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Conservation Agriculture Practices in Salt-Affected, Irrigated Areas of Central Asia: Crop Price and Input Cost Variability Effect on Revenue Risks

Boboev Hasan[1], Yoshiro Higano[1], Helmut Yabar[1], Mina Devkota[2,3] & John P. A. Lamers[2]

[1] Graduate School of Life and Environmental Science, Sustainable Environmental Studies, University of Tsukuba, Tsukuba, Japan

[2] Center for Development Research (ZEF) Walter Flex-Str. 3, 53113 Bonn, Germany

[3] International Maize and Wheat Improvement Center (CIMMYT), Kathmandu, Nepal

Correspondence: Boboev Hasan, Graduate School of Life and Environmental Science, Sustainable Environmental Studies, Tsukuba University, 1-1-1 Tennodai, Tsukuba, Ibaraki, Japan. Tel: 81-090-6042-8307. E-mail: hasanb83@yahoo.coma

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Abstract

The threats to sustainable agriculture caused by severe land degradation, high soil salinity, and increased production costs on salt-affected, irrigated croplands of Uzbekistan, Central Asia, are both challenging and urgent. The present wide-spread cultivation practices of wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.), but in particular cotton (*Gossypium hirsutum* L.), which was the predominant crop during the Soviet Union period (1924-1991) need to be altered by considering improved, technically feasible and economically viable practices. Therefore, the economic performance of three innovative crop rotation systems have been assessed and compared to Conventional Tillage (CT) practices. The cropping systems were all exposed to Bed Planting (BP) with a crop residue cover and included cotton-cover crop-cotton, cotton-wheat, and cotton-wheat-maize. Risk assessment was based on commodity prices and included State Procurement Price (SPP) and free Market Price (MP), but also variable production and input costs. A linear mathematic optimization model was employed to generate various simulations. Financial benefits (expressed in US dollars) were based on 2009 input costs and product prices. The findings revealed that Conservation Agriculture (CA)-based practices applied to the cropping systems could substantially increase economic returns especially in the early stages of adaption, provided they are flanked with appropriate agricultural practices and careful farm managements.

Keywords: conservation agriculture, bed planting, crop intensification, rotation, price fluctuation, revenue risk, Aral Sea

1. Introduction

Global agriculture can not yet match the challenges of the coming decades to feed a world population that is expected to grow by over a third, or 2.3 billion people, between 2009 and 2050 (FAO, 2009). Over a third of the global agricultural ice-free land area is used already for high-intensive, continuous cropping systems that use high levels of agrochemicals and intensive tillage and while reshaping land and waterways (CGIAR, 2003). Despite past successes, the current practices are known to hamper concurrently the sustainability of agriculture as evidenced by irreversible environmental damage. Many industrial agriculture costs have been hidden and ignored in short-term calculations of profit and productivity leading to an ill-understanding of the causes and cause-effect relations, which is exemplified by the case irrigated crop production in the Aral Sea Basin in Central Asia.

The Republic of Uzbekistan, Central Asia, depends on irrigated agriculture. It is an agrarian country where 21% of the active population is involved in the agricultural sector, which accounts in 2009-2011 years for 19% of GDP (FAOSTAT, 2012). Uzbekistan is the world's sixth largest producer and third largest exporter of cotton, accounting for ca. five percent of the global production of cotton fiber (ICAC, 2011). Historically, cotton has been the dominant crop cultivated with heavy machinery, much chemicals and with intensive tillage operations, but typified by an inefficient use of irrigation water resources (Devkota, 2011b; Abdullaev; 2009; Tursunov

2009). Consequently, up to half of the 4.3 million hectares (Mha) of Uzbekistan's irrigated land suffers from varying degrees of soil degradation (Spoor, 1999; Dubovyk, 2013). Land degradation has in turn been a key factor that triggered soil fertility loss and crop yield fall, which accumulated into an annual loss of ca. 1 billion USD in 2007 (Sutton et al., 2007).

Conservation Agriculture (CA) encompasses three major principles, cultivation with reduced or zero tillage, establishment of a permanent soil cover for instance through crop residue (mulch) or cover crops, and a judicious crop rotation, aimed at increasing production while preserving environment and natural resources. The global spread of CA practices has amounted to 155 Mha evidencing its attractiveness to many farmers worldwide (Kassam, 2014). Previous studies in irrigated areas identified raised bed planting (BP) as a superior CA practice, certainly when compared to conventional tillage (CT) mainly because of its higher energy efficiency (Sayre & Hobbs, 2004; Hassan et al., 2005), and lower production costs (Hari-Ram et al., 2013; Devkota, 2011a; Tursunov, 2009). Recurrently it has been shown that a most appealing part of CA practices for adoption is its short-term economic profitability due to a reduction in variable costs, increased energy efficiency, and decrease in farming activities and of machinery operations overheads. The environmental long-term benefits, namely improved soil quality, carbon sequestration, greater biodiversity for a better ecosystem, usually come at a later stage (FAO, 2014). Yet, despite the present advantages of CA practices in the irrigated areas of Central Asia, additional efforts are required to adapt them to the specificities of the different agro-ecological localizations in the region. Refinements and site-specific adjustments to identify optimal combinations of agronomic performance and therefore needed which demands comprehensive studies and systematical evaluations of potential strategic management decisions (Kienzler et al., 2012). Although the rising energy and input costs as well as the on-going soil degradation have all been contributing to make CA practices economically competitive in the region (Djanibekov et al., 2008; Muller, 2006) there still is an urgent need to reduce cultivation costs further and increase the sustainability of agricultural production. This can be reached by developing and adapting alternative technologies in the current and future cropping system in the salt-affected, irrigated lands and while considering risk, which had previously been identified as a potential hampering facet (Kienzler et al., 2012). Extensive research has been conducted in the different agro-ecological zones of Central Asia to determine the potential effects of CA practices on soil quality, plant establishments and farm welfare (Kienzler et al., 2012). However, limited research has addressed the combined influence of tillage, planting system and mulching for cotton-based rotation systems on crop productivity and financial benefits. The current comprehensive analysis compared therefore the economic performance of various crop rotation systems under different tillage methods while considering risk-based commodity prices, and variable production and input costs. Variability in economic returns, commodity and input prices, and sensitivity of optimal cropping systems to producer risk attitudes formed part of the assessment.

2. Method

2.1 Experimental Field Design and Description of Study Region

The current study draws on findings from field experiments conducted during two consecutive years (2008 and 2009) in the Khorezm region, an administrative district in western Uzbekistan. Many details on the bio-physical aspects have been reported previously (Devkota, 2011b) and therefore only details necessary for this analyses are briefly reported here.

The Khorezm region, located at (60°40′44″ N and 41°32‘12″ E, 100 m asl) experiences an arid climate, with long, hot and dry summers and short, cold winters. Long-term mean precipitation is less than 100 mm/year and is greatly exceeded by potential evaporation of about 1200 mm (Forkutsa, 2009).

The experimental field had been mono-cropped with cotton under Conventional Tillage (CT) for more than 20 years during which annual fertilizer applications occurred in the order of 200:140:100 kg/ha NPK. The experiment started with deep-ploughing, land leveling with laser guidance and salt leaching in February/March 2008. The soil was an irrigated alluvial meadow, with a sandy loam to loam texture (FAO Classification), low in organic matter (0.3–0.6%) but low to high salinity (2–12 dS/m).

The experiment was implemented as a randomized complete block with four replications. It involved two tillage treatments as main treatments: Bed Planting (BP) with residue retained (+R) and conventional tillage (CT) with a factorial combination of three crop rotation systems namely N1 (cotton-cotton), N2 (cotton-wheat) and N3 (cotton- wheat-maize). The CT with residue retained (+R) and the BP without residues were not analyzed here as previous bio-physical assessments (Devkota et al., 2013a; Devkota, 2011b) showed inferior performance (Table 1, Appendix A). The experimental subplots sized 550 m^2 (11 m × 50 m).

Table 1. Experimental design, treatments and crop management used in the scenario analyses

Treatments	**N1**	**N2**	**N3**
CT	C – C	C - W	C - W - M
BP	C - cc - C	C+R - W+R	C+R-W+R-M+R

Note. C= Cotton, cc= cover crop, M= maize, and W= wheat, + R= retained crop residue (or mulch), CT= conventional tillage, BP= bed planting.

2.2 Field Preparation, Sowing and Sequence of Cultivation Operations

Permanent beds (BP) were prepared after completing field preparation. They were shaped with 90-cm spacing between furrows, and afterwards not tilled anymore. The beds were 15 cm high and 60 cm wide at the top. The width of the furrows was 15 cm. In early May 2008, Cotton (*Gossypium hirsutum* L., cv. Khorezm 127) was planted using a cotton seeder at the recommended seed rate of 60 kg/ha in the center of these beds resulting in an average plant density of 45,000 plants/ha. In CT Cotton was sown on the tilled flat land using a seeder with the same spacing and seed rate (60 kg/ha). A defoliant (9 kg magnesium chloride dissolved in 200 l/ha water) was applied to induce boll opening 10–15 days before the first cotton pick. Since cotton it was the first crop in the rotation experiment, wheat straw was imported to satisfy the mulch demands and mulched in the +R plots at a rate of 3 t/ha. The residues were surface-mulched in both beds and furrows immediately after seeding.

