluded from the analyses. Accordingly, it was assumed that the two strategic crops such as cotton and wheat are cultivated on soils covering six classes of lands only: from BtC 2 till BtC 7.

### 2.2. Data sources

The physical data sets on crop and biomass yields under different cultivation technologies needed for the cost–benefit analyses were taken from previously conducted field experiments to test CA in the Khorezm region (Devkota, 2011; Devkota, Martius, Lamers, Sayre, Devkota, Gupta, et al., 2013; Devkota, Martius, Lamers, Sayre, Devkota, & Vlek, 2013).

The financial analyses considered the characteristics of this region while farm/market surveys complemented the need for specific data (see http://www.zef.de/proposal_khorezm.0.html). The costs and benefits of the different crop production systems were assessed through surveys of 80 farms (see Tables A2 and A3) conducted in 2010 and 2011 (Djanibekov et al., 2012). This permitted the calculation of crop gross margins (GM = gross revenue−total variable costs). Data on the variability of crop yields and prices and land fertility classes were collected from various government land and water management organizations (MAWR, 2010; State Statistical Committee of Uzbekistan, 2010). Since data on crop yields under different soil tillage practices was only available for good quality lands (BtC = 7; Devkota, 2011), crop yields for other land classes, including those with lower productivity were estimated considering the yield in good quality land and crop yield equivalent of BS. the BS is allotted relative to the yield of cotton and wheat on good quality soils (e.g. cotton yield of 0.04 tons per 1 BS and wheat yield of 0.06 tons per 1 BS; Rahmatullaev et al., 2012), yields of other crops and their by-products for the land quality classes of

BtC 6, BtC 5, BtC 4, BtC 3 and BtC 2 were assumed being 90%, 80%, 70%, 60%, and 50% of the yields monitored for BtC 7 (100%), respectively (Table A4).

### *2.3. Crop rotation optimization model*

The four crop rotation systems ($i$) analysed also included four different crops, namely spring wheat ($j = 1$), maize ($j = 2$), cotton ($j = 3$), and winter-wheat ($j = 4$). Spring wheat was cultivated as a cover crop between two cotton harvesting seasons in the C–cc–C rotation (Devkota, Martius, Lamers, Sayre, Devkota, Gupta, et al., 2013). A monthly time step ($t = 1, 2 \ldots \bar{T}$) was introduced to account for cultivation and harvesting activities across the rotations for the entire rotation cycle of 2 years. The $\bar{T}$ time horizon of the model equalled 24 months. In the linear programming (LP) model, land can be allocated for typical crop rotation cycles (e.g. N1 and N2) and for a certain tillage type (e.g. PB or CT) in each month (Table 1).

It was assumed that $X_{b,i,t}$ is the total cropland area (in ha) in the region, which was allotted to a particular soil *bonitet* class ($b = BtC2, \ldots, BtC7$) devoted to a certain crop rotation $i$ in month $t$. Therefore, the following equational constraint was considered for the total area of land available for the various crop rotations over a 24-month screening period:

$$\sum_{i=1}^{2} X_{b,i,t} \leq \bar{X}_b - \Delta X_{b,t} \; (t = 1, 2, \ldots, T; \quad b = 1, 2, \ldots, \bar{B}), \tag{1}$$

where $\bar{X}_b$ is the total area of land classes $b$ available for the four crop rotations considered (Table 1). $\Delta X_{b,t}$ is the area of idle land with a *BtC* level of $b$ in month $t$. Idle cropland is considered as unproductive or abandoned cropland, and cultivation of crops on these lands was not included. The cropland area that belonged to a certain *BtC* and cropped with a particular crop $j$ in month $t$ ($L_{b,i,j,t}$) was assessed as:

$$L_{b,i,j,t} = a_{i,j,t} \, X_{b,i,t}, \tag{2}$$

where $a_{i,j,t}$ is a binary parameter that can take the value of 1 if crop $j$ is cultivated under rotation $i$ in month $t$ ($i = 1, 2; \; j = 1, 2, 3, 4; \; t = 1, 2, \ldots, 24$), but otherwise is considered 0.

Based on the value of $L_{b,i,j,t}$, other input requirements, production costs, yields, and benefits have been estimated. The input requirements of the two different tillage methods tested (PB or CT), crop and by-product productivity (yield), and input costs linked to the various management operations (crop rotations) determine the profitability, which may impact the potential that farmers adopt one of the practices. The crop residue management and mulching costs that depended on the tillage methods were calculated as:

$$\mathrm{DR}_{b,r,t} = \sum_{i=1}^{2} \sum_{j=1}^{4} \Gamma_{b,r,i,j} \lambda_{i,j,t} L_{b,i,j,t} \tag{3}$$

where $\mathrm{DR}_{b,r,t}$ is the demand for crop residues of type $r$ in lands with a BtC of $b$ in month $t$; $\Gamma_{b,r,i,j}$ is the crop residue of type $r$ required per hectare of land, with a BtC $\eta$ and allocated for cultivating crop $j$ under crop rotation type $i$ (crop residue is required only when CA systems are considered); $\lambda_{i,j,t}$ is a binary parameter taking the value of 1 if crop $j$ is produced under rotation $i$ in month $t$, and 0 otherwise.

Finally, the gross margin ($\mathrm{GM}_b$) was derived as the difference between all revenues and costs. The resulting GM served as an indicator to compare the financial feasibility of each tillage – "crop rotation" system. Total revenues were calculated as the sum of the revenues when assuming the sale of agricultural outputs including raw cotton to the ginneries, wheat grain to the state-owned mills, and maize grain ($\mathrm{RP}_{b,t}$) on the domestic markets as well as the crop by-products such as cotton stalks, wheat straw, and maize stalks ($\mathrm{RS}_{b,r,t}$) traded at the local markets. The total variable costs were estimated as the sum of fertilizer application costs ($\mathrm{FC}_{b,t}$), mulching costs, and other cultivation costs ($C_{b,t}^{\mathrm{CUL}}$). Thus, GM is formulated as:

$$\mathrm{GM}_b = \sum_{t=1}^{24} \left( \mathrm{RP}_{b,t} + \sum_{R=1}^{4} \mathrm{RS}_{b,r,t} - \mathrm{FC}_{b,t} - \sum_{r=1}^{4} \left(P_r^{\mathrm{RES}} \, \mathrm{DR}_{b,r,t}\right) - \; C_{b,t}^{\mathrm{CUL}} \right), \tag{4}$$

**Table 1.** Experimental design, treatments, and crop management.

| Soil tillage treatments | N1 systems | N2 systems |
|---|---|---|
| Conventional tillage | C–C | C–W–M |
| PB planting | C–cc–C | R + C–R + W–R + M |

Key: C, cotton; cc, cover crop; M, maize; W, wheat; +R, retained crop residue (or mulch), PB, permanent bed planting with crop residue (without tillage).

