Djanibekov, N., Sommer, R. and U. Djanibekov (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

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

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Abstract Various agricultural policies have been implemented in post-Soviet countries as they move from centrally planned to market economies. In the agriculture sector of Uzbekistan, Central Asia, several reforms have been implemented to increase the operational autonomy of agricultural producers. However, land and water use in agriculture remains directly linked to the centrally regulated cotton production. Still partly resembling the design of the state orders imposed during the planned economy, cotton production policy is used to ensure the stability of national export revenues at the expense of farm incomes. In this paper we argue that modifying the cotton policy may improve the situation with farm incomes and food production, and reduce pressure on water resources, the availability of which in Central Asia is expected to decrease. To conduct an ex ante analysis of cotton policy modifications intended to improve rural incomes, a bio-economic optimization model was developed at the level of a water users association in the Khorezm region of Uzbekistan. Policy simulations showed that abolishing the current cotton policy would be a more economically attractive option for farmers and also increase grain production rather than various forms of this policy modification. However, abolishing the current cotton policy can present pressure on irrigation water resources as farmers would opt to cultivate water-intensive crops, thus requiring supplemental policies and institutions for sustainable resources use.

Keywords: Agricultural policy analysis; Cotton targets; Food grain production; Farm incomes

1. Introduction

Previous studies have showed to which extent government policies of intervention or liberalization in agriculture impact production and consumption of farm products, as well as welfare and ecology (Spoor, 2002; Anderson, 2007). These studies on agricultural policies have provided contrasting results. For instance, in China agrarian success was due to the lack of restrictions on farmer's decision-making, which led to the adoption of agricultural innovations and shifts in the output mix (Pomfret, 2000). At the same time agricultural liberalization in developing countries increased the level of crops output through intensification and cultivated land area expansion, both of which also resulted in negative environmental effects (Lutz, 1992). State agricultural price support in Switzerland led to chemical application per hectare being ten times higher than in Argentina and Australia, thereby affecting the Swiss environment (Anderson, 1998). In post-Soviet countries the transition from a planned to a market economy has been motivated by various political and economic objectives (Csaki and Nucifora, 2005). The discrepancies between centrally set plans and actually realizable farm output in the late-1980s led to ongoing and substantial losses in agricultural production (Lerman, 2009) and to increasing deterioration of the environment (Spoor, 2002). Since these countries' independence in 1991 there have been various agricultural reforms, such as the abolishment of state planned production and the distribution of land to individual producers. However, the main agricultural policies have remained centrally set in some countries even after their independence, for example cotton production policy in Uzbekistan.

Uzbekistan ranks fifth among 90 cotton-growing countries (6% of the global cotton production) and is the second-largest exporter in the world (11% of the world cotton export; FAO, 2011). Cotton occupies up to half of the country's total cropland area under the state regulated production that implies an implicit taxation of cotton-growing farmers (Müller, 2008). The design of cotton policy in Uzbekistan was detailed by Müller (2008), Pomfret (2008), Bobojonov et al. (2010) and Djanibekov et al. (2012). A centerpiece of this policy is farmers' fulfillment of production targets fostered through the maintenance of exclusive state land ownership. Farmers are granted solely non-transferable, usufruct rights based on land lease contracts up to 50 years (Djanibekov et al., 2012). According to the cotton policy, the state determines a certain set of rules related to the location, area and output of cotton cultivation. The first element of this policy is the *location-based target* according to which cotton farmers have to grow cotton on fields that are considered the most suitable for cotton cultivation. Following this the *area-based* target of cotton policy states that farmers should annually allocate about half of their cropland to cotton cultivation. Finally, the *quantity-based target* implies that farmers have to reach a certain level of cotton yield to fulfill the production level assigned to the cotton cultivation area. The state purchases the entire cotton harvest from farmers at prices below the potential border prices. In 2003-2009, the average price paid to Uzbek farmers for raw cotton was about 290 USD t^{-1} (OblStat, 2010). This price was higher than in Tajikistan (165 USD t^{-1}) and Turkmenistan (188 USD t^{-1}), but lower than in neighboring countries such as Kazakhstan (550 USD t^{-1}) and Kyrgyzstan (450 USD t^{-1}), who abolished their cotton policies in 1990s (Pomfret, 2008). Despite guaranteeing the accumulation of the current state accounts (CDPR, 2008) the present cotton policy has been causing farm losses and reducing farm incentives to produce more cotton beyond the production target. Continuous failure to fulfill the cotton production target by a farmer can in turn constitute grounds for losing his land lease (Djanibekov et al., 2012).

The supply infrastructure of main input that rural livelihood rely upon in the drylands of Uzbekistan - irrigation water resources - is primarily designed for supporting cotton cultivation. Consequently, cotton production goes at the expense of cultivating other crops, e.g. those required for achieving food security. Furthermore, currently inefficient irrigation practices lead to environmental deterioration (Cai et al., 2003), and it is expected that in the near future the national water demand will by far outstrip its supply (O’Hara, 2000). In this respect, the likelihood of food insecurity and vulnerability to reduced water supply will depend on the design of cotton production policy.

Modifying the cotton policy could be an approach for increasing rural incomes and food security, as well as enabling agricultural resilience to the expected water scarcity and increasing demand for water. The state policy of cotton production can be modified within a wide range of options: shifting from area-based to quantity-based targets, up to the complete abolishment of this policy (Müller, 2008; Pomfret, 2008; Rudenko et al., 2009; Bobojonov et al., 2010; Kienzler et al., 2011). In African countries, liberalizing the cotton production sector has contributed to a higher benefit for producers and a resurgence in output, despite threats from the depressed world cotton fiber prices (Poulton et al., 2004). Govereh and Jayne (2003), using instrumental variable analysis, showed that under no state intervention in production those farmers cultivating cotton could obtain higher grain yields than non-cotton producers in Zimbabwe.

The complexities of farming systems and agricultural policies as a whole necessitate an integrated assessment that covers various facets in a holistic fashion (Bland, 1999). Development policies need to focus on sustainability issues that consider multidimensional physical, environmental and economic aspects (Sulser et al., 2001). This diversity of options highlights the necessity to quantitatively assess the impacts of cotton policy changes on other crops, as well as on land and water use. To address these issues, we apply a mathematical programming model that combines economic and ecological aspects to a case study of a water users association in the Khorezm region, Uzbekistan, which mirrors properties of the country's cotton production policy. The objectives of this paper are twofold: (i) to identify the income and foodgrain prospects of modifying the state policy of cotton production towards a more flexible decision-making of farmers; and by doing so (ii) to discuss the impact of examined changes in cotton policy on farmers' sustainability incentives through changes in land and water use.

2. Methodology for analyzing cotton policy changes

2.1 Study area

The Khorezm region lies between 60°05′ N and 61°39′ E longitude and between 41°13′ and 42°02′ N latitude, in the Northwest of Uzbekistan, in the lower reaches of the Amudarya River (Fig. 1). In Khorezm, the agricultural sector accounts for roughly 35% of regional GDP. Nearly 1.7 million people reside in Khorezm, with 70% living in rural areas (Djanibekov U. et al., 2012). The region consists of 680,000 ha, of which nearly 270,000 ha are suitable for irrigated agricultural production, which is subject to the water inflow from the Amudarya River. The region is characterized by a semi-desert climate. Potential evapotranspiration exceeds precipitation during most of the year. Each year from October to May, Khorezm receives an average precipitation near 101 mm, making crop cultivation fully dependent on irrigation water that is withdrawn from the Amudarya. The annual water supply to Khorezm fluctuates between 2.2-5.4 km^3, and almost all of it is used for irrigation and leaching in the agricultural sector with a total annual withdrawal of 4.5 km^3 in water-abundant years (Tischbein et al., 2012). During the last thirty years, the frequency of water shortages experienced in Khorezm has increased (Müller, 2006).