Winter wheat (*Triticum aestivum* L., cv. Krasnodar) was relay seeded into the standing cotton at the recommended seed rate of 200 kg/ha on October 10, 2008 coinciding with the moment after the second cotton pick. Wheat was seeded in rows at a distance of 22.5 cm (4 rows on each 90-cm bed) with double disk seed openers into the standing cotton. As the standing cotton occupied the center of the beds, wheat rows were placed on the shoulders and slope of the beds rather than on the top. In CT, seeds were broadcasted manually into standing cotton after a single cultivation. A second cultivation covered the seeds, an intervention which is commonly practiced by local farmers. Average plant density was 400 plants /m² in both tillage methods. The cotton stalks (6 t/ha) were chopped (about 12–15 cm length) and equally distributed over the plot bed and surface in BP. In the CT treatments all cotton stalks were cut at ground level and removed from the plots. After the wheat harvest on June, 16, 2009, the stover (10 t/ha) was uniformly spread over the BP plots, but both standing and loose stover was removed from all CT plots.

Hybrid maize (*Zea mays* L., cv. Maldoshki) was sown with a double disk seed opener as a summer crop after wheat harvest and at a seed rate of 40 kg/ha with 45 cm row spacing (2 rows in each bed) on June 28, 2009, in both BP and CT. The plants were thinned 10 days after emergence to maintain an average plant density of 50,000 plants/ha. In CT, maize was sown after three cultivations followed by rough leveling, whereas under BP no soil tillage occurred aside from drilling in bands of seed and N fertilizer. Grain and stover harvests occurred in September 2009. Further details can be found elsewhere (Devkota et al., 2013a; Devkota, 2011b).

Further on in the treatment N2 and N3, winter wheat was grown as cover crop (cc) prior to cotton planting for the treatment N1 in April (Table 1). Neither fertilizer, nor irrigation water was applied after seeding except for single flood irrigation during the leaching period in October to prevent salt movement from neighboring fields. Two weeks before cotton sowing in April, glyphsate {N-(phosponomenthyl) glycine} was applied to terminate the growth of wheat. At this time, wheat was near the booting stage (Zadoks et al., 1974), and had accumulated a dry biomass of 1.8–2 t/ha.

Phosphorus (P) was applied at 160 kg/ha and potash (K, applied as muriate of potash (60% K2O)) at 70 kg/ha for both wheat and maize but at 140 kg P/ha and 100 kg K/ha for cotton cultivation. All these fertilizers were applied as a basal application during sowing. The N fertilizer was top-dressed through urea granules (46% N) with a band application in cotton (at budding (38 days after sowing, days after sowing (DAS)) and flowering stages (52 DAS) and in maize (at 32 and 42 DAS). Urea was broadcasted in two equal splits at 172 DAS (F6 stage) and 190 DAS (F8) in wheat. Further details are reported elsewhere (Devkota, 2013b; Devkota, 2011b).

2.3 Model Description

The mathematic optimization and simulation model (Lingo software or LINDO system, 2006) was initially developed as a land use planning support tool for decision-making at farm-level. It has here been used for integrated ecological-economic optimizations of land allocation based on various types of crop rotations (C-C, C-W and C-W-M for CT and C-cc-C and C+R-W+R, C+R-W+R-M+R for BP, Table 1). The model allows for a consideration of basic features of agricultural practices in Central Asia (e.g. irrigation, crop rotations, and tillage operations) and the interrelations of dominating production activities. The typical crop sequences in the region, cotton-cotton, cotton-wheat and cotton-wheat-secondary crop (maize) could therefore be analyzed. During the simulations it was assumed that sufficient irrigation water was applied to satisfy crop water demands.

The model belongs to the class of linear programming model without integer variables. It is a new approach aiming to solving mathematical programming problems, which are usually formulated with mixed integer programming (MIP). The model used here is unique way in its way of calculating and a modification of previously used MIP models (e.g. Cobuloglu et al., 2015; Cobuloglu et al., 2014; Mohamad et al., 2011; Watkins et al., 2011; Alfandari et al., 2009; Sarker et al., 1997). Alfandari et al. (2009) for instance aimed at a better control of agricultural space and prevention of deforestation, while covering seasonal needs of farmers. Therefore constraints of choice between cultivation and leaving fallow have been included. The current model was developed with an attempt to include economic features of optimal cropping systems while imposing different technologies and while considering fluctuating commodity price and input cost conditions as risk parameters. The length of a single rotation cycle was therefore fixed (two years only). Such challenges could address by MIP models, however using many variables with 0 and 1 is complex and error-prone, which is a recurrent mentioned drawback of MIP models. Hence, developing an alternative mathematical model for the analyses provided the opportunity to precisely formulate the problem using "integer variables" (mostly 0 or 1). And maximize the objective function while considering many variables, subject to the constraints typical for each variable. The elaboration of a new programming model yielded much more accurate and reliable results with minimum errors. The modifications were required to cope with site-specific practices and unique approach to solve the same problem. Since the type of analyses undertaken are new for the study region, and since these could be implemented with minimum changes in the constraints, extended efforts for validation are not appropriate , which is a clear advantage over other, more complex, but also error-prone simulation models (Janova, 2012). Similar approaches in modeling crop rotation planning was utilized by Mohamad et al. (2011), who employed the LINDO system to maximize total returns at the end of planning horizons. It was argued as well to apply the MIP model for longer planning horizons (more than 12 months). On the other hand, Cobuloglu et al. (2014, 2015) developed a more sophisticated version of a multi-objective, mixed-integer optimization model to analyze tradeoffs and competition between fuel and food product production using switch-grass in corn cultivated on marginal crop- and grasslands. Based on these experiences, a calibration and validation of the current model was assessed as not necessary. In contrast extended sensitivity analyses are made well as manual calculations to test the accuracy of the model outcomes.

Gross margins (GM) were estimated to explore the financial performance of each tillage-rotation management system. The GMs were estimated as GM = GR - TVC; where GR equals the gross revenue from selling agricultural outputs such as raw cotton, wheat grain, maize grain, cotton stalk, wheat straw and maize stalk and TVC equals the total variable costs which included fertilizer costs (FC), Mulching cost (MC), and Cultivation costs (CLC). Rate of Return (RR) was consequently estimated as RR = GM / TVC (Tursunov, 2009)

2.3.1 Crop Rotation and Crops

Included in the analysis were a cover crop and three main crops that were considered in combination: cover crop (spring wheat) ($j = 1$), maize ($j = 2$), cotton ($j = 3$), and winter wheat ($j = 4$). A month was assumed as the smallest time unit. Therefore, the index of a crop rotation cycle was indicated as $\tau = 1, 2, \ldots \bar{T}$, where $\bar{T}$ is the time horizon of crop rotation planning (2 years or 24 months). Here, land was devoted for crop rotation i (i = N1, N2 and N3) for each crop rotation cycle (τ). $X(\eta, i, \tau)$ is a land area in tract η devoted for crop rotation i at crop rotation cycles τ ($\tau = 1, 2, \ldots, \bar{T}$). So, once the total area of land available for crop rotation planning is fixed over the imposed time horizon of a crop rotation planning, the following constraint is considered:

$$\sum_{i=1}^{3} X(\eta, i, \tau) \leq \bar{X}(\eta) - \Delta X(\eta, \tau) \quad \left(\tau = 1, 2, \ldots, T;\ \eta = 1, 2, \ldots, \bar{h}\right) \tag{1}$$

in which: $\bar{X}(\eta)$ is given total area of tract of land η available for crop rotation planning; $\Delta X(\eta, \tau)$ is an area of idle land in η during period τ.

2.3.2 Land Area of the Tract of Lands

There should be a minimum module of land on which all crop and crop rotation and other technologies must be satisfied equally. Once the value of $X(\eta, i, \tau)$ is determined, one can determine as well how much land is devoted to each crop cultivation at each month of the crop rotation cycle (period). Therefore, the main model structure parameter is a $a(i, j, t) = 1$ if crop rotation of i cultivates crop j in month t ($i = 1,2,3$; $j = 1,2,3,4$; $t = 1, 2, \ldots, 24$); $a(i, j, t)$= 0 if crop rotation of i does not cultivate crop j in month t. Using $a(i, j, t)$, we can calculate $L(\eta, i, j, t, \tau)$, the area of tract of land η devoted for cultivation of crop j with crop rotation of i in month t of period τ:

$$L(\eta,i,j,t,\tau)=a(i,j,t)X(\eta,i,\tau) \tag{2}$$

Note: Equation (2) shows $L(\eta,i,j,t,\tau)$ is fixed once $X(\eta,i,\tau)$, which is free, is determined.

The $L(\eta,i,j,t,\tau)$ is free as far as Equation (1) is satisfied and therefore it must be optimally determined. Once the $L(\eta,i,j,t,\tau)$ is determined, the important variables can be estimated as well as the optimization of crop rotations and area of lands devoted to cultivation of each crop are easily calculated.

2.3.3 Input of Fertilizer

$$\mathrm{IF}(\eta,\alpha,t,\tau)=\sum_{i=1}^{3}\sum_{j=1}^{4}\pi(\eta,\alpha,i,j,t)\,L(\eta,i,j,t,\tau)\ (\alpha=1,2,3) \tag{3}$$

in which: $IF(\eta,\alpha,t,\tau)$ is a necessary input of fertilizer of α in tract of land η in month t of period τ (the same amount of (NPK) fertilizer was applied for both tillage practices); $\pi(\eta,\alpha,i,j,t)$ is a necessary input of fertilizer of α per unit of land devoted for cultivation of crop j with crop rotation i in tract of land η in month t (otherwise, it is zero).

2.3.4 Production of Crop and Byproduct

(a) Crop production:

$$\mathrm{PP}(\eta,j,t,\tau)=\sum_{i=1}^{3}\Pi(\eta,i,j,t)\,L(\eta,i,j,t,\tau) \tag{4}$$

in which: $PP(\eta,j,t,\tau)$ is products of j in month t of period τ in tract of land η (productivity rate is different depending on tillage method); $\Pi(\eta,i,j,t)$ is productivity of crop j with crop rotation i in tract of land η in harvesting month t. If no harvest, it is 0 (zero).