Source: Devkota, Martius, Lamers, Sayre, Devkota, Gupta, et al. (2013), Devkota, Martius, Lamers, Sayre, Devkota, and Vlek (2013) and Hasan, Higano, Yabar, Devkota, & Lamers (2015).

where $P_r^{\mathrm{RES}}$ is the price of crop residue of type $r$. The $\mathrm{DR}_{b,r,t}$ is the demand for crop residue of type $r$.

The calculation of the total fertilizer application ($\mathrm{FC}_{b,t}$) and cultivation ($C_{b,t}^{\mathrm{CUL}}$) costs were based on the main fertilizer use requirements (i.e. nitrogen, phosphorous, and potassium) per hectare of cropped land, fertilizer prices, and total cropped land area. Likewise, total cultivation costs were based on machinery-labour use costs per hectare and total area of cropped land.

Crop production revenue ($\mathrm{RP}_{b,t}$) was calculated by multiplying crop price ($P_j^{\mathrm{CRP}}$) with crop output, which was composed of the product of crop yield ($Y_{b,i,j,t}^{\mathrm{CRP}}$) and cropped areas ($L_{b,i,j,t}$):

$$\mathrm{RP}_{b,t} = \sum_{i=1}^{2}\sum_{j=1}^{4}\left(P_j^{\mathrm{CRP}}\, Y_{b,i,j,t}^{\mathrm{CRP}}\, L_{b,i,j,t}\right) \tag{5}$$

Similarly, crop residue production revenue ($\mathrm{RS}_{b,r,t}$) was found by multiplying crop residue price ($P_r^{\mathrm{RES}}$) with crop residue output, which in turn was determined by multiplying the crop residue yield ($Y_{b,r,i,j,t}^{\mathrm{RES}}$) to cropped areas ($L_{b,i,j,t}$):

$$\mathrm{RS}_{b,r,t} = \sum_{i=1}^{2}\sum_{j=1}^{4}\left(P_r^{\mathrm{RES}}\quad Y_{b,r,i,j,t}^{\mathrm{RES}}\, L_{b,i,j,t}\right) \tag{6}$$

### 2.4. Simulation of crop price changes: scenarios

Cost–benefit analyses were conducted for crop rotations under different crop output prices due to the presence of SPP for cotton, SPP and MP for wheat, and MP for maize. The sensitivity analyses with different crop prices allowed identifying those price levels that are the most promising and supportive to CA systems. In the model, the SPP and local MP were not differentiated for by-products and other input costs (Table A2). It was assumed furthermore that inputs and other expenses, except for the mulching costs, are the same for all six soil fertility classes unless additional soil melioration practices are considered since machinery and fuel costs that account for substantial share of total costs are almost the same in all soil productivity classes (similar assumption was used in Djanibekov et al. (2012)). Furthermore, it was assumed that the crop residues from the previous crop was entirely used as inputs (mulch) when considering crops such as wheat (6 t ha$^{-1}$) and maize (10 t ha$^{-1}$). For cotton, it was considered that only 30% of the total residue production (3 t ha$^{-1}$) was used for mulching (Table A5), and the rest was harvested for further use by rural households as a biofuel (Djanibekov et al., 2013).

For simulating the impact of changes in crop MPs, they were changed in the range of "zero" up to the potentially highest price for this crop as evidenced by observed levels of prices during the period of 2001 and 2009 in the Khorezm region (Table A3), and keeping all other parameters constant (Table 2).

The price effect for cotton and its impact on the economic relevance of a rotation type ($i$) for each soil *BtC* was analysed stepwise. First, the prices of wheat and maize were kept at the baseline levels (Table 2). Second, the threshold points of cotton prices that changed the values of the model's objective function (gross margin) and thus impacted the crop rotation pattern change across the soil bonitet types were estimated assuming only CA options. Third, a model similar to the former yet assuming CT practices was simulated by considering the varying threshold price levels received as an output of step 2. The respective GMs were determined from a crop production and crop rotation pattern changes across the soil BtCs. This is a more complex procedure than the usual way of changing prices at equal intervals when conducting a sensitivity analysis. However, it is conducive in showing clearer the differences of the impacts of CA and CT on the rotation types for each soil BtC. A similar reasoning and approach was used in the case of varying wheat prices, consequently keeping the cotton and maize prices unchanged. Finally, in the case of varying maize prices, we assumed fixed price rates for wheat and maize. The baseline prices used for raw cotton, winter wheat, and maize were 227, 108, and 227 US$ ton$^{-1}$, respectively (as of 2009).

**Table 2.** Price scenarios (in US$ ton$^{-1}$) for three crops used in the profitability and sensitivity analyses.

| Scenarios | Crop prices (US$ ton$^{-1}$) | | |
|---|---|---|---|
| | Cotton-Wheat-Maize | | |
| Baseline | 227 | 108 | 227 |
| Scenario 1 – varying cotton price (in the range of 0–422 US$ ton$^{-1}$) under fixed wheat and maize prices | Varying | 108 | 227 |
| Scenario 2 – varying wheat price (in the range of 0–227 US$ ton$^{-1}$) under fixed cotton and maize prices | 227 | Varying | 227 |
| Scenario 3 – varying maize price (in the range of 0–345 US$ ton$^{-1}$) under fixed cotton and wheat prices | 227 | 108 | Varying |

Source for prices: MAWR (2010).

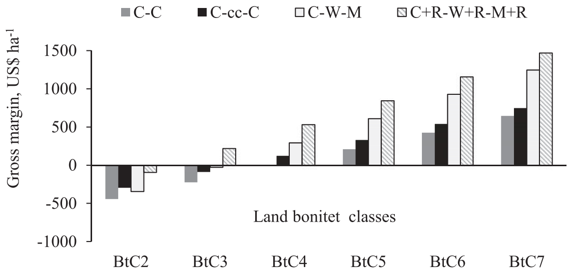


**Figure 2.** Profitability (gross margin in US$ ha$^{-1}$) of crops under permanent-bed planting and conventional soil tillage under crop prices (baseline scenario) for six land fertility classes (BtC 2–BtC 7). Key: C, cotton; cc, cover crop; M, maize; W, wheat; +R, retained crop residue (or mulch); BtC, soil quality (bonitet) classes (starting from BtC 2 (marginal) to … BtC 7 "good" classes). The crop prices used for cotton, wheat, and maize were 227, 108, and 227 US$ ton$^{-1}$, respectively.