<Fig. 1>

To represent the Khorezm region we selected the *Pakhlavan Makhmud* water users association (WUA) located in the Khiva district of the Khorezm region (Fig. 2a). The WUA covers 822 ha and consists of 227 distinct farm fields (with a maximum size of about 15 ha) with four soil textures prevailing: sand, loamy sand, sandy loam and loam. From this WUA we selected seven cotton-grain growing farms.

<Fig.2>

The sizes of the modeled farms range from 83 ha to 161 ha. Each farm is distinguished by the soil typology of its fields and location to irrigation canals (and thus accompanying water conveyance losses) according to which the most suitable locations for cotton cultivation are identified (Fig. 2b). Farms 1, 2 and 5 have advantages in cotton cultivation over other modeled farms, as they are endowed with the largest share of land with loamy soils, which are most suitable for cotton cultivation. The distance to irrigation canals reduces this advantage in cotton production for Farm 1 compared to Farm 5. The soil types with low suitability for cotton cultivation are mainly found in Farms 3 and 6. Compared to Farm 6, Farm 3 is further disadvantaged in cotton production due to the distance of its fields to irrigation canal.

<Table 1>

2.2 The model

To address the research objectives, a Farm Level Economic Ecological Optimization Model (FLEOM) was developed within the framework of a ZEF/UNESCO Khorezm project (www.khorezm.zef.de) as a land use planning support tool for decision-making at the level of farms and water users associations (WUA), aimed at providing coupled ecological-economical optimization of land allocation. Designed at a WUA level, the model allows for a quantitative analysis of agricultural policies in Uzbekistan. The FLEOM captures the basic features of the regional agriculture, as well as the interrelations of production activities most prevalent to the local farmers. It integrates, aggregates and optimizes field-level management decisions on the allocation of water, inputs and labor in a spatially-explicit way. Furthermore, the FLEOM relates farm-level decisions with constraints or goals (optimization) of networks at the next-higher level, such as WUAs or farmer associations. To meet these requirements, the size of a target area for FLEOM lies in the range of a WUA of around 1,000 ha, but it can also handle individual farms of different sizes. The overall objectives of developing FLEOM were to:

- understand options for optimal and sustainable land and resource allocation that improve agricultural incomes without compromising the quality of land and water resources;
- explore options to increase farm income while maintaining crop production with medium-term sustainable land management;
- assess opportunities to promote the efficient use of irrigation water;
- analyze the effects of various external 'shocks' on farm incomes and crop production, cropping patterns, water and resource use;
- develop and suggest optimal land use under alternative environmental conditions, e.g., water scarcity, to stakeholders.

Potential users of this tool are medium-level stakeholders such as WUA representatives, the local water authority, and farmer associations. Moreover, the model is intended to be a tool for scientists and to suit university education. The detailed description of the FLEOM model is presented in Sommer et al. (2010).

At the core of FLEOM, a linear programming approach is utilized. In the objective function (Eq. 1), production activities and management variants (X) are optimized at an individual farm level by maximizing the total farm gross margin (Z) of producing i crops on j farm fields with c crop-specific gross margins (USD ha^{-1}). The model takes into account the available arable land (b) comprising j fields in each farm (Eq. 2) and the amount (w) of irrigation water supply (Eq. 3). The design of the cotton policy is incorporated via several constraints. Each farm has to allocate at least 55% of its arable land to cotton cultivation, i.e., the area ($\bar{x}$) set by the state with respect to farm size (Eq. 4), to deliver cotton output at an amount not less than the product of average achievable cotton yield ($\bar{y}$) and the target area ($\bar{x}$) (Eq. 5), as well as produce cotton on fields identified to be the most suitable for this (Eq. 6). In detail, the model comprises the following equations:

Objective function of the model is the maximization of farm gross margins:

$$max\ Z = \sum_i \sum_j c_{ij} X_{ij} \tag{1}$$

The crop gross margins are calculated as output value per unit of activity, less the sum of imputed costs such as seeds, fertilizers, pesticides, labor and machinery costs, land tax, and other fixed costs observed in 2010.

Constraint of farm land endowments implies that cultivation area X under *i* crops should not exceed a specified area b of various *j* fields:

$$\sum_i X_{ij} \leq b_j \tag{2}$$

The farms receive a certain amount of water w that they use for irrigation of *i* crops at k irrigation rates:

$$\sum_i \sum_j k_{ij} X_{ij} \leq w \tag{3}$$

According to the *area-based* target of the cotton policy, the area of cotton cultivation X should not be less than the one set by the state $\bar{x}$ (in ha):

$$\sum_j X_{ij} \geq \bar{x}_i \quad \text{, where } i = \text{cotton.} \tag{4}$$

In our case, each farm has to allocate at least 55% of its arable land to cotton cultivation.

According to the *quantity-based* target of the policy, the total cotton output (in t) should not be less than the one set by the state. In our case, the amount of cotton produced by a farm should not be less than target yield $\bar{y}$ of 2.6 t ha^{-1} multiplied by the area set for cotton cultivation $\bar{x}$:

$$\sum_j Y_{ij} X_{ij} \geq \bar{y}_i \bar{x}_i \quad \text{, where } i = \text{cotton, and } Y \text{ is the cotton yield.} \tag{5}$$

Finally, the *location-based* target of the cotton policy implies that farmers should allocate not less than a certain area of their *j* fields predetermined as the most suitable for cotton cultivation (s):

$$X_{ij} \geq s_{ij} \quad \text{, where } i = \text{cotton, and } j = \text{fields most suitable for cotton cultivation.} \tag{6}$$

Production activities comprise four major crops: cotton (*Gossypiumhirsutum L.*), winter wheat (*Triticumaestivum L.*), rice (*Oryzasativa L.*) and maize (*Zeamais L.*), which occupied more than 76% of the sown area and required 82% of total irrigation water in the

Khorezm region in 1998-2006 (OblStat, 2010). Among the modeled crops, winter wheat (hereafter referred to as wheat) covers 60% of the total annual food energy supply in Uzbekistan (FAO, 2011). Cotton has the lowest profit per hectare and the longest period of land occupation, while rice is the most profitable and water-intensive crop in the region and, along with maize, has the shortest period of land occupation to be included in double-cropping with wheat (Djanibekov U. et al., 2012).

The socio-economic dataset was compiled from survey data of 80 randomly selected farmers conducted in Khorezm in 2010, and provides information on input and output prices, crop labor requirements, diesel use, working hours of combine harvesters, costs at different field operations for four modeled crops, and transportation costs.

The agronomic database for cotton, wheat and maize that underlines FLEOM was established with the cropping system simulation model, CropSyst (Stöckle et al., 2003), using data sets, field experience and knowledge of a range of agronomic and hydrological studies on irrigation and fertilizer responses, planting dates, tillage and residue management within the ZEF/UNESCO Khorezm project (see Sommer et al. (2010) for details on agronomic data generation, and Djumaniyazova et al. (2010) for details on the wheat simulations). The database on rice is based on the socio-economic evaluation completed by Djanibekov (2008). The irrigation amount and timing used in CropSyst simulations were based on irrigation recommendations of the Uzbek hydro-module scheme developed for Khorezm (Forkutsa et al., 2009; Djumaniyazova et al., 2010) considering climate, crop, maximum rooting depth, soil texture, groundwater depth, and field efficiency.

2.3 Cotton policy scenarios

To evaluate the coupled effects of the cotton policy changes, we simulated several directions in which cotton policy can be modified under a *ceteris paribus* condition jointly for the seven modeled farms. We assumed that the total irrigation water volume in a year with normal water availability, i.e., 11,355 m^3 ha^{-1}, for the modeled farms is equal to the amount of irrigation water that was used for the modeled crops in 1998-2009, except the water scarce years in 2000-2001, when the water supply dropped by almost 41% (OblStat, 2010). The water availability levels were assumed to vary within a range of ±50% of the normal water availability level. Concurrently, in the simulations we maintain the observations that the farmers are not charged for water use, namely the costs related to irrigation are only those born by using diesel and electric water pumps (Djanibekov et al., 2012).