(b) Production of byproduct or crop residue:

Given that the instruction of three $\bar{\xi}$ types of crop residues provided by the three crops (cotton, wheat and maize), the amount of crop residue depends on the production of each crop:

$$\mathrm{PR}(\eta,\beta,t,\tau)=\sum_{j=1}^{4}\sum_{i=1}^{3}\Phi(\beta,i,j)\Lambda(\eta,i,j,t)\,L(\eta,i,j,t,\tau)\ \ (\beta=1,2,\dots,\bar{\xi}) \tag{5}$$

In which: $PR(\eta,\beta,t,\tau)$ is the crop residue of β produced in tract of land η at (the end of) month t of period τ; $\Lambda(\eta,i,j,t)$ is (productivity of) crop residue in month t in land area η produced by unit area of land with crop rotation i devoted for cultivation of crop j; $\Phi(\beta,i,j)$ is structural parameter or timing; it is 1 if area of land devoted for cultivation of crop j with crop rotation i, produces agricultural residue β at month t; otherwise it is 0.

Note: $PR(\eta,\beta,t,\tau)$ is supply of crop residue of type β in tract of land η at (the end of) month t of period τ.

2.3.5 Demand and Supply of Crop Residue (Mulch)

$$\mathrm{DR}(\eta,\beta,t,\tau)=\sum_{i=1}^{3}\sum_{j=1}^{4}\Gamma(\eta,\beta,i,j)\,\lambda(i,j,t)L(\eta,i,j,t,\tau) \tag{6}$$

Where: $DR(\eta,\beta,t,\tau)$ is the demand for crop residues of type β in tract of land η at month t of period τ; $\Gamma(\eta,\beta,i,j)$ is the crop residue of type β necessary for one unit of land tract η devoted for the cultivation of crop j with crop rotaion i (in CT each type of crop residue is "0"); $\lambda(i,j,t)$ is a structural parameter; it is 1 if demand for crop residue occurs during the month t for cultivation of crop j with crop rotation; otherwise it is 0 (for example, there is no demand for crop residues in CT)

2.3.6 Revenue From Crop and Crop Residue

(a) Revenue from crop sale

$$\mathrm{RP}(\eta,t,\tau)=\sum_{j=1}^{4}p(j)\,\mathrm{PP}(\eta,j,t,\tau) \tag{7}$$

in which: $p(j)$ is price of crop j; $RP(\eta,t,\tau)$ is total revenue of crop sale in tract of land η at month t of period τ.

(b) Revenue of crop residue sale

$$\mathrm{RS}(\eta,\beta,t,\tau)=\mathrm{pcr}(\beta)\mathrm{PR}(\eta,\beta,t,\tau) \tag{8}$$

in which: $PR(\eta,\beta,t,\tau)$ is production of crop residue of β produced in η at (the end of) month t of period τ; $pcr(\beta)$ is price of crop residue of type β.

2.3.7 Variable Costs

(a) Fertilizer costs

$$\mathrm{FC}(\eta,t,\tau)=\sum_{\alpha=1}^{3}\mathrm{pf}(\alpha)\,\mathrm{F}(\eta,\alpha,t,\tau) \tag{9}$$

$pf(\alpha)$ is price of fertilizer α; $FC(\eta,t,\tau)$ is total cost of fertilizers in tract of land η at month t of period τ.

(b) Mulching cost (MC)

$$\mathrm{MC}(\eta,\beta,t,\tau) = \mathrm{pcr}(\beta)\mathrm{DR}(\eta,\beta,t,\tau) \tag{10}$$

in which: $pcr(\beta)$ is price of crop residue of type β.

(c) Cultivation costs (CLC)

Cultivation Cost (CLC) comprised agricultural operation and intervention costs for machinery use, fuel, labour and herbicides (Appendix B). This was estimated as:

$$\mathrm{CLC}(\eta,t,\tau) = \sum_{i=1}^{3}\sum_{j=1}^{4}\mathrm{pclv}(i,j,t)\mathrm{L}(\eta,i,j,t,\tau) \tag{11}$$

in which: $CLC(\eta,t,\tau)$ is total cultivation costs in tract of land η in month t of period τ (which is different depending on the type of tillage); $pclv(i,j,t)$ are cultivation costs other than fertilizer and mulching costs; irrigation, seeds, machine operations and maintenance cost, labor costs of contingent employment, herbicide costs) per unit area of land devoted cultivation of crop j with crop rotation i, in month t.

2.3.8 Revenue From Crop and Crop Residue

(a) Gross Margin (GM)

$$\mathrm{GM}(\eta,t,\tau) = \mathrm{RP}(\eta,t,\tau) + \sum_{\beta=1}^{\bar{\xi}}\mathrm{RS}(\eta,\beta,t,\tau) - \mathrm{FC}(\eta,t,\tau) - \sum_{\beta=1}^{\bar{\xi}}\mathrm{MC}(\beta,\eta,t,\tau) - \mathrm{CLC}(\eta,t,\tau) \tag{12}$$

in which: $GM(\eta,t,\tau)$ is net revenue (if it is *positive*) or/deficit(if it is *negative*) in η at month t of period τ (unit: USD per ton).

3. Results

3.1 Crop yield and Byproducts

Bed Planting (BP) with mulch increased grain yields and byproducts significantly: For instance wheat yields increased by 12% and maize by 29% in BP compared to CT, whilst wheat stover increased by 13% and maize stover by 37% (Table 2). Above ground biomass (AGB) and crop residue amounts on BP with mulch were superior to CT in all cases (Table 2). In general BP with residue retention showed higher grain yield for wheat and maize, but not for cotton.

3.2 Cost and Revenues

Farmers often prioritize on-site (direct) benefits rather than off-site (indirect) ones because of their concern for attractive, short-term returns from investments. Fertilizer costs for cotton amounted to 128.7 $/ha, which equaled about 16-18% of the total variable cost (TVC). In contrast, the share of fertilizers to TVC during wheat cultivation ranged between 15-19% and for maize between 14-21%, depending on the treatments (Table 2, Appendix B).

Cultivation Cost (CLC) differed according to tillage treatments and crops (Table 2). These differences (of CLC) between tillage systems amounted to 121 $/ha for cotton and ca. 79 $/ha for both wheat and maize. The lowered expenses for machinery under CA practices could however not offset the mulching cost that were incurred under BP systems owing to the cost of crop residue (99 $/ha, 216 $/ha 330 $/ha) of cotton, wheat and maize. The GM in BP exceeded nevertheless that of CT for all individual crops owing to a higher production of crop and byproducts. This increase of GM was most apparent for wheat (19%) and very outstanding for maize (28%), compared to cotton (in the range of 17-20% only). Similar, positive trends emerged through the Gross Revenue (GR) analyses whilst the Rate of Return (RR) analyses indicated contradicting results for wheat and maize due to the high costs for mulching. In this case, the RR of CT was much higher than for BP (Table 2).

Table 2. Main input parameters for individual crops for economic analysis section of the simulation model

TRTs	PP t/ha	RP $/ha	PR t/ha	RS $/ha	NPK t/ha	TFC $/ha	DR t/ha	MC $/ha	CLC $/ha	GR $/ha	TVC $/ha	GM $/ha	RR
cc	0	0	2	65	0	0	0	0	55	65	55	10	0.19
M	3.91	887.6	4.198	125.9	0.43	118.2	0	0	438	1013.5	556.2	457.3	0.82
M+R	5.52	1253	6.16	184.8	0.43	118.2	10	330	359	1437.8	807.2	630.6	0.78
C	3.877	880.1	5.699	205.1	0.44	128.7	0	0	635	1085.2	763.7	321.5	0.42
C-cc(-C)	3.79	860.3	6.008	216.3	0.44	128.7	2	65	514	1076.6	708.1	368.6	0.52
C(-W)	3.916	888.9	5.721	205.9	0.44	128.7	0	0	635	1094.9	763.7	331.2	0.43
C(-W)+R	3.929	891.9	6.002	216.1	0.44	128.7	3	99	514	1107.9	741.7	366.3	0.49
W	7.345	793.2	8.727	287.9	0.43	118.2	0	0	497	1081.2	615.3	466.1	0.75
W+R	8.269	893.1	10.01	330.4	0.43	118.2	6	216	418	1223.4	752.2	471.2	0.62

Note. TRTs= treatments, cc= wheat grown as a cover crop, M= maize in CT, M+R= maize with crop residue in BP, C= cotton in CT, C-cc(-C)= cotton with cover crop in BP, C (-W)= cotton from cotton-wheat rotation in CT, C (-W) +R= cotton from cotton-wheat rotation with crop residue in BP, W= wheat in CT, W+R= wheat with crop residue in BP, PP= crop yield (t/ha), RP= Revenue from raw cotton or grains ($/ha), PR= residue amount harvested (t/ha), RS= Revenue from byproducts ($/ha), NPK= total amount of applied fertilizers (t/ha), TFC= Total Fertilizer Cost ($/ha), DR= Demand of crop Residue for mulch ($/ha), MC= Mulching Costs ($/ha), CLC= overall Cultivation operation and rest of the application Costs ($/ha), GR= Gross Revenue ($/ha), TVC= Total Variable Cost ($/ha), GM= Gross Margin ($/ha), (RR) = Rate of Return.