## 3. Results

### 3.1. Costs and benefits of CA

The analyses of the GMs for cotton, wheat, and maize according to the four crop rotation systems examined under CT and CA systems as well as with and without crop residue retention showed the benefit of CA systems, especially with crop rotations that included wheat and maize (Figure 2). Reduced input and cultivation costs (mainly reduced costs for labour, machinery, and fuel) under CA systems outbalanced the mulching costs rendering such CA profitable on the six BtC classes examined. The difference between the C–cc–C and C–C system remained stable at any rate of crop yield, implying that the costs associated with the use of the cover crop (spring wheat) was not as high as the costs of mulching in the cotton-wheat-maize rotation (C + R–W + R–M + R). Under different crop output pricing schemes, all crop rotation systems considered are unlikely to be non-beneficial or less profitable on croplands with BtC 2 and BtC 3 levels. This underlines for such land areas the urge for implementing financially more efficient cropping systems.

The two diversified crop rotation systems exhibited much higher benefits than the cotton–cotton rotation (Figure 2). Practically, not only the cultivation of three crops (cotton-wheat-maize) rather than of two under a double cropping system, as, for instance, under the cotton-cotton system, may definitely bear higher incomes but also improved soil nutrient management due to a positive impact of a rotation and a diversified cropping system (Bullock, 1992; Conrad, Lamers, Ibragimov, Löw, & Martius, 2016; Wright, Marois, Wiatrak, & Katsvairo, 2005). The difference between the GMs under CA and CT practices was in favour of the latter in the cotton-wheat-maize system. These gains were also higher than the ones estimated following the introducing of CA options in the cotton-cotton system. Thus, the effect of cropping spring wheat as a cover crop and green manuring option between the two cycles of cotton cultivation was much lower than the effect of crop residue retention as a mulch under the cotton-wheat-maize system.

### 3.2. Ca under different crop output pricing scheme

As expected, changes in output prices of crops strongly affected the profitability of all rotation systems and hence are decisive in the choice of the tillage technology in general but in particular for those croplands with a low soil quality (Table 3). In the baseline scenario (Figure 2), the GM of the cotton-wheat-maize rotation was higher than that of the cotton-cotton rotation system under CT for the soil classes BtC 4–7, while no rotation system was found profitable for soil classes BtC 2–3. Similar results were found when additional CA systems (together with crop rotations) were taken into account, yet differing from the former case, where the GM of the cotton-wheat-maize rotation was also profitable for BtC 3. With reduced cotton prices (lower than the base price of 227 US$ ton $^{-1}$), the GM of the cotton-wheat-maize rotation became negative for most croplands with lower soil quality. Nevertheless, the abandonment rates of croplands would likely to become lower under CA compared with CT practices because of the reduced cultivation costs and higher economic returns. When assuming cotton prices higher than under the baseline scenario (Table 3), the cotton-cotton system became gradually beneficial on croplands with a growing soil quality due to the replacement of the diversified system (cotton-wheat-maize). When assuming a cotton price of 391 US$ ton$^{-1}$ under CT and 422 US$ ton$^{-1}$ under CA, the back-to-back cotton system became more beneficial than the cotton-wheat-maize rotation system for all six types of land quality classes. In contrast to changes in prices of raw cotton, the changes in wheat grain prices led to an inverse allocation of the crop rotation technologies tested (Table 4).

At wheat prices lower than those in the baseline scenario, the back-to-back cotton system could become advantageous over the diversified cropping system cotton-wheat-maize. Furthermore, with such decreasing wheat prices, the cotton-wheat-maize

**Table 3.** Expected changes in the allocation of optimal cropping systems on cropland with various fertility levels (*bonitet* classes) and soil tillage practices (Conservation Agriculture and conventional) triggered by varying cotton prices ($P^{COTTON} = 0$ to $P^{COTTON} = 422$ US$ ton$^{-1}$) but fixed wheat ($P^{WHEAT} = 108$ US$ ton$^{-1}$) and maize prices ($P^{MAIZE} = 227$ US$ ton$^{-1}$).

| Cotton price (US$ ton$^{-1}$) | Rotation types for soil *bonitet* classes under Conservation Agriculture | | | | | | Rotation type for soil *bonitet* classes under conventional tillage | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bt2 | Bt3 | Bt4 | Bt5 | Bt6 | Bt7 | Bt2 | Bt3 | Bt4 | Bt5 | Bt6 | Bt7 |
| 0 | ░ | ░ | ░ | ▒ | ▒ | ▒ | ░ | ░ | ░ | ░ | ▒ | ▒ |
| 34 | ░ | ░ | ▒ | ▒ | ▒ | ▒ | ░ | ░ | ░ | ▒ | ▒ | ▒ |
| 135 | ░ | ▒ | ▒ | ▒ | ▒ | ▒ | ░ | ░ | ▒ | ▒ | ▒ | ▒ |
| **227** | ░ | ▒ | ▒ | ▒ | ▒ | ▒ | ░ | ░ | ▒ | ▒ | ▒ | ▒ |
| 275 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ░ | ▒ | ▒ | ▒ | ▒ | ▒ |
| 333 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▓ | ▒ | ▒ | ▒ | ▒ | ▒ |
| 351 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▓ | ▓ | ▓ | ▒ | ▒ | ▒ |
| 374 | ▓ | ▓ | ▒ | ▒ | ▒ | ▒ | ▓ | ▓ | ▓ | ▓ | ▒ | ▒ |
| 391 | ▓ | ▓ | ▓ | ▒ | ▒ | ▒ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ |
| 404 | ▓ | ▓ | ▓ | ▓ | ▒ | ▒ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ |
| 414 | ▓ | ▓ | ▓ | ▓ | ▓ | ▒ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ |
| 422 | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ | ▓ |

Legend:

░ *crop production is not profitable on this (Bt) class of land;*

▒ *intensified cropping systems with wheat and maize, C-W-M or C*+R-W+R-M+R;