We analyze four scenarios of cotton policies distinguished by changes in raw cotton prices and the type of considered production targets (Table 2):

- *Present cotton production policy* scenario (SCEN1) reflects the baseline scenario with the existent design of cotton policy that determines the farm fields, area and output targets for cotton cultivation. Cotton producing farmers have to allocate a certain area of their land for cotton plantations and produce at least a specified amount of cotton at the state-determined price;
- *'Flexible area- and quantity-based policy'* scenario (SCEN2) assumes a slight modification of the first scenario, where farmers are free to decide locations of cotton cultivation, i.e., the location-based production targets are relaxed. Still, farmers have to allocate a specified area of their land to produce a predetermined amount of cotton and sell it at the state-determined price;
- *'Flexible quantity-based policy'* scenario (SCEN 3) assumes further modification in cotton policy, where farmers are free to decide not only the location but also the total area of cotton cultivation. Still, these farmers have to produce a predetermined amount of cotton at the state-determined price;
- *'Liberalized policy'* scenario (SCEN4) assumes a situation where farmers are fully flexible in their decision making of what crop, where, and using what technology to cultivate for maximizing their profits on an entire cropland area subject to water availability. In contrast to studies by Rudenko et al. (2009) and Bobojonov et al. (2010), we did not observe input price differentials previously practiced by the government as an integral part of subsidizing the cotton-growing farmers. Therefore, SCEN4 assumes only the increase in the farm-gate price of raw cotton without changes in input prices. The grain prices are kept unchanged in the scenario simulations. In addition, while in the previous three scenarios the government purchases the entire cotton harvest, in SCEN4 we assume that new buyers enter the market (e.g. private ginneries), which then purchase the harvest from farmers. The simulation results are compared between modification scenarios and the baseline situation.

The results of scenario simulations are reported by showing changes in profits, production activities, and shadow prices of land and water use at the aggregated WUA-level.

<Table 2>

2.4 Locations most suitable for cotton cultivation

Prior to simulating the proposed cotton policy changes we first identify those fields that are the most suited for cotton cultivation in the modeled WUA. These fields are further used in the SCEN1 simulation accounting for the *location*- and *quantity-based* targets of the cotton policy. For this we run the model using the business-as-usual information only for cotton cultivation, i.e., the activities for other modeled crops are fixed to zero. The model solution identifies the fields where each modeled farm can achieve the highest possible cotton yield (Fig. 2b). In this respect, the cotton yields vary among farms in response to distance of their fields to irrigation canals and their soil attributes. For instance, in the modeled situation, farms with land less suitable for cotton cultivation or fields located relatively further in irrigation system (Farms 3, 4, 6 and 7 in Fig. 2a and Table 1) would only be able to achieve cotton yields below 2.6 t ha^{-1}. Farms endowed with fields with loamy soil structure - most suitable for cotton cultivation - even if their fields are located further from the irrigation canals (Farms 1, 2 and 5 in Fig. 2a and Table 1), would be able to achieve cotton yields above 3 t ha^{-1}.

2.5 Alternative cotton prices

To determine an alternative price (‘new’) for raw cotton for SCEN 4 that would maintain the same level of cotton production without imposing the cotton production targets, we simulated a stepwise increase in levels of the quantity-based target of cotton policy from zero (no-cotton) to maximum possible level at normal water availability. The simulation results show that it is possible to increase the quantity-based cotton target up to 60% from the observed level, the highest possible level of cotton production within the modeled area. The increase in the cotton target would result in economic losses of the modeled farms, measured as a decrease in the average land profitability, i.e., in the value of the model’s objective function divided by total cultivated area. These economic losses are highly elastic (1.18) to the cotton production target levels (Fig. 3). With no cotton policy in place, the average profitability of land would be 535 USD ha^{-1}, while at the business-as-usual situation, land profitability would be 212 USD ha^{-1} (see SCEN 4 and SCEN1 at normal water availability level in Fig. 7a). Among the modeled grain crops, the production of maize is more sensitive to changes in the cotton production target. These results indicate that grain crops are highly responsive to modifications in the cotton policy.

<Fig. 3>

At the observed prices of wheat, maize, rice and inputs, the new cotton prices would be the sum of the procurement price observed in 2009 (274 USD t^{-1}), and the shadow price of the constraint imposed by the cotton production target (249 USD t^{-1}). In our case, the shadow price of the policy instrument indicates the value by which the profit of the modeled system would increase once the state target for mandatory land allocation under cotton cultivation and the amount of cotton to be produced is reduced by one hectare and one ton, respectively. When the state policy of cotton production is abolished, a substantially higher raw cotton price compared to the observed level in 2009 would be needed to achieve the same amount of cotton production. In this way, an increase in raw cotton price to 524 USD t^{-1} (an increase by 90% compared to the observed price level) would keep the cotton production at the present level that was imposed by the cotton policy in 2009 (1,045 t of raw cotton for the modeled area). This level of raw cotton price is used further in SCEN4.

The new price of raw cotton is close to what cotton producers received in 2003 in Kazakhstan (i.e., 550 USD t^{-1}; Pomfret, 2008). This new price would increase the gross margins of cotton from 51 USD ha^{-1} to 952 USD ha^{-1}, making it competitive with a wheat-maize rotation within the modeled system. Since raw cotton is not exported, to compare its price with world market prices we convert raw cotton into cotton fiber using the ginning ratio of 33% (Rudenko et al., 2009). In this way, we derive the price of 1,563 USD t^{-1} of cotton fiber at no processing costs. This fiber price falls into the range of monthly world market prices of cotton fiber, which varied between 880 USD t^{-1} and 1,798 USD t^{-1} in 2002-2009 (Cotton A Indices; NCC, 2010). As shown in Fig. 4a, in the modeled system, it would be economically unattractive to produce cotton at prices below 1,306 USD t^{-1} of cotton fiber, or 431 USD t^{-1} of raw cotton. This cotton fiber price was observed in less than half of the cases of average monthly world prices in 2002-2009 (Fig. 4b).

Furthermore, the modeled system would be unresponsive to increases in cotton fiber prices between 1,790 USD t^{-1} and 2,400 USD t^{-1}. The latter value is 80% higher than the average level of monthly world market prices of cotton fiber observed in 2002-2009. Only under such substantial increase in cotton price cotton cultivation could expand further by competing with the high value wheat-rice rotation, as well as shift to fields that are less suitable for cotton cultivation. In this respect, at least the same amount of produced cotton would be ensured by about 17% of cases of observed monthly world prices in 2002-2009.

<Fig. 4>

3. Model results

3.1 Spatial location of crops

The model results show that with the modification of the cotton policy the cotton cultivation will be shifted from fields located next to irrigation canals to fields further away (Fig. 5; see Table A in the Appendix for the values of cultivated area at different distances to irrigation canal). The results of the four scenarios at the normal water availability levels are summarized in Table B in the Appendix. In the overall structure of land use and water demand, the comparison between the present situation (SCEN1) and the situation with abolished cotton policy (SCEN4) shows that the cotton cultivation area would decline (-27%), while the area under grain crops would expand (+23%). Furthermore, with the abolishment of the current cotton policy, the structure of water demand would shift towards grain crops. In all simulations of modification of cotton policy under normal water availability, rice would be the largest consumer of water. However, when water is scarce, in all scenarios, cotton would require the largest amount of water. In all scenarios with the increase in water availability, the area of rice cultivation would expand at the expense of less water-intensive maize production.