Total revenues from crop production, which included benefits from crop and biomass (byproduct), were affected also by the financial value attributed to the residues and mulching activities thus generating Mulching Costs (MC). The accumulated biomass of wheat as cc amounted to about 2 t/ha, estimated to be 9% of TVC (Table 2). During wheat and maize cultivation, both crops had been mulched with the crop residues from the previous crop (100% cotton stalks and wheat straw), which amounted to 6 t/ha and 10 t/ha respectively. In contrast, during cotton cultivation only 33% of all crop residues produced by the previous crop (meaning 3 t/ha wheat straw) were utilized as mulch as this was considered an appropriate amount (Devkota et al., 2013a). The MC of the cotton-wheat-maize cropping system made up a substantial share (13.3%, 28.7% and 40.8%) of TVC, respectively. Consequently, the ratio (22 $/ha, 136.9 $/ha and 251 $/ha) in TVC between CT and BP for cotton was 1.03, but for wheat 1.22, and for maize 1.45 (Table 2).

3.3 Sensitivity Analyses: Raw Cotton Price Response

The profitability of the three crop rotation systems was examined for changes in costs of major inputs and product prices. The individual crop price varied from 0% (index equals 0 or no benefit from crop and byproduct) to 200% higher (almost equal to MP) than their base SPP 2009 values (taken as 100%). The crop prices obviously strongly determined the sensitivity of the economic rankings of the rotation systems to changes in absolute and relative price levels. The base value of raw cotton, wheat and maize grain crops determined by the SPP, which equaled to 227 $/t, 108 $/t and 227 $/t), and the Market Price (MP) which equaled to 333 $/t, 227 $/t and 227 $/t. Maize however was not part of the SPP as not being a strategic crop according to government declarations (see also Appendix B). While price (or costs) of the byproducts and other parameters had been kept constant during analyses, the effect of an individual product price change on optimized GM of crop rotation system (N1, N2, and N3) was calculated. It was hereby assumed that when the revenue from a component crop production was "zero", only profits from the crop residues (res_pr) had been estimated and considered as a minimum benefit (Figure 1). The maximum benefits could be achieved at potentially high (at MP or higher) prices of that crop production (Table 3).

Table 3. Crossing points of Gross Margin lines of each treatments at varying cotton prices

Treatments	Cotton ($/t)	GM ($/ha)
C - cc - C	238	840.3
C - W		841.2
C - cc - C	249	924.6
C+R - W+R		923.9
C - C	267	953.3
C - W		953.8
C - C	278	1038.6
C+R - W+R		1037.9
C - cc - C	363	1787.1
C - W - M		1788.7
C - C	386	1876.1
C - W - M		1877.1
C - cc - C	422	2235.9
C+R-W+R-M+R		2234.3
C - C	443	2317.9
C+R-W+R-M+R		2316.8

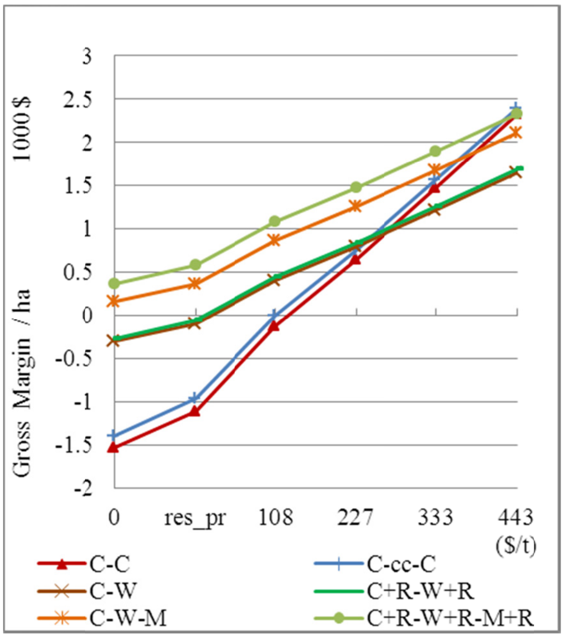

Figure 1. Economic performance of rotation-tillage treatments response to varying cotton prices. For the legends and explanations see Table 1

The GM of all three cropping systems was much most responsive to changes in raw cotton price compared to the other individual crop prices obviously since cotton was the key crop in all three rotation systems. With increasing production prices, the GM increased relatively more for C-C and C-cc-C treatments due to the double crop rotation feature of both systems. On the other hand, both cropping systems produced the lowest GM under the base case assumptions, but they surpassed the GM of all other treatments one by one and finally reached the top assuming the highest range of production prices (Figure 1). The C+R-W+R, C-W, C-cc-C and C-C rotations would become beneficial at raw cotton prices of 14 $/t, 23 $/t, 127 $/t 144 $/t, respectively. However, the C+R-W+R-M+R and C-W-M rotations remained profitable, even without the benefits of raw cotton: they yielded 576 $/t and 365 $/t GM (data not shown). Across all treatments, at any price of the products, GM of BP was superior to that of CT. Assuming the rule of thumb that producers prefer production systems that provide high economic returns, based on the comparisons of GM for the rotational-tillage treatments at selected price scenarios, the results indicated that unless raw cotton price is increased beyond 249 $/t and 267 $/t (9% and 15% higher than the price in the base case) in BP and CT respectively (Table 3), farmers would be ill-advised to continue C-cc-C and C-C, even when considering the current subsidy levels by the government. Furthermore, a back-to-back cotton sequence, to a certain extent still practices by farmers in the study region, would become superior to all rotation systems when raw cotton prices would increase to beyond 422 $/t and 443 $/t in BP and CT respectively.

Table 4. Gross Margin and its difference (df)s according to rotation-tillage systems in various combinations of Market Price (MP) and State Procurement Price system (SPP)

Cotton ($/ t) Wheat ($/t) Maize ($/t)	227* 108* 227	df I (SPP) case	227* 227 227	df II case	333 108* 227	df III case	333 227 227	df IV (MP) case
C – C	643.1	114.7	643.1	114.7	1465.1	96.3	1465.1	96.3
C - cc - C	757.9		757.9		1561.4		1561.4	
C – W	797.2	40.3	1671.3	150.2	1212.3	41.6	2086.4	151.6
C+R - W+R	837.5		1821.5		1253.9		2237.9	
C - W - M	1254.5	213.6	2128.6	323.5	1669.7	214.9	2543.7	324.9
C+R-W+R-M+R	1468.1		2452.1		1884.6		2868.6	

Note, *State Procurement Price (SPP) MP= market price ($/t), df= difference between treatments ($/t), all crop prices are at SPP for case I and at MP for case IV, case II and case III are other possible options in the medium with mixed commodity prices.

Changes in raw cotton price marginally affected profitability determined by tillage management as introduced within the rotation system N2 and when compared to the rotation system N1 and N3 (Figure 1). This is very likely due to the difference in GM values of these rotations, which were determined while considering the compensation rate of MC in BP caused by added expenses of overhead machinery operations in CT. In cropping system N1, the GM differences of tillage treatments (114.7 $/t) was higher than within cropping system N2 (40.3 $/t), but much lower than in system N3 when considering the assumptions in the base level or case I (213.6 $/t) (Table 4). Similar trends were observed for case III, while other cases (cases II and IV) presented quite different phenomena at various combinations of crop price. Whereas for case I all prices were set at SPP and for case IV at MP, for case II and III possible options in the medium terms were considered for instance through mixed commodity prices (Table 4).

3.4 Sensitivity Analyses: Wheat Grain Price Response

During the sensitivity test that considered varying wheat grain prices, the C-C and C-cc-C rotations did not respond to the changes of this product (Figure 2). The GM under BP was always superior to that under CT for all treatments of N1 and N3. For cropping system N2, this was true only after assuming a wheat price of 65 $/t (60% of base level) (Table 5), which is caused by the structure of the TVC and owing to different crop productivity rates in C+R-W+R and C-W rotations. At this, the TVC of the C+R-W+R system was estimated 114.9 $/ha more compared to the C-W rotation due to the added mulching expenses in C+R-W+R (Table 2).

The differences in additional overheads for agricultural operations in CT were fully compensated for by a higher productivity of wheat and its byproducts under BP. The GM line of C+R-W+R system maintained further growth, but would cross with the C-W-M rotation line at an exceptionally high (559 $/t) product price (not shown). When assuming increased wheat grain prices to more than 87 $/t and 98 $/t in CT and BP respectively, the rotations systems N2 and N3 rather than N1 (C-C and C-cc-C) would become more profitable (Table 5). The C+R-W+R and C-W rotations would become beneficial at even 7 $/t and "zero" product prices respectively, including the benefit of byproducts, while the C+R-W+R-M+R and C-W-M cycles generated 575 $/t and 461 $/t GM without benefits from wheat grain product (data not shown). These results indicate the combined effect of high maize yield and relative high prices of maize grain. The GM of C+R-W+R-M+R and C-W-M sequences could surpass that of C-C at 8 $/t and 25 $/t (very low) wheat grain prices, although further balanced with of C-cc-C at 22 $/t and 40 $/t crop prices respectively (Table 5).