▓ *back-to-back cotton crop rotation, as assumed under C-C or C-cc-C*

system under CT gradually became unprofitable, not only for the land classes BtC 2–3 but also for BtC 4. Consequently, it would become more profitable to replace the C–C system by a cotton-cover crop-cotton system on croplands with soil quality levels of BtC 5–7. Similarly, under CA systems and while assuming lower wheat prices, the cotton-wheat-maize rotation gradually became nonbeneficial on soil types BtC 2–3. Hence, in the optimization output, the rotation was replaced by the back-to-back cotton rotation system. When assuming a wheat price lower than 36 US$ ton$^{-1}$, crop cultivation (C–cc–C and C + R–W + R–M + R) tested on the two lowest land quality classes (BtC 2–3) became unprofitable under PB. In contrast, under the same price scenarios, the cultivation of C–C and C–W–M cropping systems on more fertile land classes, for example, BtC 2–4, became nonbeneficial under CT. These findings overall point at higher financial gains under CA systems over CT. At the baseline price of wheat grain (108 US$ ton$^{-1}$), only cropping on land fertility level of BtC 2 would become

**Table 4.** Expected changes in the allocation of optimal cropping systems on cropland with various fertility levels (*bonitet* classes) and soil tillage practices (Conservation Agriculture and conventional) triggered by varying wheat prices ($P^{WHEAT} = 0$ to $P^{WHEAT} = 227$ US$ ton$^{-1}$), but fixed cotton ($P^{COTTON} = 227$ US$ ton$^{-1}$) and maize prices ($P^{MAIZE} = 227$ US$ ton$^{-1}$).

| Wheat price (US$ ton$^{-1}$) | Rotation type for soil *bonitet* classes under Conservation Agriculture | | | | | | Rotation type for soil *bonitet* classes under conventional tillage | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bt2 | Bt3 | Bt4 | Bt5 | Bt6 | Bt7 | Bt2 | Bt3 | Bt4 | Bt5 | Bt6 | Bt7 |
| 0 | ░ | ░ | ▓ | ▓ | ▓ | ▓ | ░ | ░ | ░ | ▓ | ▓ | ▓ |
| 23 | ░ | ░ | ▓ | ▓ | ▓ | ▒ | ░ | ░ | ░ | ▓ | ▓ | ▓ |
| 26 | ░ | ░ | ▓ | ▓ | ▒ | ▒ | ░ | ░ | ░ | ▓ | ▓ | ▒ |
| 30 | ░ | ░ | ▓ | ▒ | ▒ | ▒ | ░ | ░ | ░ | ▓ | ▓ | ▒ |
| 36 | ░ | ░ | ▒ | ▒ | ▒ | ▒ | ░ | ░ | ░ | ▓ | ▒ | ▒ |
| 64 | ░ | ▒ | ▒ | ▒ | ▒ | ▒ | ░ | ░ | ▒ | ▒ | ▒ | ▒ |
| **108** | ░ | ▒ | ▒ | ▒ | ▒ | ▒ | ░ | ░ | ▒ | ▒ | ▒ | ▒ |
| 145 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ░ | ▒ | ▒ | ▒ | ▒ | ▒ |
| 227 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ |

Legend:

░ *crop production is not profitable on this (Bt) class of land;*

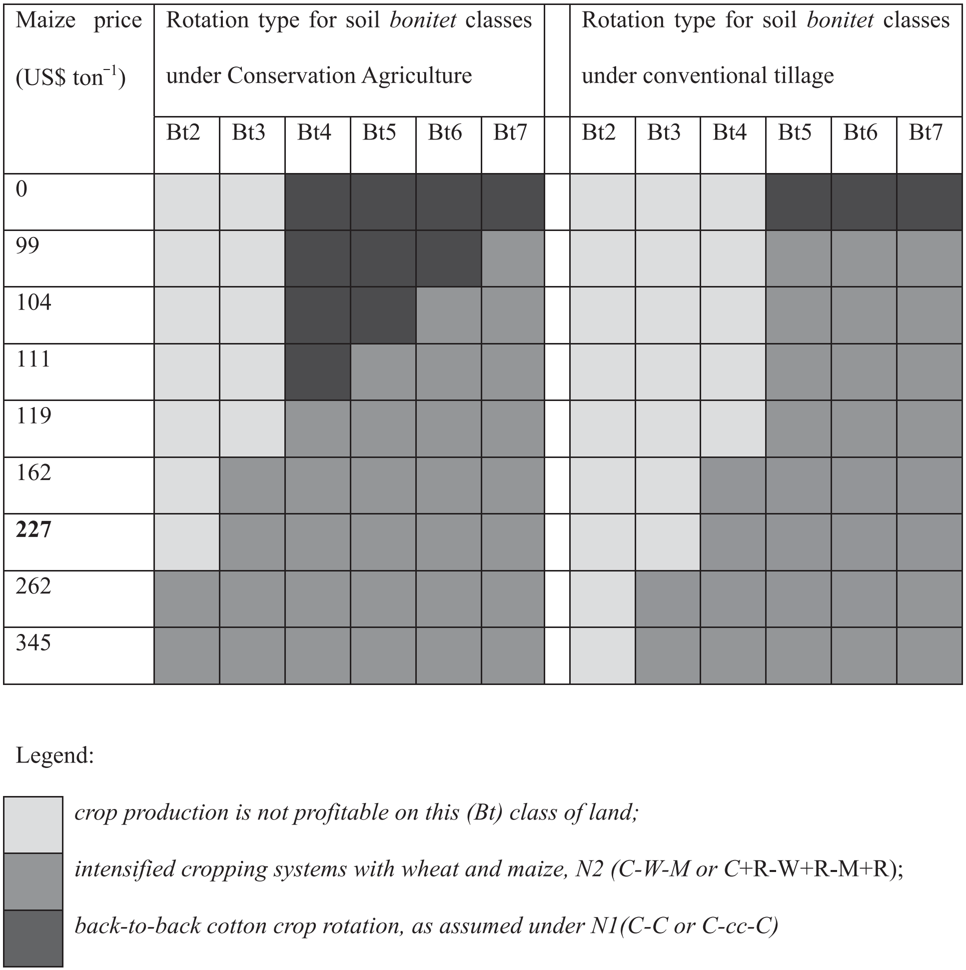
▒ *intensified cropping systems with wheat and maize, N2 (C-W-M or C*+R-W+R-M+R);

▓ *back-to-back cotton crop rotation, as assumed under N1(C-C or C-cc-C)*

unprofitable under PB, while profits from lands with BtC 2–3 would be not attractive under CT. When assuming wheat prices higher than in the baseline scenario, the cotton-wheat-maize system would become economically feasible on higher land fertility classes. When assuming, for example, wheat grain prices higher than 145 US$ ton$^{-1}$, the cotton-wheat-maize system became beneficial over all land classes under PB, while wheat prices had to reach 227 US$ ton$^{-1}$ to render the cotton-cotton system under CT beneficial for all land classes.