<Fig. 5>

The model reveals three distinct shifts in land use driven by the cotton policy modification and the availability of irrigation water (Fig. 6). As can be seen from Fig. 6, in case farmers are free to decide on cotton location and area, at the new cotton price of 524 USD ha^{-1} they would specialize in crops according to their endowment in land (soil type) as well as distance to the main irrigation canal. Farms with land most suitable for cotton cultivation (Farms 1, 2 and 5 in Fig. 2a and Table 1) would increase their specialization in cotton production at the expense of grain crops. Producers endowed with land less suitable for cotton cultivation and fields bordering irrigation canals (Farm 6 in Fig. 2a and Table 1) would reduce cotton production in favor of rice cultivation. Farms endowed with land less suitable for cotton and located further from irrigation canals (Farms 3, 4 and 7) would opt for less water-intensive crops, such as maize. Thus, in general, the farmers' flexible decision-making could result in a shift to crops with higher economic returns in locations closer to the main irrigation canals.

<Fig. 6>

Although the observed output and input prices favor water-intensive rice cultivation, the decrease in water availability in the baseline scenario (SCEN1) would replace wheat-rice rotation with wheat-maize rotation in fields located nearest (following cotton fields) to irrigation canals. The increase of water availability when cotton production is not bound to certain fields (SCEN2) would shift cotton to the fields located further away from irrigation canals and instead favor the wheat-rice rotation. This shift would also result in a reduced area of the wheat-maize rotation. When farmers have to fulfill only a quantity-based target, (SCEN3), cotton would be cultivated on fields located even further away from the irrigation canals. In this case, the production technologies (such as nitrogen application and irrigation rates) could be selected to increase the yields of cotton while reducing its cultivation area. Under the liberalization of cotton production (SCEN4), the cropping pattern would be presented by combinations of wheat, rice, and maize. Similar to other scenarios where the water availability is decreased, the wheat-rice rotation would be replaced by wheat-maize on fields located near the irrigation canals. This is consistent with field observations, and in the range of results from other studies that used models of different scales in Khorezm (Djanibekov, 2008; Bobojonov et al., 2010).

3.2 Farmland and water profitability

As expected, modifying the cotton policy would increase farm profits (Fig. 7a). In years with normal water availability and operating under a business-as-usual design of the cotton policy (SCEN1), the profitability of land would be about 212 USD ha^{-1}. The removal of the location-based target of cotton policy (SCEN2) would increase the average farm profit per hectare of sown area by 11%, while the additional removal of the area-based target (SCEN3) would increase farm profits by about 20%. Furthermore, the land profitability curves diverge between SCEN 1, SCEN2 and SCEN 3 when the water availability increases. The complete abolishment of the cotton policy (SCEN4) would have the highest impact on land profitability, and the land profitability curve becomes more flat compared to the other scenarios of cotton policy. This indicates that profits of farmers with more freedom in their decision-making would become more resilient to water scarcity. In SCEN2 and SCEN3, the water profitability, or farm profits produced by a cubic meter of water, will peak at some level of water availability and decrease thereafter (Fig. 7b). However, when the cotton policy is abolished (SCEN4), the model results show that the water profitability curve would have a downward trend as response to the increase in the area of rice cultivation.

<Fig. 7>

3.3 Production of cotton and grains

The removal of the location-based target (SCEN2), which determines that farmers grow cotton on fields most suited for its cultivation, would reduce the average cotton yield when compared with those in SCEN1 (Fig. 8a). The abolishment of the area-based target in SCEN3 would increase cotton yields such as to fulfill the quantity-based target by allocating less land. The exempted land would be available for more profitable double-cropping systems of wheat-rice and wheat-maize. The liberalization of cotton production in SCEN4 would result in the highest cotton yield among all scenarios. Under normal water availability, the liberalized cotton production would result in higher average cotton yields compared with the baseline situation (3.1 t ha^{-1} in SCEN4 against 2.6 t ha^{-1} in SCEN1). Furthermore, the increased decision-making flexibility would allow farmers to achieve higher cotton yields at about 3.3 t ha^{-1} when the water availability is decreased. This demonstrates that when cotton production is liberalized, cotton may become more attractive than rice in water scarce years.

The model results show that fixing fields for cotton growing (SCEN1) would limit the ability of farmers to adjust their cropping patterns according as response to the water availability level. Among analyzed scenarios, SCEN1 has the lowest grain output (Fig. 8b). Removing solely the location-based target (SCEN2) would provide prospects for improving grain production irrespective of the level of water availability. Removing the area-based target (SCEN3) would result in a further increase in grain production, while the complete abolishment of the cotton policy (SCEN4) would result in the highest level of grain production.

<Fig. 8>

3.4 Value of land and water under policy changes

To assess the implications of cotton policy modifications on land and water use within the modeled system, we analyzed shadow prices of land and water availability constraints. In our case, the shadow prices of land and water availability constraints imply the maximum price that farmers would be willing to pay for an extra unit of these resources, i.e., for land (in USD ha^{-1}) and water (in USD m^{-3}). As the FLEOM comprises 227 farm fields, the shadow price of land in our case is the average value of all farm fields. The shadow price of land (Fig. 9a) determined by FLEOM fell in the range of observed seasonal rents for cropland (200-700 USD ha^{-1}in June-September) which differed according to the location of the field and its soil attributes.

Among the simulated scenarios in the situation of decreased water availability, the value of water was highest when the cotton policy was modified (SCEN2 and 3; Fig. 9b). This indicated that when the location-based target is modified, the emerging most profitable cropping patterns would increase the pressure on irrigation water resources. However, when the farmers are free in their production decisions (SCEN4), the shadow price of water would be less responsive to water availability. In the situations of water abundance, SCEN4 produced the highest shadow price of water among simulated policies, thus indicating the pressure on irrigation water resources would grow further when farmers are more flexible in making their production decisions.

When comparing the trends between shadow prices of land and water, the model results show that abolishing the current cotton policy (SCEN4) would increase the value of water (Fig. 9b), in turn causing the stagnation of the land value (Fig. 9a). In other words, withdrawing 1 ha of cropland from agricultural production (for instance due to land degradation) would have the highest adverse impact on farm profits when the cotton policy comprised location-, area- and quantity-based targets that limit the availability of land for cultivating high value crops. In contrast to modified cotton policy (SCEN2 and 3), its complete abolishment would give more flat response of land values to the levels of water availability. This implies that in a situation when farmers are free to decide where and what crop to cultivate, the shadow price of land can be lower compared to the situation where the government assigns the cotton production targets. At the same time, the effect of abolishing the cotton policy on the value of farmlands located in some distance from irrigation canals would not be substantial, as crop cultivation on these fields is also determined by distance to a main irrigation canal. Since abolishing the current cotton policy increases land available for use at farmers' discretion they may tend to turn towards more water-intensive rice cultivation. This shift in cropping pattern towards water-intensive crops would raise the water demand and in turn increase the value of water compared to the situation with the current cotton policy.

<Fig. 9>

4. Discussion

Although this study is based on one water user association in Khorezm, the model results can contribute to the discussion on policy options available for promoting income and food security of agricultural producers in other irrigated areas of Uzbekistan that are prone to water scarcity and have their largest share of land and water allocated to cotton cultivation. Furthermore, the analysis can be extended to Turkmenistan, where large irrigated areas with agro-ecological conditions that closely resemble those observed in Khorezm are still under state-regulated cotton production (Pomfret, 2008). The analyzed case demonstrates how the increase in flexibility of farmers' decision-making can improve grain production and farm profits. It is repeatedly stated that the design of cotton policy is not conducive for farmers to produce more cotton beyond the state target (Pomfret, 2008). For instance, the lack of restrictions on farmer's production decisions was among the key elements in China's agricultural growth in the early 1980s (Pomfret, 2000). Our results show that abolishing the restrictive cotton policy would likely cause the cotton yield in Khorezm to increase from 2.6 tha^{-1} to 3.2 t ha^{-1} without affecting its production level. Among the analyzed scenarios, the deregulation of cotton production would result in a substantial improvement of farm profits, while modifying the cotton policy would bring only a slight increase in farm profits. However, this gain in profits would likely be offset by additional transaction costs that farmers would have to bear when negotiating with new players (e.g., private ginneries) entering the more profitable cotton sector and facing stricter quality standards when the cotton production is liberalized. The changes implied by the increase in the domestic price of raw cotton may also lead to changes beyond the agricultural sector, particularly since such reform would reduce governmental revenues from the present price differentials (Müller, 2008).