Table 5. Crossing points of GM lines of each rotation system at varying wheat prices

Rotations	Wheat ($/ha)	GM ($ /ha)
C+R-W+R-M+R	8	641.2
C – C		643.1
C+R-W+R-M+R	22	756.9
C - cc - C		757.8
C-C	25	643.1
C - W - M		644.9
C - W - M	40	755.1
C - cc - C		757.9
C-W	65	481.4
C+R - W+R		481.9
C+R - W+R	84	639.1
C - C		643.1
C - W	87	642.9
C - C		643.1
C+R - W+R	98	754.8
C - cc - C		757.9
C - cc - C	103	757.9
C - W		760.5

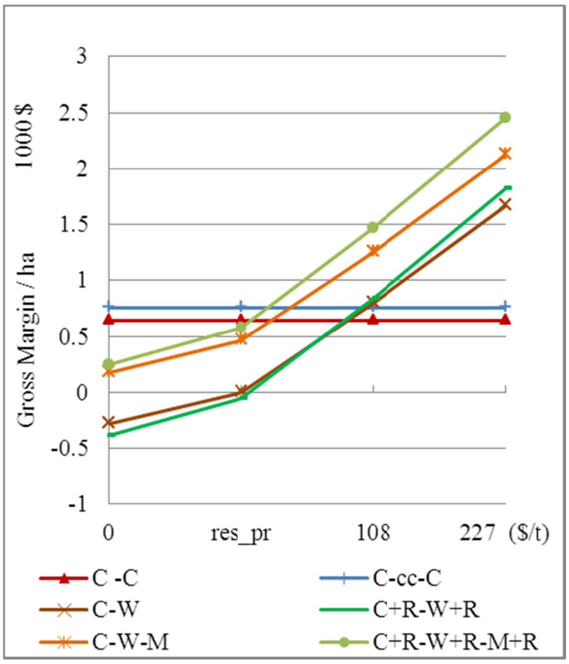

Figure 2. Economic performance of rotation-tillage treatments to varying wheat prices. For the legends and explanations see Table 1

3.5 Sensitivity Analyses: Maize Grain Price Response

Table 6. Crossing points of Gross Margin lines of each rotations systems at varying maize prices

Treatment	Maize ($/ha)	GM($/ha)
C - C	71	643.1
C - W - M		644.5
C - C	78	643.1
C+R-W+R-M+R		645.6
C+R-W+R-M+R	94	733.9
C - W - M		734.5
C+R-W+R-M+R	98	756.1
C - cc - C		757.9
C - W - M	100	757.9
C - cc - C		757.9
C+R-W+R-M+R	100	797.1
C - W		797.2
C - W - M	110	797.1
C - W		797.2
C - W - M	120	836.1
C+R - W+R		837.5
C+R - W+R	113	837.5
C+R-W+R-M+R		838.8

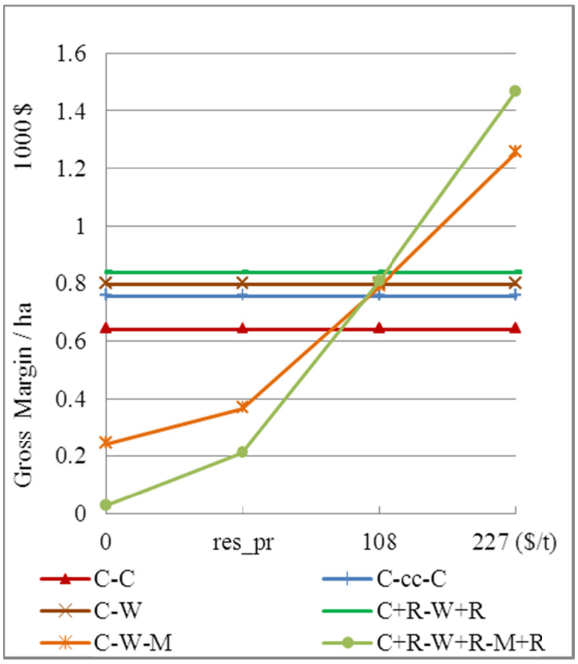

Figure 3. Economic performance of rotation-tillage treatments response to varying maize prices. For the legends and explanations see Table 1

Maize was the second most passive element in the cropping systems, as it was included only in crop rotation N3 (Figure 3). However, it turned out to be the most profitable crop among those tested due to its short vegetative period and low input costs, which did not affect crop establishment. In turn, the RR of maize increased especially under BP with mulch compared to the other crops. The GM of BP and CT gave significantly different outputs for maize, but these differences became balanced at 94 $/t (41% of the base value) maize prices (Table 6). At lower than 94 $/t, C-W-M was superior to C+R-W+R-M+R. The GM lines of C-W-M and C+R-W+R-M+R cycles had intersections with a C-C rotation at 71 $/t and 78 $/t, and with C-cc-C at 100 $/t and 98 $/t maize grain prices. The C-W-M and C+R-W+R-M+R rotations could become competitive with the C-W rotation at high prices (110 $/t and 100 $/t) compared to the base level. They would become balanced with C+R-W+R at elevated prices (120 $/t and 113 $/t) (Table 6). Even with a "zero" benefit from maize grain, C-W-M and C+R-W+R-M+R rotations stayed profitable and yielded 215 $/t and 461 $/t GM at the base price.

3.6 Effect of Changes in TVC

For getting in addition a better feeling on the robustness of the findings, the cost characteristics of the rotation-tillage systems under BP and CT had been evaluated while assuming a wide range of input price of the crops. The potential increases in TVC for each treatment were estimated while assuming that in the case of a complete abolishment of the omni-present state procurement policy for cotton and wheat, the increased rate of TVC of all treatments would vary from 0 (index equals 100) to 100% (index equals 200) above the prices in the base case (assuming the SPP). This allowed determining the sensitivity of the economic rankings for all rotations to fluctuations in TVC (Figure 4). Here the GM of tillage-rotation systems at SPP values had therefore been adjusted to the relative value of GM at MP prices for each rotation system through artificially increasing the TVC. The findings showed that a 100% cut of the state subsidy and services resulted in an 53.8%, 66.6%, and 93.5% increase in TVC for C-C, C-W and C-W-M rotations under CT, respectively (Table 7). On the other hand, a 100% cut of the state subsidy and services resulted in an 52.7%, 60.9% and 93.7% increase in TVC for C-cc-C, C+R-W+R, C+R-W+R-M+R cycles under BP, respectively.

Table 7. Increased rate of Total Variable Cost to adjust the Gross Margin of all treatments at two pricing systems, and thier relative Rate of Return

Rotations	**TVC %**	**RR**	
		SPP	MP
C - cc - C	152.7	1.49	2.02
C - C	153.8	1.42	1.96
C+R-W+R	160.9	1.56	2.5
C-W	166.6	1.58	2.51
C-W-M	193.5	1.65	2.31
C+R-W+R-M+R	193.7	1.64	2.25

Table 8. Intersections of Gross Margin lines and relative Rate of Return at increased rate of Total Variable Cost

Rotations	**TVC (%)**	**GM ($/ha)**	**RR**
C+R - W+R	169.3	1202.9	1.48
C-W-M		1202.9	1.37
C+R - W+R	178.2	1069.7	1.4
C+R-W+R-M+R		1069.1	1.26
C-W	182.2	952.9	1.38
C-W-M		952.9	1.27
C+R-W+R-M+R	184.8	917.2	1.21
C-W		917	1.36
C+R-W+R-M+R	188.8	825.2	1.19
C-W-M		825.2	1.22

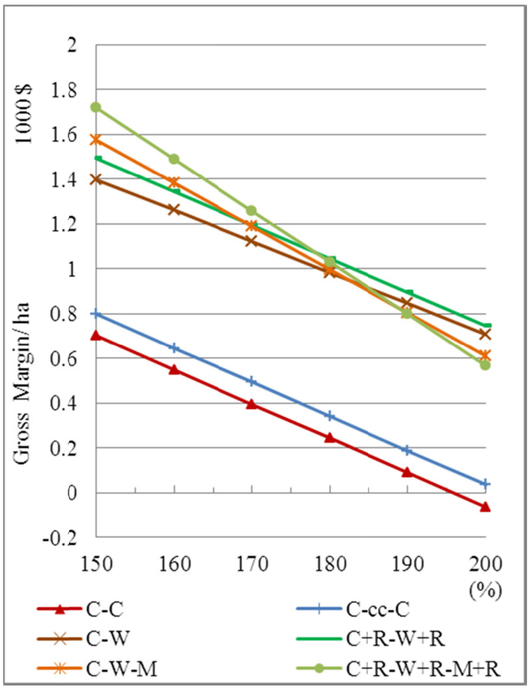

Figure 4. Effect of six rotations on Gross Margin under increased rate of Total Variable Cost. For the legends and explanations see Table 1

While assuming the conditions and price relatioins in the base case, the relative profitability ranking of the rotation systems followed the order of C-C < C-cc-C < C-W < C+R-W+R < C-W-M < C+R-W+R-M+R. However, with an increasing TVC (e.g. 78.2% from the base value, where the GM of these two treatmens intersected), the C+R-W+R-M+R rotation would become more beneficial than the C+R-W+R rotation system under BP. Furthermore, at 82.2% or higher TVC levels, the C-W-M rotation would loose its status to C-W under CT. Finally, at higher than 88.8% of the increased TVC, the order of the treatments according to profitability would become C-C < C-cc-C < C+R-W+R-M+R < C-W-M < C-W < C+R-W+R. (Figure 4).

4. Discussion

4.1 Crop Yield and Biomass

The bio-physical benefits under BP plantings compared to CT in the irrigated areas of Central Asia have been caused by increased biomass, yields and stover production as well as due to a better plant establishment (Sayre & Hobbs, 2004; Boulal et al., 2012; Gürsoy et al., 2010). The short-term effects of CA practices are attributed to a mulch with crop residue (e.g. Mulumba & Lal, 2008; Bezborodov et al., 2010).Yet, these benefits have been observed for the typical grain crops in the region such as wheat and maize, but less for cotton (Devkota et al., 2013a; Naresh et al., 2012; Hobbs, 2007; Sayre & Hobbs, 2004; Hassan et al., 2005). Also the number cost-benefit analyses of CA practices in Central Asia are limited (Kienzler et al., 2012).