The simulation outcomes under the assumption of maize price changes became very similar to the results in the case of wheat price changes (Table 5). Prices for maize lower than in the baseline scenario (less than 162 US $ ton$^{-1}$) reduced the profitability of the cotton-wheat-maize system. Consequently, this would render croplands with BtC 2–4 in general unprofitable under CT and are likely to be abandoned. In contrast, under CA systems, only croplands of BtC 2–3 became unprofitable. For all other land fertility classes (BtC 4–7), a back-to-back cotton system became more advantageous over the cotton-wheat-maize system. When assuming maize grain prices to increase, the C + R–W + R–M + R production became more profitable than the C–cc–C system even on the BtC 2–3 lands. From maize prices of 262 US$ ton$^{-1}$ onward, the cotton-wheat-maize system would become financial feasible on all six land classes tested when CA systems were implemented. However, at a maize price of 262 US$ ton$^{-1}$ and under CT, even the financial feasibility of C–W–M system on BtC 2 was not given.

**Table 5.** Expected changes in the allocation of optimal cropping systems on cropland with various fertility levels (*bonitet* classes) and soil tillage practices (Conservation Agriculture and conventional) triggered by varying maize prices ($P^{MAIZE} = 0$ to $P^{MAIZE} = 227$ US\$ ton$^{-1}$), but fixed cotton ($P^{COTTON} = 227$ US\$ ton$^{-1}$) and wheat prices ($P^{WHEAT} = 108$ US\$ ton$^{-1}$).



| Maize price (US\$ ton$^{-1}$) | Rotation type for soil *bonitet* classes under Conservation Agriculture | | | | | | Rotation type for soil *bonitet* classes under conventional tillage | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bt2 | Bt3 | Bt4 | Bt5 | Bt6 | Bt7 | Bt2 | Bt3 | Bt4 | Bt5 | Bt6 | Bt7 |
| 0 | ░ | ░ | ▓ | ▓ | ▓ | ▓ | ░ | ░ | ░ | ▓ | ▓ | ▓ |
| 99 | ░ | ░ | ▓ | ▓ | ▓ | ▒ | ░ | ░ | ░ | ▒ | ▒ | ▒ |
| 104 | ░ | ░ | ▓ | ▓ | ▒ | ▒ | ░ | ░ | ░ | ▒ | ▒ | ▒ |
| 111 | ░ | ░ | ▓ | ▒ | ▒ | ▒ | ░ | ░ | ░ | ▒ | ▒ | ▒ |
| 119 | ░ | ░ | ▒ | ▒ | ▒ | ▒ | ░ | ░ | ░ | ▒ | ▒ | ▒ |
| 162 | ░ | ▒ | ▒ | ▒ | ▒ | ▒ | ░ | ░ | ▒ | ▒ | ▒ | ▒ |
| **227** | ░ | ▒ | ▒ | ▒ | ▒ | ▒ | ░ | ░ | ▒ | ▒ | ▒ | ▒ |
| 262 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ░ | ▒ | ▒ | ▒ | ▒ | ▒ |
| 345 | ▒ | ▒ | ▒ | ▒ | ▒ | ▒ | ░ | ▒ | ▒ | ▒ | ▒ | ▒ |

Legend:

░ *crop production is not profitable on this (Bt) class of land;*

▒ *intensified cropping systems with wheat and maize, N2 (C-W-M or C*+R-W+R-M+R);

▓ *back-to-back cotton crop rotation, as assumed under N1(C-C or C-cc-C)*

## 4. Discussion

### *4.1. Economic feasibility of CA*

From the larger number of factors reportedly mentioned as drivers of CA adoption, the most prominent are the costs and benefits (D'Emden, Llewellyn, & Burton, 2006; Knowler, Bradshaw, & Gordon, 2011; Pannell, Llewellyn, & Corbeels, 2014). The highest adoption rates therefore can be expected in the first place in situations that potentially generate sufficient benefits to outweigh all costs. The current analysis indicated that overall higher benefits of CA could be expected compared with CT practices under the irrigated systems prevailing in the lower reaches of the Amu Darya River Basin. As reported previously (Devkota, Lamers, et al., 2015; Hari-Ram, Saini, Kler, & Timsina, 2013) also improvement in energy efficiency, as well as saving opportunities of machinery and production costs substantially improved the economic attractiveness of the CA systems. Positive environmental effects of CA systems also pointed out previously and included, for example, that CA systems can counterbalance soil salinity (Devkota, 2011; Devkota, Martius, et al., 2015; Egamberdiev, 2007).

The LP models are a widely used methods in studies analysing the planning of an optimal use of resource allocation by farmers (Evans et al., 2003; Wang & Zhou, 2004), which also have been successfully employed in the study region (Bobojonov, Martius, & Lamers, 2010; Djanibekov, Djanibekov, Sommer, & Petrick, 2015). Yet, the financial analysis of CA systems on cotton-based production systems, especially with the use of LP optimization models, is limited. Indeed, several modelling approaches have been used to assess the economic and ecological potential of CA systems yet without considering the varying effects across different levels of soil quality (Erenstein, 2011). The LP model developed considers the economic effects of CA systems to cope with soil quality reduction or enhance the yields in low productive (marginal) lands in Central Asia. The modelling scenarios are designed for comparing not only the income and yield effects of CA and CT practices but also those of different cotton-based crop rotations. The findings showed that the LP model elaborated is an appropriate tool for this type of studies aiming for assessing the economic feasibility of PB with crop residue retention practices under different soil quality levels of Central Asia. The LP approach is considered more effective than other approaches given a lower number of iterations (Amaranth & Bhatt, 2014; Sofi, Ahmed, Ahmad, & Bhat, 2015; Wankhade & Lunge, 2012).