The current cotton policy design affects cotton production in Uzbekistan, which appears to be wasteful with water relative to cotton sectors outside of Central Asia. For instance, farmers in Uzbekistan produce about 273 kg of raw cotton per 1,000 m^3 of water, which is much below the levels in Syria (462 kg per 1,000 m^3), USA (487 kg per 1,000 m^3), Australia (610 kg per 1,000 m^3), and Greece (1,027 kg per 1,000 m^3) (Goletti and Chabot, 2000). Such wasteful water use in agriculture can be attributed to the low price ratio between water and capital (Müller, 2006). For instance, for Khorezm farmers it is cheaper to irrigate their fields with more water than to level them properly. Consequently, in the context of current discussions about water pricing, which may aggravate the economic pressure on farmers, it would be environmentally rational to facilitate access to cheaper machinery services.

In general, the modification of cotton policy and its deregulation would increase grain production. The greater flexibility in farmers' decision-making achieved via the abolishment of cotton policy would allow farmers to select a cropping pattern by considering the distance to the main irrigation canal and attributes of their fields. Farmers located closer to irrigation canals can benefit from better access to water, and in an effort to maximize profits they would cultivate more water-intensive crops, e.g., rice, and reduce water availability to the downstream farmers (Bobojonov et al., 2010). In this respect, modifying the cotton policy can be an instrument to offset the deleterious effect of water shortages on the revenues of farmers located in distance from irrigation canals.

The model results showed that in water-abundant years, the more the elements of the current cotton policy are in place, the higher the price for land and the lower the price for additional unit of water farmers would be willing to pay. It is likely that adjusting cotton policy in this way might put more pressure on water when the latter is abundant compared to the current policy design. Abolishing the current cotton policy can increase the value of land during water-scarce years. However, the land value can decline when the abolishment of the current cotton policy takes place in years with water abundance, as the farmers would opt to cultivate water-intensive rice, thus increasing the pressure on water resources. This may imply that due to higher pressure on water, farmers will lose their interest in investing in land improvement measures (such as proper field leveling and lined drainage canals), as the loss of a hectare of cropland (for instance, due to land degradation) would imply only little economic loss. At the same time, further expanding the cotton area due to substantially higher cotton prices or governmentally imposed policies can also lead to a similar stagnation of land value. This indicates at the existence of a risk of exacerbating the vulnerability of irrigated agriculture to water scarcity and land degradation when cotton-growing policies are modified.

Supplemental agricultural policies and institutions are required for promoting more efficient water use and farm investments in land improvement. In this respect, abolishing the current cotton policy can be an option if combined with water pricing (Bobojonov et al., 2010). When cotton production is deregulated, water markets, reflecting the increasing value of scarce supplies of irrigation water over time on one hand and the increasing demand for irrigation water on the other hand, can promote water use flexibility and establish a recognized water value, and thus provide incentives for more efficient use (Godden et al., 2011). Yet, institutional design with respect to the introduction of a water market will depend on the extent of agricultural reforms in the scope of infrastructure design and allocation principles so that the efficiency of water markets may be low (Harris, 2011). On the other hand, as the water pricing may impose additional financial burdens to agricultural producers, the trend towards increased rice cultivation can be halted at substantially higher (but still realistic) farm-gate prices for raw cotton. Improved land tenure security can also raise farmers' incentives to improve the quality of their lands. According to the model's results, the change of cotton policy would improve the cotton yields and allow the same amount of cotton, thus reducing pressure on productive land. The land released from cotton cultivation could be allocated to other crops, for instance to implement an ecologically more sustainable crop rotation and improve soil fertility (Kienzler et al., 2011), or could be allotted to ecological service provisions, such as those rendered by small-scale tree plantations (Djanibekov U et al., 2012). Additional economic and ecological benefits can be realized if the current cotton policy persists via the expansion of the local textile sector. This will allow the same revenues to be gained from exporting cotton products while reducing land and water use in agriculture by two-thirds

(Rudenko et al., 2009). The resilience of rural population to droughts can be achieved by investing in more water-efficient cropping practices, particularly in rice cultivation that showed to be less responsive to the liberalization of the cotton market and, consequently, accounted for the largest share of water demand.

5. Conclusions

According to our study the current design of cotton policy, including its more liberalized modifications, can both increase the pressure on farmers' cropland in water abundant years and aggravate the pressure on water resources. Thus, abolishing the current cotton policy can be a viable option for enhancing farmers' resilience to growing water scarcity and improving foodgrain production. Moreover, such a policy can ensure the same level of cotton production at raw cotton prices close to ones observed in other Central Asian countries that have abolished the state procurement system.

However, if farmers were released from cotton production targets, during water abundant years the gross farm income may increase at the expense of higher demands for irrigation water. In this respect, the government would have to create farm incentives in a way that, if the cotton market is liberalized, does not degenerate sustainable farm development by the overuse of irrigation water and a lack of farmers' interest in improving land quality. If abolishing the existing cotton policy is not an option, then quantity-based rather than location- and area-based cotton policy would meet the national strategy of maintaining cotton production, while also improving grain production and farm incomes.

Acknowledgments

The authors gratefully acknowledge financial support from the German Ministry for Education and Research (BMBF; project reference number 0339970A). The research was conducted within the framework of ZEF/UNESCO Landscape Restructuring project in the Khorezm province (Uzbekistan). The authors are grateful to two anonymous reviewers for their valuable comments.

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Table 1. Main characteristics of the modeled farms.

	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6	Farm 7
Farm size, ha	90	121	135	161	83	84	147
Loamy soils	76	114	6	0	65	0	14
Loamy sand soils	6	1	13	5	2	9	32
Sandy soils	0	0	13	140	0	15	84
Sandy loamy soils	8	6	104	16	16	60	17
Number of fields	28	32	31	55	27	19	35
Average size of field, ha	3.2	3.8	4.4	2.9	3.1	4.4	4.2
Average distance to irrigation canals, m	1,685	533	1,065	1,134	405	612	1,157
Average cotton yield, t ha^{-1}	3.37	3.32	1.72	2.41	3.55	1.77	2.43

Table 2: Scenario parameters.

	SCEN1 Present policy	SCEN2 Flexible area- and quantity-based policy	SCEN3 Flexible quantity-based policy	SCEN4 Liberalized policy
Product prices (USD t^{-1})				
Raw cotton	274	274	274	524
Wheat,	220	220	220	220
Rice	753	753	753	753
Maize	247	247	247	247
Fertilizer prices (USD t^{-1})				
Ammonium nitrate	174	174	174	174
Ammonium phosphate	400	400	400	400
Potassium chloride	286	286	286	286
Ammonium sulfate	157	157	157	157
Diesel price (USD t^{-1})	553	553	553	553
Seed price (USD t^{-1})				
Cotton	735	735	735	735
Wheat	341	341	341	341
Rice	682	682	682	682
Maize	265	265	265	265
Cotton policy design				
Location-based target, yes/no	yes	no	no	no
Area-based target, % of total farm land	55	55	0	0
Quantity-based target, t ha^{-1}	2.6	2.6	2.6	0

Appendix

Table A. Crop area with respect to the design of cotton policy and water availability levels.