4.2 Cost and Economic Analysis

The cost and benefit structures of BP and CT turned out to be quite different except in the case of fertilizer use (Table 2). On the other hand, long-term conservation tillage is attributed growing fertilizer efficiency over time also due to the effect of the mulch and effective and suitable crop rotations (Uri, 2000). Although the present modeling efforts had been based on short-term duration experiments with CA practices and empirical evidence of long-term effects under the agro-ecological conditions of Central Asia are absence these could not be considered. In general, the findings confirmed that the BP system was most profitable due to savings in energy and production costs as previously underlined for the region (e.g. Hari-Ram et al., 2013; Devkota, 2011a; Tursunov, 2009). However, the MC made up the highest share of TVC, which more than offset benefits caused by a lowering e.g. of overhead, machinery and operation costs during BP activities. Consequently, BP practices under wheat and maize generated lower RR compared to CT. Devkota (2011a) conducted similar research on rice-wheat cropping system in the same agro-climate region (Korezm) with 50% (R 50) and 100% (R100) crop residue retention. According to his calculations, the MC amounted to about 33% of TVC for wheat with R 100.

Furthermore, the TVC between two tillage methods was 1.45 times higher under BP due to the high monetary value of the wheat straw. As a result, the GM in BP was 8% less than in CT. Tursunov (2009) estimated the financial benefits of conservation practices versus CT for cotton and wheat as well and with and without mulching in the same region (2004-2006). He concluded that an average TVC for cotton and wheat decreased by 18% and 35% in CA practices in comparison to CT. As a consequence, GM increased up to 5% and 30% in 2006, respectively. Tursunov (2009) stated that savings in production costs for fuel, labour and machinery could be as high as 45- 116 $ per ha when using CA practices in Uzbekistan. It should be noted however that the MC considered here are a result from the agronomic demands of the trial from which the data was taken (Devkota et al., 2011b) and since the time horizon considered here was only 24 months. Such high MC could be avoided in practice when preparing a shift from CT to CA practices well in advance (Kienzler et al., 2012).

4.3 Price Response to Individual Crops and System Productivity

The cotton-based cropping systems under CT were not as beneficial as under BP while assuming production conditions in 2009. Under these conditions, they consistently indicated lower GM for all rotation-tillage systems in CT than in BP at any cotton price assumed. Particularly, the C-C rotation was inferior to any other rotation system, although it is still is commonly practiced by farmers. This result is consistent with the findings of Sommer et al. (2010), who simulated various cropping system scenarios underpinning that a cotton-cotton rotation could not compete with wheat-rice or wheat-maize cropping systems under the SPP production conditions. Later, the same optimization model was employed by Djanibekov (2013) to evaluate the effects of cotton policy changes on land and water use in Uzbekistan. Based on this, possible consequences of policy impacts through various scenarios had been analyzed including a stepwise abolishment of the state procurement system for cotton production, while determining farm-gate price (524 $/t). Also, the shadow price (of 249 $/t) was calculated reflecting the constraints imposed by the cotton production target for 2009. The previous findings together with the present ones emphasize that warranted, minimum raw cotton price, even when subsidized, makes cotton production competitive with other systems (Table 3). The chain value of cotton (CVC), showing average production cost of 487 $/t/ha (Rudenko et al., 2008) is more than 1.5 times higher than that of our calculations, which is 321.5 $/t/ha for cotton monoculture crop (Table 2). The simulations findings revealed that only at higher than 443 $/t raw cotton prices, a back-to-back cotton cropping system could become superior to any other cropping pattern system. Yet, these prices are not only far beyond historic prices, but also it shows that as long as farmers are restricted in their crop choice and rotations, their gains are sub-optimal (see also Djanibekov, 2008).

Wheat and maize have also been more profitable compared to cotton in previous studies (Boulal et al., 2012; Tursunov, 2009; Hassan et al., 2005; Sayre & Hobbs, 2004). Especially, maize under BP with mulch was the most beneficial practice for various reasons. First, it performed better with targeted mulch on a sandy loam soil and the crop price is not troubled by state procurement regulations (Djanibekov, 2014). Maize and wheat based cropping system (C-W-M and C-W) could stay competitive with cotton monoculture (C-C) at comparatively low (as low as 71 $/t and 87 $/t, respectively) crop prices under CT. Compared to a wheat value chain (WVC) analyses (Rudenko, 2008), the required crop production (296 $/t/ha) equaled our calculations (466 $/t/ha) for wheat under CT. This implies that wheat could compete with other individual crops such as cotton and maize as previously postulated (Devkota at. el., 2013a; Sommer, 2010; Tursunov, 2009). Thus, maize-based or intensive cropping systems are much more resilient to the increase of component crop prices and are therefore a more reliable option for the risk-averse producers in Uzbekistan. The diversification of crop rotations reduces production risk in contrast to monoculture cropping. Other scolars observed similar findings (see for instance Stanger et. al., 2008; Meyer-Aurich et al., 2006; Zentner et al., 2002; Zentner et al., 1992).

4.4 Effect of cost Structure and State Policy Changes on Cropping System Profitability

According to recent findings, complexity in the cost structure and difference in cost distributions for various crops, especially when considering tillage-rotational management crops grown under different agricultural practice and agronomic conditions, pose difficulties during decision-making (Jeffery et al., 2012; USDA, 2012; Delbridge et al., 2011; Guadagni et al., 2005). Many studies underscored that because production costs differ according to tillage treatments, and CA practices often requires investments in planters and seeders, savings gained from a shift to CA practices at the onset are modest and not conducive to farmers to invest (Jeffery et al., 2012; Delbridge et al., 2011). Hence, the distinct distribution of the agricultural operations and interventions of each tillage system tested created mixed effects on GM. This combined with fluctuating product price introduced another risk. In Uzbekistan, the SPP conditions are not only comparatively low (almost twice) compared to the MP, but also changeable over time. On the other hand, the government subsidizes all agricultural inputs for cotton and wheat production including fertilizer, seed and pesticides (Guadagni et al., 2005), and in addition provides low interest rates for credits and even irrigation water for a fixed, low price (Gilham et al., 1995). It also ensures a score of supportive services such as machinery and maintenance of irrigation infrastructure or drainage networks, which generate lower variable costs for farmers, often much lower than the actual and true costs (Djanibekov, 2010; Rudenko et al., 2009; Abdullaev, 2009). The discrimination in crop support often ensures farmers to continue with cotton production despite the uncertainty and ambiguity. Furthermore, the actual value of implicit tax (or subsidy) is difficult to calculate (USDA, 2012; Guadagni et al., 2005) and there is on-going debate if overall cotton production in Uzbekistan is in fact taxed or subsidized. It is repeatedly stated that the design of the current cotton policy is outdated and not a motivation for farmers to produce more cotton than the state target (Pomfret, 2008). Djanibekov et al. (2013) argued even that abolishing of the restrictive cotton policy would likely cause an increase in cotton yield without affecting its production level. Our results showed that abolishing the existing state policy (the state subsidy and service supports), would increase the TVC in the range of 1.5-2 fold for various cropping systems (Table 7). Hence, this indirectly showed how improvements in the flexibility of farmer's decision making can improve crop production and farm profits. Surprisingly, even without water constraints, when assuming profit maximization, farmers are more likely to shift from maize-based intensive cropping system (C-W-M and C+R-W+R-M+R) to wheat-based double cropping system (C-W and C+R-W+R) (Table 7), at least a after a deregulation of the current state policy. When considering only economic benefits, the choice between cropping systems under BP and CT would not change. As mentioned above, the maize price is the same for MP and SPP, while the difference between the two is about 1.5 fold for cotton and wheat crops. Even when the treatments tested generated equal GMs when assuming different but increasing TVCs, the RR of the same treatments varied (table 8). It is likely that a maize-based intensive cropping system is prone to generate lower RR due to the stable maize costs regardless the pricing systems.

A number of studies worldwide underlined better economic and environmental positive impacts of CA practices in the long run. For example, the findings by Sayre and Hobbs (2004) on wheat-maize cropping system inspired the success in an early stage for wheat, but for maize this occurred after about 10 years only. A similar trend observed by other scholars during the long term rotation-tillage experiments (see for instance Jeffery et al., 2012; Delbridge et al., 2011; Stanger et al., 2008; Meyer-Aurich et al., 2006; Zentner et al., 2002; Sayre & Hobbs, 2004; Dos Santos et al., 1993; Zentner et al., 1992).

5. Conclusion

The study intended disclosing financial and economic benefits when integrating wheat and maize crops into the current cotton-dominated rotations and in addition when using conservation agricultural principles (here permanent bed with mulch) BP as compared to conventional practices (CT) of cotton, wheat and maize production. The maize under BP with crop residue retention (M+R) showed the highest potential, given the highest (630.6 \$/t) Gross Margin (GM) owing in particular to increased yields (29%). However, this practice under BP concurrently had a much lower RR than under CT, owing to the high costs of mulching (MC) which were caused by a purchase of the stover at the very onset of the trial. In contrast, wheat under BP with mulch (W+R) turned out to be the second most profitable practice that yielded a 16% higher GM than under CT, but a 1.2 fold lower RR.

The effect of tillage on cotton yield was not significant over the two years under examination as evidenced by similar GMs. On the other hand, the C-cc-C and C-C rotation systems had the lowest profitability among all the systems tested and are therefore least likely to be adopted by the risk averse farmers in Uzbekistan, unless higher rates of subsidy or better supportive services are to be provided. The scenario analyses showed that at higher than 249 \$/t and 267 \$/t raw cotton prices, which are at present only 91% and 85% of the current prices paid to farmers at SPP level, back-to-back cotton cropping systems could be kept competitive with the C+R-W+R and C-W rotations. To become the most profitable cropping system, the farm-gate price had to be increased to as high as 422 \$/t and 443 \$/t respectively, which is presently far out of reach.