Generally, most of the experimental findings worldwide and across production systems demonstrated both short-term (e.g. lower production costs, decreased wind- and draining-induced soil erosion, increased soil moisture) and long-term benefits of CA systems (e.g. improved soil quality, organic matters, and soil structure) despite the varying magnitude of these benefits, which could, however, be attributed to site-specific conditions (Erenstein, 2002; Giller et al., 2011; Kienzler et al., 2012). It recurrently had been reported that CA systems often result in higher weed rates, in turn demanding higher herbicide costs, which consequently may reduce financial feasibility of CA and in particular in areas prone to weed growth. Especially in dry years, a lower production of fodder crops may increase the demand for crop residues, consequently decreasing the benefits of CA. Studies reported on the unsuitability of CA systems on cotton-based production systems (Devkota, 2011; Tursunov, 2009) although the lower crop yields and benefits monitored had been attributed to inappropriate land preparations, less efficient seeders, or unawareness of farmers on crop residue management.

### 4.2. Crop rotation

The current findings pointed out at the increase in financial gains from diversified crop rotation systems such as a cotton-wheat-maize rotation over a back-to-back cotton rotation system, at least under a wide range of crop prices and combinations thereof. In general, the cultivation of three crops such as in the cotton-wheat-maize system rather than two crops such as under the double cropping system improved GMs. Previous studies in the region reported lower GMs when cultivating cotton compared to the GMs of wheat and maize production as well (e.g. Djanibekov et al., 2012; Rudenko, 2008; Sommer, Djanibekov, & Salaev, 2010). This obviously reduces the overall profitability of the current predominant back-to-back cotton cropping systems and certainly compared with the more diversified crop rotation systems. Although it was beyond the scope of this study to examine the reasons for such responses, it has been recurrently reported that crop diversification reduces nutrient losses, prevents soil erosion, improves resource use efficiency, and increases the sustainability of crop production system (Bobojonov et al., 2013; Conrad et al., 2016; Tilman, Lehman, & Thomson, 1997), which may become mirrored in the increase in GMs. Hence, more diversified cropping systems are also likely to increase the financial stability under the irrigated cropping practices in Central Asia, where in turn reduces the risk of crop failures and income losses (Bobojonov et al., 2013). Given the historically loaded political and economic importance of cotton production for Uzbekistan, and despite the declarations for reforms following independence in 1991, irrigated cotton production still is heavily promoted by the national administration in Uzbekistan, and this is likely to remain so in the near and middle future. Yet, a score of evidence underlines that in the long run, this crop-discrimination approach may not be the most recommendable pathway to follow due to the low profit generation and the negative environmental consequences of the current production practices (Lerman, 2009). Given the high subsidy levels and differential crop support that disincentives farmers in Uzbekistan to increase the efficiencies of natural resources use, implement crop diversification, and feasible crop rotations, it has been postulated to abandon the differential crop support or to give equal importance to all crops and sectors (Bekchanov, Müller, & Lamers, 2012).

### 4.3. Benefits of cover crop and mulch

Mulching is recognized as a viable principle for smallholder conservation farming worldwide due to its numerous benefits, albeit depending on biophysical, technological, and institutional factors (Erenstein, 2003). Mulching minimized soil erosion, improved soil quality, including soil organic matter, soil nitrogen content, and soil moisture retention capacity (Erenstein, 2011). Under the current input and output prices, CA with mulching were more beneficial than the CT system. However, in Uzbekistan, rural households frequently use crop residues for feeding livestock, as construction material, or for satisfying domestic energy demands for cooking and heating. The "fixed" demand for crop residues from these nonagricultural activities renders it less available for mulching, which is likely to be mirrored in a raise in prices, and in turn may render mulching less profitable (Kienzler et al., 2012). Hence, the use of cover crops or the expansion of fodder productionthrough the cultivation of alternative crops, or the inclusion of halophytes in the crop rotations, may improve economic gains for farmers and reduce the demand for crop residues and thus prevent price shocks in the local crop residue markets.

The current findings are based on the assumption that all crop residues would be used even though presently farmers do not retain crop residues as a mulch. However, previous studies (e.g. Devkota, 2011; Kienzler et al., 2012) hinted that only a partial retention of crop residues for mulching is needed based on the interpretation of empirical data from field trials where a restricted number of crop residue amounts with relatively high incremental steps had been examined (Devkota, 2011). Since the current findings indicated that the amount of crop residues utilized as a mulch during wheat and/or maize cultivation followed a sigmoidal trend, the application of residues for crop production have consequently marginal diminishing returns. This shows that optimal level of crop residue use can be determined by field trials or by improving the current LP model with crop production functions that considers the crop residue effect on crop yields with marginal returns. The current results indicated also that higher economic gains could be expected following a crop residue retention compared with the use of spring wheat as cover crop. When considering spring wheat as a cover crop and the consequent lower economic gains, the use of other potential cover crops such as mungbean or clover rather than spring wheat might lead to better economic outcomes.

### 4.4. CA to address land degradation

The findings indicated that an implementation of CA systems rather than CT could become financially relevant particularly on land with a low inherent productivity (e.g. BtC 3) and when assuming low crop prices. The promotion of CA systems could help counterbalancing the on-going abandonment of croplands with lower soil quality and certainly when crop prices reduce further. When assuming the well-known physical benefits of the CA systems tested, such as an increased soil moisture retention capacity because of mulching and reduced evaporation losses from the soil surface, the decrease in water and energy demands under CA systems lower cultivation costs due to lower fuel and machinery use. Accordingly, the resulting financial gains under CA systems can cushion better situations with reduced prices. However, the findings showed as well that even though CA systems may become instrumental in reducing land abandonment, they are unlikely to counterbalance the economic losses on marginalized lands (BtC 2–BtC 3) at low crop prices. It is therefore no surprise that Herrero et al. (2010) argued that a diverse, multiple-crop-livestock pasture (mixed crop-livestock) system are more effective than crop rotation with CA system without livestock (Franzluebbers, Sawchik, & Taboada, 2014). Afforestation and agroforestry-based practices are additional means to counterbalance the abandoning of marginal lands (Djanibekov et al., 2012). These practices do not only re-vegetate saline landscapes but have concurrently positive impacts such as reducing soil erosion, maintaining/increasing soil fertility, water use efficiency, biodiversity, and carbon sequestration (Khamzina, Lamers, & Vlek, 2012). Moreover, such practices offer benefits to smallholder farm households by providing environmentally friendly fertilizers, fruits for consumption, livestock fodder, timber, and fuelwood (Khamzina et al., 2012; Shahid, Rehman, & Afzal, 2002). The domestication of wild halophytes was previously suggested to improve the fodder base and support reaching food security owing to a huge biomass production on degraded lands (field margins, degraded desert rangelands; solonchaks) that in turn could serve a as potential source for bioenergy production (Akinshina, Azizov, Karasyova, & Klose, 2016; Khujanazarov, Toderich, & Tanaka, 2014; Shahid, Shabbir, Mahmoud, & Faisal, 2013). Toderich et al. (2015) argued that even the rehabilitation of abandoned and salt-affected soils are feasible through crop-based interventions. The introduction of the halophyte "licorice" (*Glycyrrhiza glabra* L.) as a bioremediation strategy demonstrated, for example, the potential of this crop to increase the productivity of abandoned saline fields during the reclamation of salt-affected lands and subsequent restoration of irrigated cropland (Hasanuzzaman et al., 2014; Heshmati, 2013; Kushiev, Noble, Abdullaev, & Toshbekov, 2005; Qadir, Noble, Karajeh, & Biju, 2015).