Crops	Field distance to irrigation canal, m	Cultivated area, ha											
		Water availability level at 60%				Water availability level at 100%				Water availability level at 140%			
		SCEN1	SCEN2	SCEN3	SCEN4	SCEN1	SCEN2	SCEN3	SCEN4	SCEN1	SCEN2	SCEN3	SCEN4
Cotton	0-500	128	71	66	106	128	36	40	96	128	40	52	27
	500-1,000	163	177	159	81	163	202	175	103	163	196	159	151
	1,000-1,500	124	170	150	50	124	150	142	83	124	140	132	114
	1,500-2,000	27	28	29	30	27	48	46	32	27	68	54	40
	2,000-2,500	11	8	12	19	11	19	15	19	11	19	19	19
Wheat	0-500	42	99	104	64	42	134	130	74	42	130	118	143
	500-1,000	108	94	113	124	108	69	96	168	108	76	112	120
	1,000-1,500	61	34	40	77	132	70	81	164	133	117	125	144
	1,500-2,000	7	3	0	4	51	26	24	33	78	36	50	59
	2,000-2,500	0	0	0	0	8	0	0	0	8	0	0	0
Rice	0-500	13	21	21	45	39	132	124	68	42	130	118	140
	500-1,000	0	0	0	0	85	26	39	55	107	69	96	98
	1,000-1,500	0	0	0	0	6	4	0	18	59	65	43	42
	1,500-2,000	0	0	0	0	0	0	0	0	40	17	23	6
	2,000-2,500	0	0	0	0	0	0	0	0	8	0	0	0
Maize	0-500	30	78	83	19	3	3	6	6	0	0	0	3
	500-1,000	108	94	113	190	23	43	57	113	1	6	16	23
	1,000-1,500	75	31	52	123	100	74	86	129	48	26	56	74
	1,500-2,000	38	37	33	32	69	31	33	59	35	17	24	50
	2,000-2,500	8	11	7	0	8	0	4	0	0	0	0	0

Table B. Simulation results at the normal water availability levels.

	SCEN1	SCEN2	SCEN3	SCEN4
Area, ha				
Cotton	452	454	418	332
Wheat	341	300	330	440
Rice	131	162	163	142
Maize	203	151	186	306
Production, t				
Cotton	1,170	1,120	1,040	1,042
Wheat	1,666	1,470	1,622	2,109
Rice	553	696	699	605
Maize	688	496	615	1,003
Yield, t ha^{-1}				
Cotton	2.59	2.47	2.49	3.14
Wheat	4.88	4.90	4.92	4.79
Rice	4.23	4.29	4.29	4.26
Maize	3.38	3.29	3.31	3.27
Water use, m^3 ha^{-1}				
Cotton	9,216	9,116	9,197	9,837
Wheat	5719	5214	5242	5,455
Rice	30,145	28,223	28,249	29,305
Maize	3,091	2,671	2,696	2,772
Gross margins, USD ha^{-1}				
Cotton	51	23	23	952
Wheat	427	444	445	417
Rice	1,649	1,717	1,713	1,678
Maize	303	295	303	283
Profitability of land and water				
Land , USD ha^{-1}	212	234	252	535
Water , USD 10^{-3} m^{-3}	22	25	27	56
Shadow price of land and water				
Land , USD ha^{-1}	187	139	137	170
Water , USD 10^{-3} m^{-3}	31	36	36	33

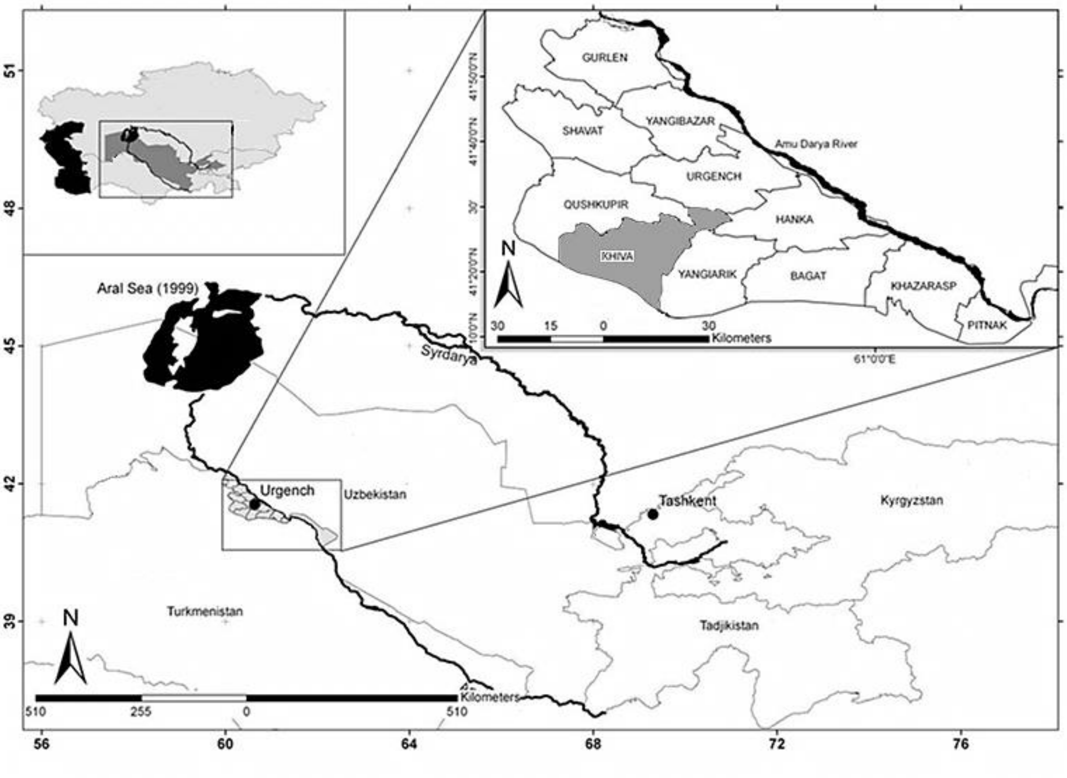
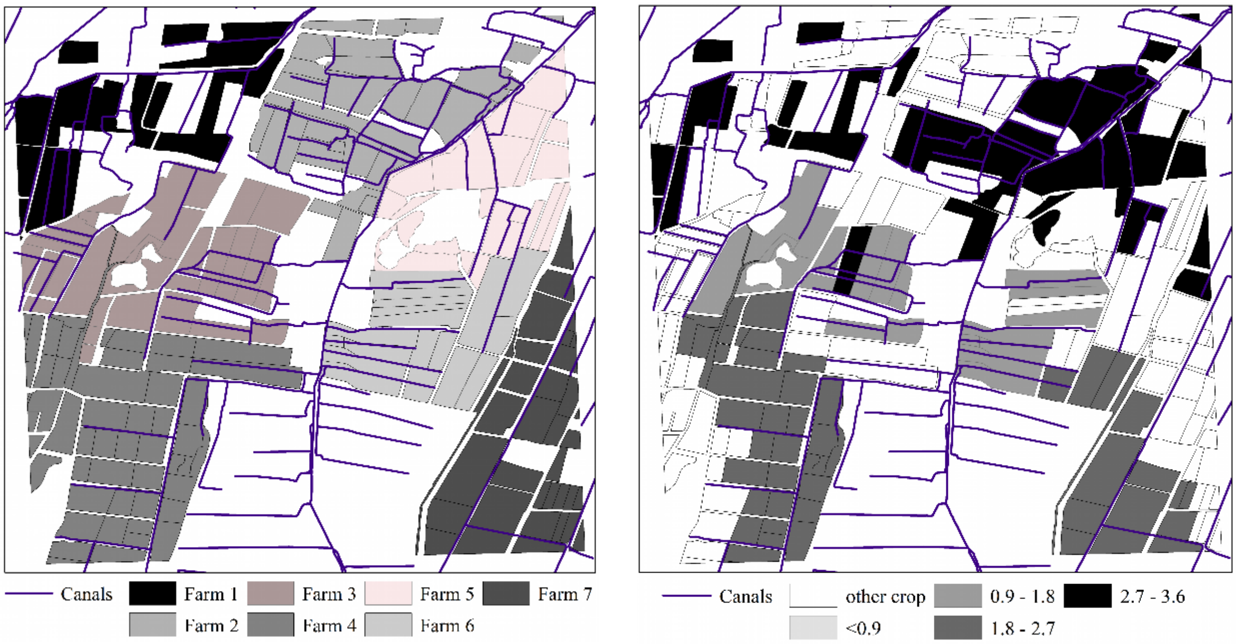


Fig. 1. Location of the Khorezm region in Uzbekistan and its administrative divisions (top right).



a) **b)**

Fig. 2. Field boundaries (a) and fields most suitable for cotton cultivation (b).