At any cotton price tested, the BP practices were more beneficial than CT. This was true for wheat only at prices higher than 65 \$/t, and for maize at 94 \$/t which are presently 60% and 41% of the (SPP) prices paid. In any case, findings from previous studies combined with the current outputs underlined that wheat and maize are more beneficial compared to cotton even though at present the share of cotton production in the country is about 50% of all irrigated lands. Even at relatively low wheat grain prices, the GM of C-W (gain 87 \$/t) and C+R-W+R (98 \$/t) crop rotations were equal to the GMs of the C-C and C-cc-C rotations indicating the low profitability of the present cotton-dominant systems. With reference to maize, at grain prices as low as 71 \$/t, the C-W-M would become competitive with the C-C rotation systems whilst the same was true for the C+R-W+R-M+R cycle, which could compete with C-cc-C rotation system at a grain price of 98 \$/t. The relative ranking according to the profitability was in the order of C-C < C-cc-C < C-W < C+R-W+R < C-W-M < C+R-W+R-M+R. The C+R-W+R-M+R rotation ranked on top of the economic ranking among all rotation systems tested and therefore seems to be most resilient to an increase in raw cotton prices and increases in costs. On the other hand, at present cotton growing farmers have a fixed and warranted cotton price, which is attractive, at least to some extent. However, when abandoning all the state subsidies and service support for cotton and wheat, the C-W and C+R-W+R crop rotations appeared to have the highest potential, although the current ranking of C-C and C-cc-C would not change: C-C < C-cc-C < C+R-W+R-M+R < C-W-M < C-W < C+R-W+R. When assuming a liberalization of market prices, the total variable cost (TVC) would increase in the range of 1.5-2 folds in both BP and CT systems.

The main crops grown under BP with mulch provided better agronomic and economic performance and generated comparatively higher economic returns even under minimum crop prices and cultivation costs, which was due mainly to reduced external inputs combined with sustainable agronomic practices. However, the current level of residue amounts (10 t/ha) tested is far from an optimal value, generating substantially high costs (about 40% of TVC) owing to the high demand for livestock. Thus, supportive studies need to be initiated to evaluate the tradeoff that satisfies both sides of interest. Further studies need to be conducted while considering various land productivity and water constraints. When there is no water limit, diversified or intensive cropping systems are superior to other cropping patterns. Wider of crop options and more diversified crop cycles should be involved to evaluate long-term impact of tillage & rotation interactions under various constraints.

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References

Abdullaev, I. C., De Fraiture, M. G., Yakubov, M., & Rasulov, A. (2009). Agricultural Water Use and Trade in Uzbekistan: Situation and Potential Impacts of Market Liberalization. *Water Resources Development, 25*(1), 47-63. http://dx.doi.org/10.1080/07900620802517533

Alfandari, L., Lemalade, J. L., Nagih, A., & Plateau, G. A. (2011). MIP flow model for crop-rotation planning in a sustainable development context. *Annals of Operations Research, 190*(1), 149-164. http://dx.doi.org/10.1007/s10479-009-0553-0

Bezborodov, G., Shadmanov, Mirhashimov, D., Yuldashev, T. R., Qureshi, A., Noble, A., & Qadir, M. (2010). Mulching and water quality effects on soil salinity and sodicity dynamics and cotton productivity in CentralAsia. *Agriculture, Ecosystems and Environment, 138*, 95-102. http://dx.doi.org/10.1016/j.agee.2010.04.005

Boulal, H., Gómez-Macphersona, H., & Villalobosa, F. J. (2012). Permanent bed planting in irrigated Mediterranean conditions: short-term effects on soil quality, crop yield and water use efficiency. *Field Crops Research, 130*, 120-127. http://dx.doi.org/10.1016/j.fcr.2012.02.026

CGIAR. (2003). Conservation and Sustainable Use of Agricultural Biodiversity. Retrieved from https://idl-bnc.idrc.ca/dspace/bitstream/10625/35111/4/118718_v1.pdf

Cobuloglu, H. I., & Buyuktahtakin, I. E. (2015). Food vs Biofuel: An Optimization Approach to the Spatio-Temporal Analysis of Land-Use Competition and Environmental Impacts. *Applied Energy, 140*, 418-434. http://dx.doi.org/10.1016/j.apenergy.2014.11.080

Cobuloglu, H. I., & Buyuktahtakin, I. E. (2014). A Mixed-Integer Optimization Model for the Economic and Environmental Analysis of Biomass Production. *Biomass & Bioenergy, 67*, 8-23. http://dx.doi.org/10.1016/j.biombioe.2014.03.025

Delbridge, T. A., Jeffrey, A., C., Robert P., K., Craig C., Sh., & Donald W., L. (2012). Economic Performance of Long-Term Organic and Conventional Cropping Systems in Minnesota. *Agronomy Journal, 103*, 1372-1382. http://dx.doi.org/10.2134/agronj2011.0371

Devkota, K. P. (2011a). Resource utilization and sustainability of conservation based rice-wheat cropping systems in Central Asia. Ecology and Development Series No. 81, ZEF/University of Bonn, p. 180 (Doctoral Dissertation). Retrieved from http://www.zef.de/index.php?id=2212

Devkota, M. K. (2011b). Nitrogen management in irrigated cotton-based systems under conservation agriculture on salt-affected lands of Uzbekistan. ZEF/Rheinische Friedrich-Wilhelms-Universität Bonn, Germany, Bonn Germany, pp. 163 (Doctoral Dissertation). Retrieved from http://www.zef.de/index.php?id=2212

Devkota, M., Martius, C., Lamers, J. P. A., Sayre, K. D., Devkota, K. P., Gupta, R. K., …Vlek, P. L. G. (2013a). Combining permanent beds and residue retention with nitrogen fertilization improves crop yields and productivity in irrigated arid lands under cotton, wheat and maize. *Field Crops Research, 149*, 105-114. http://dx.doi.org/10.1016/j.fcr.2013.04.012

Devkota, M., Martius, C., Lamers, J. P. A., Sayre, K. D., Devkota, K. P., & Vlek, P. L., G. (2013b). Tillage anitrogen fertilization effects on yield and nitrogen use efficiency of irrigated cotton. *Soil & tillag Research, 134*, 72-82.

Djanibekov, N. (2008). A Micro-economic analysis of farm restructuring in the Khorezm region, Uzbekistan. (ZEF/University of Bonn, pp. 170 Doctoral Dissertation), from http://www.zef.de/index.php?id=2212

Djanibekov, N., Rudenko, I., Lamers, J. P. A., & Bobojonov I. (2010). Pros and Cons of Cotton Production in Uzbekistan (In: Per Pinstrup-Andersen and Fuzhi Cheng (editors), "Food Policy for Developing Countries: Case Study No. 7-9. p, 13. Cornell University, Ithaca, New York.). Retrieved from http://cip.cornell.edu/dns.gfs/1279121771

Djanibekov, N., Sommer, R., & Djanibekov, U. (2013). Evaluation of effects of cotton policy changes on land and water use in Uzbekistan: Application of a bio-economic farm model at the level of a water users association. *Agricultural Systems, 118*, 1-13. http://dx.doi.org/10.1016/j.agsy.2013.02.004

Djanibekov, U. (2014). Trees, crops, and rural livelihoods: Afforestation of marginal croplands in Uzbekistan. (Bonn University, p. 153 Doctoral dissertation), from http://www.zef.de/index.php?id=2289

Dos Santos, H. P. (1993). Effect of crop rotation on yields, soil chemical characteristics, and economic returns of zero-till barely in southern Brazil. *Soil & tillage research, 28*(2), 141-158. http://dx.doi.org/10.1016/0167-1987(93)90023-I

Dubovyk, O. (2013). Multi-scale targeting of land degradation in northern Uzbekistan using satellite remote sensing. (Bonn University, p. 120 Doctoral thesis). Retrieved from http://hss.ulb.uni-bonn.de/2013/3398/3398.htm

FAO. (2009). Global agriculture towards 2050. Retrieved from http://www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Global_Agriculture.pdf

FAO. (2014). Advantages and disadvantages of Conservation agriculture. Retrieved from http://www.fao.org/ag/ca/1c.html

FAOSTAT. (2012). Demographic inicactors and population and structure (FAO statistic Report, 2012). http://www.fao.org/docrep/018/i3107e/i3107e01.pdf

Forkutsa, I., Sommer, R., Shirokova, Lamers, J. P. A., Kienzler, K., Tischbein, B. C., … Vlek, P. L. G. (2009). Modeling irrigated cotton with shallow groundwater in the Aral Sea Basin of Uzbekistan: I. Water dynamics. *Irrigation Science, 27*(4), 331-346. http://dx.doi.org/10.1007/s00271-009-0148-1

Gilham, F. E., Bell, T. M., Arin, G. A., Matthews, C., Le Rumeur, & Hearn, A. B. (1995). *Cotton Production Prospects for the Next Decade*, Technical Paper No. 287, The World Bank, Washington, D C. Retrieved from http://elibrary.worldbank.org/doi/pdf/10.1596/0-8213-3312-7

Guadagni, M. M., Crole-Rees, R., A., & Khidirov, D. (2005). *Cotton Taxation in Uzbekistan: opportunities for Reform*, ECSSD Working Paper No. 41, The World Bank, Washington, D C. Retrieved from http://documents.worldbank.org/curated/en/2005/08/6353121/cotton-taxation-uzbekistan-opportunities-reform

Gürsoy, S., Sessiz, A., & Malhi, S., S. (2010). Short-term effects of tillage and residue management followingcotton on grain yield and quality of wheat. *Field Crops Research, 119*, 260-268. http://dx.doi.org/10.1016/j.fcr.2010.07.016

Hari-Ram, Yadvinder-Singh, Saini, K. S., Kler, D. S., & Timsina, J. (2013). Tillage and planting methods effects on yield, water use efficiency and profitability of soybean-wheat system on a loamy sand soil. *Experimental Agriculture, 49*, 524-542. http://dx.doi.org/10.1017/S0014479713000264