### *4.5. Opportunities and barriers for up-scaling CA*

Although both experimental and modelling studies showed considerable economic and ecological benefits of CA systems in the dryland irrigated areas of Central Asia, there can be a series of technical and institutional factors hindering a nationwide uptake of the analysed CA. First of all, this concerns the control of crop production and tillage use and lack of incentives for cotton and wheat producing farmers to introduce innovations (Kienzler et al., 2012). Low procurement prices for cotton and wheat resulting in low farm incomes may prevent the purchase of agriculture machinery, tools, and laser-guided land levelers considered favourable for promoting CA systems in the irrigated conditions of the study region (Egamberdiev, Tischbein, Franz, Lamers, & Martius, 2008). Therefore, the establishment of farmer units and agricultural business units to purchase commonly (Djanibekov et al., 2015) and share machinery among multiple users may reduce the technical costs of introducing CA per farmer. Furthermore, it is frequently has been argued that rather than strongly regulating cultivation activities during the production process (micro-management from a distance), more freedom in the selection of production technologies (for instance, choosing type of drilling, crop residue retention, and mulching) would be an enabling environment for technological change (Erenstein, 2011; Nurbekov et al., 2016). Additional technical skills required to use the CA equipment (e.g. seeder, herbicide sprayer, and laser-guided land-levelers) calls for stronger farmer trainings or establishing related extension services in the region. Given the unawareness of benefits and ways of adopting CA among farmers in the region, a wider promotion of knowledge on CA technologies through may improve the adoption rates of this system (Kienzler et al., 2012).

### *4.6. Model shortcomings and options for further improvements*

The economic benefits of CA systems were assessed for croplands with varying soil quality. Thus, the LP model developed could address input use and output relationships for crop residue management and crop production systems while considering financial aspects only. Further improvement of the model to account for carbon emissions, water use reduction, and long-term effects of CA systems on soil carbon sequestration, water use, and change in soil fertility could render the current modelling results even more comprehensive. Including also the effects of nutrient, water, and salt balances and their impact on crop yields, the model can support policy recommendations on efficient water, fertilizer, and crop residue management. Given that such effects used to expose over time, making the model dynamic would allow for assessing the long-term economic and ecological effects of CA systems. Also, the close linkages between crop and livestock systems in the region requires an integrated crop and livestock production CA system model that would be useful to find out accurate results on optimal use of crop residues.

## 5. Conclusions

The profitability of CA was assessed in comparison with CT under different land fertility classes and series of crop prices. The findings underlined the potential to increase financial benefits of farmers (i) when integrating wheat and maize crops into the current, cotton-dominated rotation systems and/or (ii) implementing CA systems in cropping systems. Crop production under CT is unproductive on degraded lands at least under the current low price levels and input–output relationships. However, CA systems are likely to generate benefits on higher land fertility classes except for the land class with the lowest potential (i.e. BtC 2). The findings furthermore showed that intensified cropping systems is likely to yield higher GMs. Only when assuming prices for raw cotton higher than 333 US$ ton$^{-1}$ or at low prices of wheat (lower than 36 US$ ton$^{-1}$) or maize (lower than 111 US$ ton$^{-1}$), the currently promoted cotton-cotton system would become profitable in croplands with good soil quality. In contrast, the use of CA requires a minimum level of residue amounts or cover crops, which might lead to substantial costs due to the high demand of crop residues from the livestock sector, particularly for maize stalks. Under the crop price levels observed in the baseline scenario, croplands with the lowest soil quality (BtC 2–3) cannot be recommended for cultivation with CT or

CA systems. Especially when facing lower crop prices, crop cultivation becomes unprofitable on land with the lowest soil quality, yet the implementation of CA systems may increase the gains on croplands with lower soil quality and thus reduce the likelihood of abandoning them. Given the static nature of the LP model applied, a further development could consider the dynamics for diversified crop cycles with more crop options to evaluate the long-term impact of tillage and rotation interactions under different farm resources endowments related to water and soil nutrient balances.

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## Disclosure statement

No potential conflict of interest was reported by the authors.

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# Appendix

**Table A1.** Land availability under each *bonitet (soil fertility rate)* class.

| | | | Crop area, ha | | |
|---|---|---|---|---|---|
| Bonitet class (BtC) | Bonitet score (BS) | Soil fertility characterization | Cotton | Wheat | Total |
| 0 | 0–10 | Unsuitable for crops | 0 | 0 | 0 |
| BtC 1 | 11–20 | Very low | 0 | 0 | 0 |
| BtC 2 | 21–30 | Low | 652 | 178 | 830 |
| BtC 3 | 31–40 | Poor | 4500 | 919 | 5419 |
| BtC 4 | 41–50 | Lower than average | 20601 | 4276 | 24877 |
| BtC 5 | 51–60 | Average | 49754 | 14728 | 64482 |
| BtC 6 | 61–70 | Higher than average | 22312 | 8969 | 31281 |
| BtC 7 | 71–80 | Good | 2848 | 2208 | 5056 |
| BtC 8 | 81–90 | Very good | 0 | 0 | 0 |
| BtC 9 | 91–100 | Highest | 0 | 0 | 0 |
| | Total | | 100667 | 31278 | 131945 |

Source: State Statistical Committee of Uzbekistan (2010).