Note: Color grids in (2b) show cotton yields in t ha^{-1}.

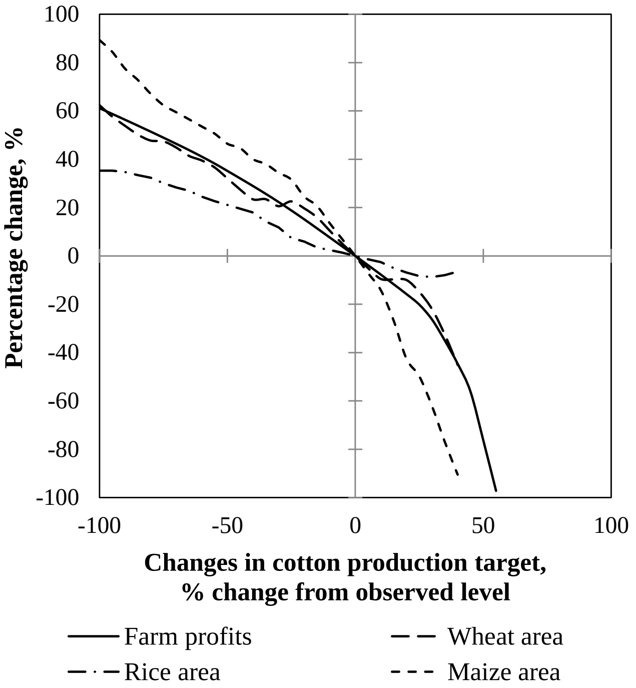
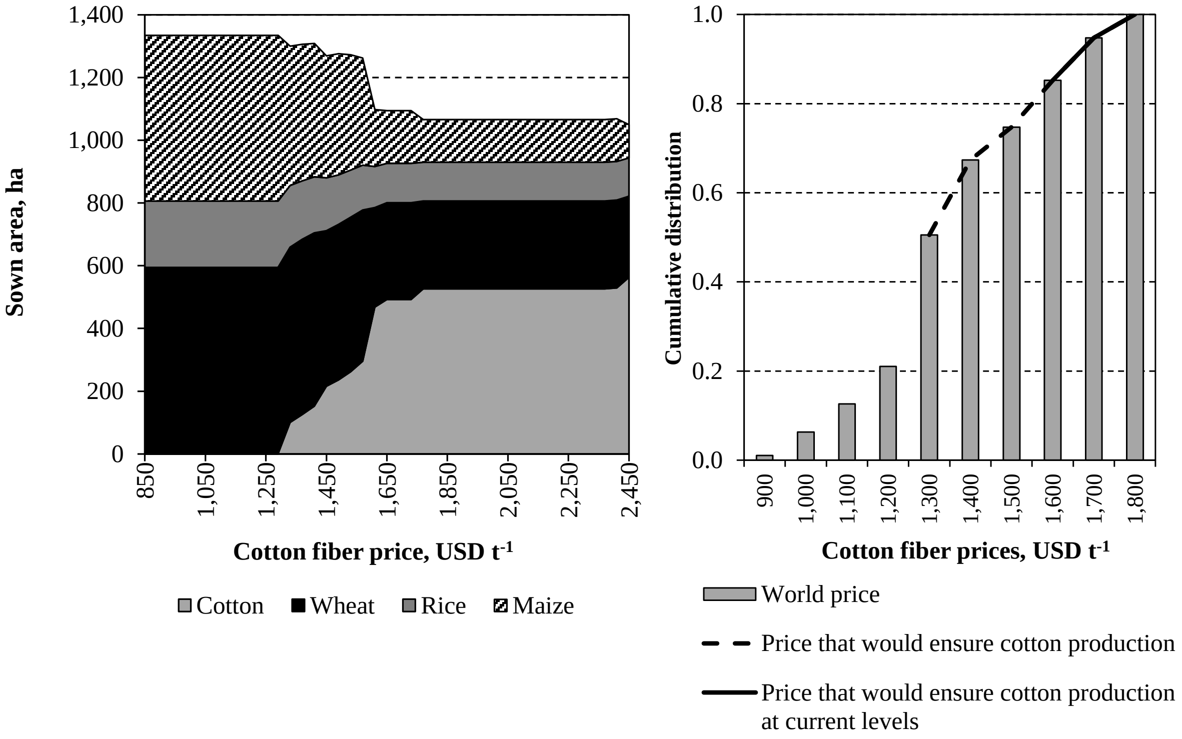


Fig. 3. Percentage changes in crop area and farm profits as a response to cotton production target under normal water availability.

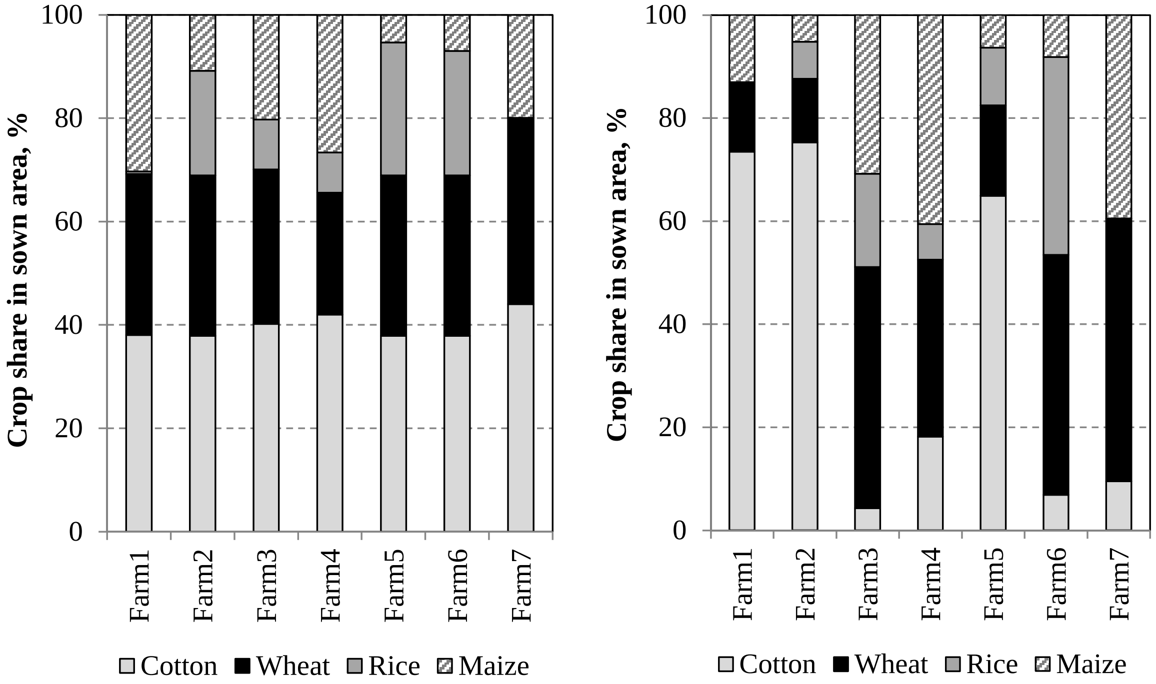


a)

b)

Fig. 4. Cropping pattern response to cotton price changes (a) and cotton fiber prices that would potentially stimulate cotton production in the study area (b) under normal water availability. *Source:* (b) NCC (2010).