Hassan, I., Hussain, Z., & Akbar, G. (2005). Effect of permanent raised beds on water productivity for irrigated maize-wheat cropping system. In C. H. Roth, R. A. Fischer & C. A. Meisner (Eds.), Evaluation and Performance of Permanent Raised Bed Cropping Systems in Asia, Australia and Mexico. ACIAR Proceeding No. 121. http://aciar.gov.au/files/node/703/PR121%20Part%20A%20for%20Web.pdf

Hobbs, P. (2007). Conservation agriculture: what is it and why is it important for future sustainable food production? *Journal of Agricultural Science, 145*, 127-138. http://dx.doi.org/10.1017/S0021859607006892011l

ICAC. (2011). Cotton Fact Sheet Uzbekistan, retrieved from https://www.icac.org/econ_stats/country_fact_sheets/fact_sheet_uzbekistan_2011.pdf

Janova, J. (2012). Crop planning optimization model: the validation and verification processes. *CEJOR, 20*(3), 451-462. http://dx.doi.org/10.1007/s10100-011-0205-8

Jeffery, R. W., Matthew, P. J., Kraig, R. L., Richard, L. V., & Mark, C. M. (2012). Risk Analysis of Tillage and Crop Rotation Alternatives with Winter Wheat. *Journal of Agriculture and applied economics, 44*(4), 561-576. http://ageconsearch.umn.edu/bitstream/137123/2/jaae487.pdf

Kassam, A. H., Friedrich, T., Derpsch, R., & Kienzle, J. (2014). Worldwide adoption of Conservation Agriculture 6th World Congress on Conservation Agriculture, 22-27 June 2014, Winnipeg, Canada. Retrieved from www.ctic.org/WCCA/Proceedings

Kienzler, K. M., Lamers, J. P. A., McDonald, A., Mirzabaev, A., Ibragimov, N., Egamberdiev, … Akramkhanov, A. (2012). Conservation agriculture in Central Asia—What do we know and where do we go from here? *Field Crops Research, 132*, 95-105. http://dx.doi.org/10.1016/j.fcr.2011.12.008

Lingo. (2006). Optimization Modeling Software for Linear: Nonlinear, and Integer Programming (Lindo system). Retrieved from http://www.lindo.com/(last accessed 20.12.2014)

Meyer-Aurich, A., Janovicek, A. K., Deen, W., & Weersink, A. (2006). Impact of tillage and rotation on yield and economic performance income based cropping system. *Agronomy Journal, 98*(5), 1204-1212. http://dx.doi.org/10.2134/agronj2005.0262

Mueller, M. (2006). A general equilibrium approach to modeling water and land use reforms in Uzbekistan. (Doctoral thesis, Bonn University). http://hss.ulb.uni-bonn.de/2006/0801/0801.pdf

Mohamad, N. H. J., & Said, F. (2011). A Mathematical Programming Approach To Crop Mix Problem. *African journal of Agricultural Research, 6*(1), 191-197.

Mulumba, L. N., & Lal, R. (2008). Mulching effects on selected soil physical properties. *Soil and Tillage Research, 98*, 106-111. http://dx.doi.org/10.1016/j.still.2007.10.011

Naresh, R. K., Singh, S. P., & Chauhan, P. (2012). Influence of conservation agriculture, permanent raised bed planting and residue management on soil quality and productivity in maize-wheat system in Western Utter Pradesh. *Int. J. Life Sc. Bt. Pharm. Research, 1*, 27-33.

Pomfret, R. (2008). Tajikistan, Turkmenistan and Uzbekistan. In K. Anderson & J. Swinnen (Eds.), Distortions to Agricultural Incentives in Europe's Transition Economies. World Bank, Washington, DC.

Rudenko, Inna. (2008).Value Chains for Rural and Regional Development: The Case of Cotton, Wheat, Fruit and Vegetable Value Chains in the Lower Reaches of the Amu Darya River, Uzbekistan,(Master's dissertation, University of Hannover). Retrieved from http://www.zef.de/fileadmin/webfiles/downloads/projects/khorezm/downloads/Publications/Doctoral_Theses/Rudenko_2008.pdf

Rudenko, I., Lamers, J., & Grote, U. (2009). Can Uzbek Farmers get More for their Cotton? *European Journal of Development Research, 21*, 283-96. http://dx.doi.org/10.1057/ejdr.2009.3

Sarker, R., Talukdar, S., & Haque. A. (1997). Determination of Optimum Crop Mix for Crop Cultivation in Bangladesh. *Applied Mathematical Modelling, 21*(10), 621-632. http://dx.doi.org/10.1016/S0307-904X(97)00083-8

Sayre, K., & Hobbs, P. (2004). The raised-bed system of cultivation for irrigated production conditions. In R. Lal, P., Hobbs, N. Uphoff & D. Hansen (Eds.), Sustainable Agriculture and the Rice–WheatSystem. Ohio StateUniversity, Columbia, OH, USA, (pp. 337-355). http://dx.doi.org/10.1201/9780203026472.ch20

Sommer, R., Djanibekov, N., & Salaev, O. (2010). Optimization of land and resource use at farm- aggregated level in the Aral Sea Basin of Uzbekistan with the integrated model FLEOM– model description and first application. (ZEF Discussion Papers 139), from http://www.zef.de/uploads/tx_zefportal/Publications/ZEF_DP_139.pdf

Spoor, M. (1999). Agrarian transition in former soviet Central Asia: a comparative study of Kazakhstan,Kyrgyzstan and Uzbekistan, Institute of Social Studies, (WP 298, 25). Retrieved from www.unece.org

Stanger, T. F., Lauer, J. G., & Chavas, J. P. (2008). The profitability and risk of long-term cropping systems featuring different rotations and nitrogen rates. *Agronomy Journal, 100*, 105-113. http://dx.doi.org/10.2134/agrojnl2006.0322

Sutton, W., Whitford, P., Stephens, E. M., Galinato, S. P., Nevel, B., Plonka, B., & Karamete, E. (2007). Integrating environment into agriculture and forestry. Progress and prospects in Eastern Europe and Central Asia. Main Report, Europe and Central Asia Region Sustainable Development Department, World Bank. Retrieved from https://ideas.repec.org/b/wbk/wbpubs/6551.html

Tursunov, M. (2009). Potential of conservation agriculture for irrigated cotton and winter wheat production in Khorezm, Aral Sea Basin. (ZEF/Rheinische Friedrich- Wilhelms-Universität Bonn, p. 94. Doctoral Dissertation). Retrieved from http://hss.ulb.uni-bonn.de/2009/1632/1632.pdf

Uri, N. D. (2000). An evaluation of the economic benefits and costs of conservation tillage. *Environmental Geology, 39*(3-4), 238-248. http://dx.doi.org/10.1007/s002540050004

USDA (2012). Economic Policy and Cotton in Uzbekistan, Report by Stephen MacDonald. (Outlook No.CWS-12h0 26 pp.). Retrieved from http://www.ers.usda.gov/media/935015/cws12h01.

Watkins, K. B., Hignight, J. A., & Anders, M. M. (2011). The impacts of farm size and economic risk on no-till rice whole-farm profitability. In Selected Paper Abstracts, Annual Meeting. *Research in Agriculture & Applied Economic, 43*,461.

Zadoks, J., C., Chang, T., T., & Zonzak, C. F. (1974). A decimal code for the growth stages of cereals. *Weed Research, 56*, 309-314. Retrieved from http://dx.doi.org10.1111/j.1365-3180.1974.tb01084.x

Zentner, R. P., Brandt, S. A., Kirkland, K. J., Campbell, C. A., & Sonntag, G. J. (1992). Economics of rotation and tillage systems for the Dark Brown soil zone of the Canadian Prairies. *Soil Tillage Research,* 24, 271-284. http://dx.doi.org/10.1016/0167-1987(92)90092-P

Zentner, R. P., Lafond, G. P., Derksen, D. A., & Campbell, C. A. (2002). Tillage method and crop diversification: Effect on economic returns and riskiness of cropping systems in a Thin Black Chernozem of the Canadian Prairies. *Soil Tillage Research, 67*, 9-21. http://dx.doi.org/10.1016/S0167-1987(02)00028-4

Appendex A. Crop rotations

Crop Rotation No 1

1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December
cover crop			COTTON							COVER CROP					COTTON							cc	
Fertilizers			PK		N	N									PK		N	N					

Crop Rotation No 2

1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December
no crop			COTTON							WHEAT B								fallow					
Fertilizers			PK		N	N								N	N			PK	N	N			

Crop Rotation No 3

1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December
no crop			COTTON							WHEAT B								MAIZE				no crop	
Fertilizers			PK		N	N								N	N			PK	N	N			

*N*ote. Here, crop rotation N1 for only in BP with cover crop (C-cc-C) was depicted. Crop rotation in CT, cotton – cotton(C-C) was back-to-back cotton rotation system without cover crop.

Appendix B. Commodity price, cost and revenue variable used to calculate total variable cost and Gross Revenue in cotton-wheat-maize cropping system, 2009

Item	Cotton	Wheat	Maize
Gross revenue			
Crop price at SPP (US$/t)	227	108	227
Crop price at MP (US$/t)	333	227	227
Byproduct			
Crop residues (US$/t)	36	33	30
Variable costs			
Ammonium-Nitrate (US$/t)	152	152	152
Ammonium-Phosphate(US$/t)	307	307	307
Potassium-Chloride(US$/t)	553	553	553
Seed (US$/t)	735	251	227
Labor (US$ a person/day)	3.308	3.308	3.308
Diesel (US$/t)	716	716	716
Electricity (US$/unit)	0.046	0.046	0.046

Note. 1 US$ - 1511 Uzbek Soum in 2009.

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