**Table A2.** Crop output and input prices used to calculate total variable costs and revenues of crop production, 2009.

| Item | Cotton | Wheat | Maize |
|---|---|---|---|
| ***Output prices*** | | | |
| State procurement price for crop (US$ ton$^{-1}$) | 227 | 108 | 227 |
| Market price of crops (US$ ton$^{-1}$) | 333 | 227 | 227 |
| *By-product* | | | |
| Crop residues (US$ ton$^{-1}$) | 36 | 33 | 30 |
| ***Input prices*** | | | |
| Ammonium nitrate (US$ ton$^{-1}$) | 152 | 152 | 152 |
| Ammonium phosphate (US$ ton$^{-1}$) | 307 | 307 | 307 |
| Potassium chloride (US$ ton$^{-1}$) | 553 | 553 | 553 |
| Seed (US$ ton$^{-1}$) | 735 | 251 | 227 |
| Labor (US$ person-day$^{-1}$) | 3.308 | 3.308 | 3.308 |
| Diesel (US$ ton$^{-1}$) | 716 | 716 | 716 |
| Electricity (US$ kWh$^{-1}$) | 0.046 | 0.046 | 0.046 |

Source: Devkota, Lamers, et al. (2015a), Djanibekov et al. (2012), Sommer, et al. 2010).

**Table A3.** Crop prices over the period of 2001–2009, US$ ton$^{-1}$.

| | Wheat | Cotton | Maize |
|---|---|---|---|
| Years | State procurement price | State procurement price | Market price |
| 2001 | 35 | 59 | 90 |
| 2002 | 71 | 109 | 109 |
| 2003 | 65 | 195 | 114 |
| 2004 | 80 | 211 | 237 |
| 2005 | 70 | 217 | 182 |
| 2006 | 103 | 241 | 302 |
| 2007 | 122 | 262 | 345 |
| 2008 | 145 | 267 | 341 |
| 2009 | 108 | 227 | 227 |

Source: MAWR (2010); State Statistical Committee of Uzbekistan (2010).

**Table A4.** Potential yield in different levels of land fertility.

| Ranking | BtC 2 | BtC 3 | BtC 4 | BtC 5 | BtC 6 | BtC 7 |
|---|---|---|---|---|---|---|
| Crop yield (ton ha$^{-1}$) | | | | | | |
| M | 1.96 | 2.35 | 2.74 | 3.13 | 3.52 | 3.91 |
| M + R | 2.76 | 3.31 | 3.86 | 4.42 | 4.97 | 5.52 |
| C | 1.94 | 2.33 | 2.71 | 3.10 | 3.49 | 3.88 |
| C + R | 1.96 | 2.36 | 2.75 | 3.14 | 3.54 | 3.93 |
| C–cc | 1.90 | 2.27 | 2.65 | 3.03 | 3.41 | 3.79 |
| W | 3.67 | 4.41 | 5.14 | 5.88 | 6.61 | 7.35 |
| W + R | 4.13 | 4.96 | 5.79 | 6.62 | 7.44 | 8.27 |
| Crop residue (by-product, ton ha$^{-1}$) | | | | | | |
| cc | 1.00 | 1.19 | 1.39 | 1.58 | 1.78 | 1.98 |
| M | 2.10 | 2.52 | 2.94 | 3.36 | 3.78 | 4.20 |
| M + R | 3.08 | 3.70 | 4.31 | 4.93 | 5.54 | 6.16 |
| C | 2.85 | 3.42 | 3.99 | 4.56 | 5.13 | 5.70 |
| C + R | 3.00 | 3.60 | 4.20 | 4.80 | 5.41 | 6.00 |
| C–cc | 3.00 | 3.60 | 4.21 | 4.81 | 5.41 | 6.01 |
| W | 4.36 | 5.24 | 6.11 | 6.98 | 7.85 | 8.73 |
| W + R | 5.00 | 6.01 | 7.01 | 8.01 | 9.01 | 10.01 |

Key: M, maize in CT; M + R, maize with crop residue in PB; C, cotton in CT; C–cc, cotton with cover crop in PB; W, wheat in CT; W + R, wheat with crop residue in PB.

Notes: Crop and by-product yields observed in experimental studies were assumed for the soil type with good quality (BtC 7). For calculating the yields for other soil classes with lower fertility, baseline yields for the soil class with BtC 7 were reduced by 10% sequentially for each lower fertility class. These assumptions were made considering relationship between BS equivalence to crop yield as shown in Rahmatullaev et al. (2012; cotton yield of 0.04 tons and wheat yield of 0.06 tons is considered per 1 BS in estimating potential crop yields from lands with various quality).

**Table A5.** Main input and output parameters for producing different crops.

| Treatments | Units | Cover crop | Maize | Maize with crop residue | Cotton | Cotton with cover crop | Wheat | Wheat with crop residue |
|---|---|---|---|---|---|---|---|---|
| Crop yield | ton ha$^{-1}$ | 0 | 3.91 | 5.52 | 3.88 | 3.79 | 7.35 | 8.27 |
| Revenue | US\$ ha$^{-1}$ | 0 | 887.6 | 1253 | 880.1 | 860.3 | 793.2 | 893.1 |
| By-product yield | ton ha$^{-1}$ | 2 | 4.2 | 6.16 | 5.7 | 6.01 | 8.73 | 10 |
| Revenue from by-products | US\$ ha$^{-1}$ | 66 | 126 | 185 | 205 | 216 | 288 | 330 |
| Fertilizer uses | ton ha$^{-1}$ | 0 | 0.43 | 0.43 | 0.44 | 0.44 | 0.43 | 0.43 |
| Total fertilizer costs | US\$ ha$^{-1}$ | 0 | 118.2 | 118.2 | 128.7 | 128.7 | 118.2 | 118.2 |
| Demand for mulching | ton ha$^{-1}$ | 0 | 0 | 10 | 0 | 2 | 0 | 6 |
| Mulching costs | US\$ ha$^{-1}$ | 0 | 0 | 330 | 0 | 66 | 0 | 216 |
| Production costs except mulching, fertilizer use and fixed costs | US\$ ha$^{-1}$ | 55 | 438 | 359 | 635 | 514 | 497 | 418 |
| Gross revenue | US\$ ha$^{-1}$ | 66 | 1014 | 1438 | 1085 | 1077 | 1081 | 1223 |
| Total variable costs | US\$ ha$^{-1}$ | 55 | 556.2 | 807.2 | 763.7 | 708.1 | 615.3 | 752.2 |
| Gross margin | US\$ ha$^{-1}$ | 11 | 457 | 631 | 322 | 369 | 466 | 471 |
| Rate of return | US\$ US\$$^{-1}$ | 0.19 | 0.82 | 0.78 | 0.42 | 0.52 | 0.75 | 0.62 |

Source: Hasan et al. (2015).