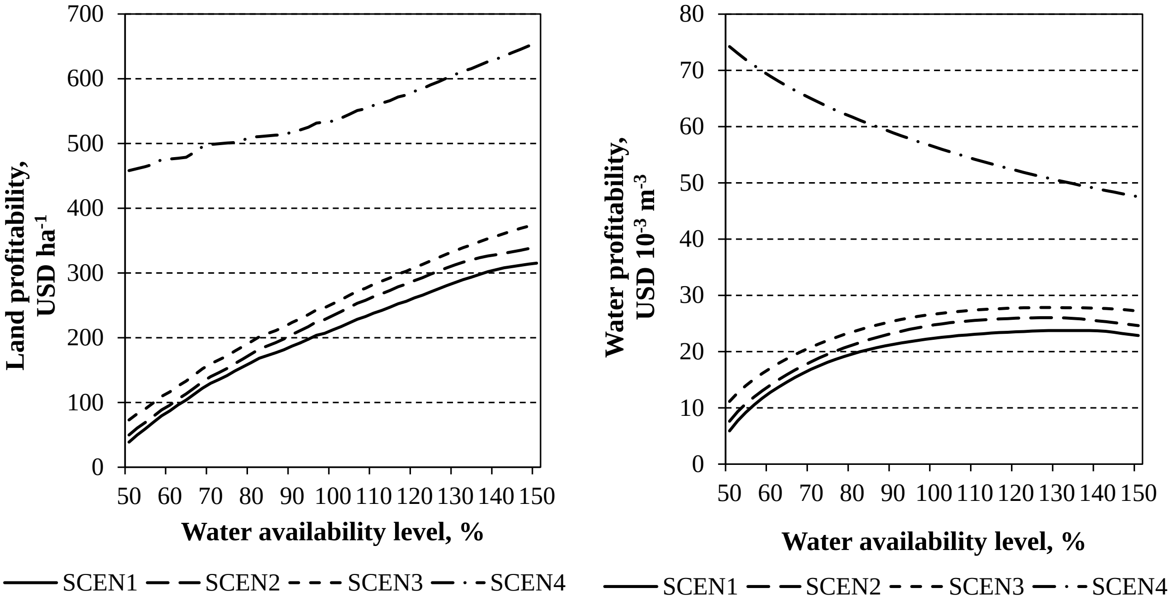
Fig. 5. Spatial allocation of crops with respect to cotton policy and water availability.



a)

b)

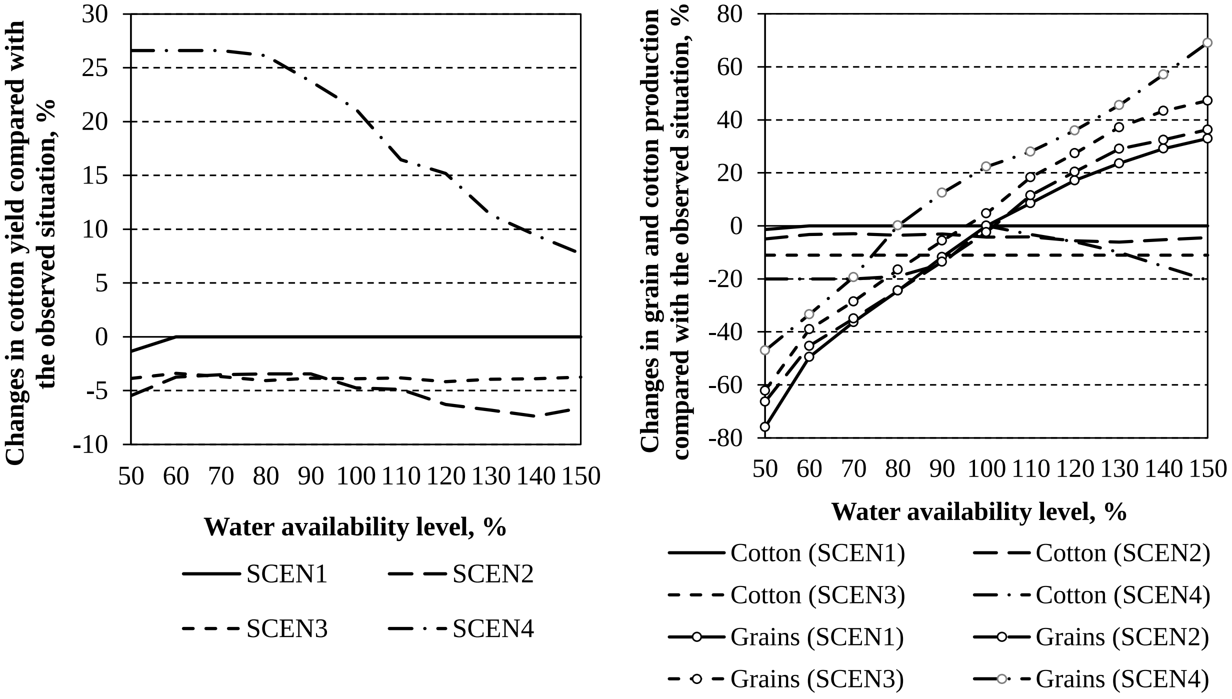
Fig. 6. Farm specialization in SCEN 1 (a) and SCEN 4 (b) under normal water availability.



a)

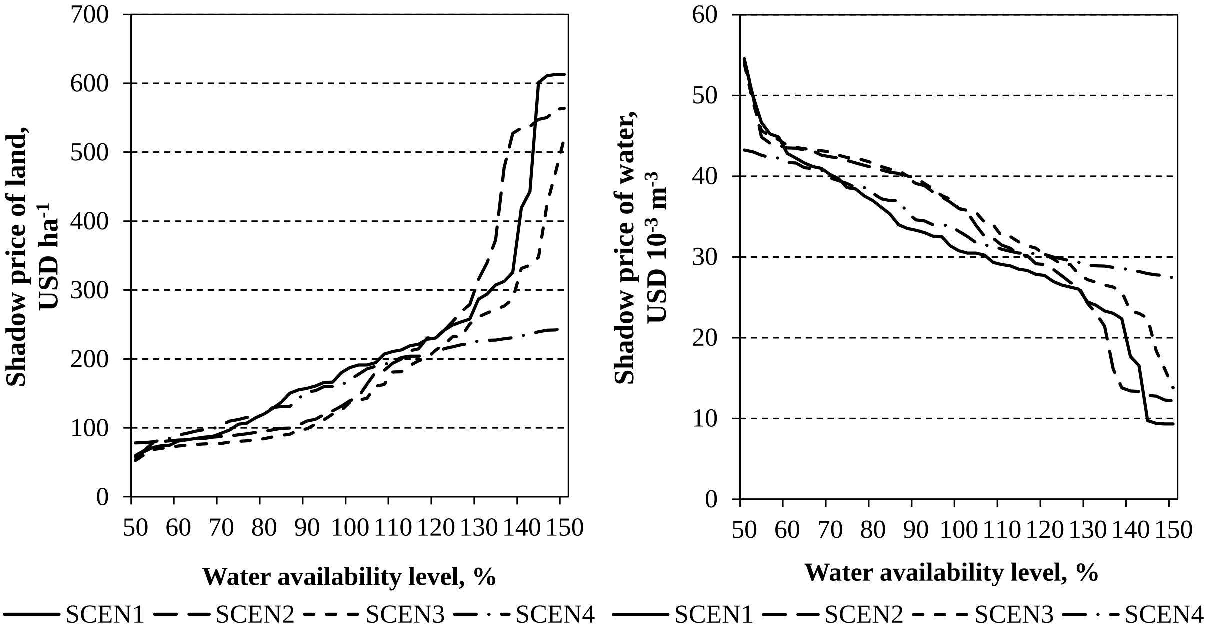
b)

Fig. 7. Land (a) and water (b) profitability under different levels of water availability (100% = normal water availability).



a) **b)**

Fig. 8. Cotton yields (a) and cotton/grain production (b) under different levels of water availability (100% = normal water availability).



a) **b)**

Fig. 9. Shadow prices of land (a) and water (b) under different levels of water availability (100% = normal water availability).