Improving Cotton Production and Crop Diversification in Uzbekistan: Tradable Cotton Production Targets

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Cotton production contributes considerably to Uzbekistan's export earnings. The various reforms implemented to increase the operational autonomy of agricultural producers considered the stability of cotton production, yet often at the expense of farm incomes. Options for improving the farm incomes can be achieved through modifications of the cotton policy settings. Such options are analyzed by replacing the present area-based yield prescriptions by tradable cotton targets between cotton-growing farms. As part of ongoing research, the findings indicate the scope for promoting such modification to tradable production targets as it would potentially increase farm revenues, cotton yields, crop diversification, and sustainable water use at the same level of cotton output as today. The net benefits would increase due to the difference in land fertility and location to irrigation canal between contracted farms. However, the sustainability of such policy modifications would depend on strong mechanisms for price negotiation and conflict resolution.

1. Introduction

Cotton has a long-lasting production and export history in Uzbekistan, Central Asia Cotton production has a high economic priority and has been covering up to a half of the total cropland. Uzbekistan ranks fifth among the 90 cotton-growing countries, covers ca. 6% of the global cotton production, and is with 11% of the world cotton export, after the U.S., the largest cotton exporter in the world (Djanibekov et al., 2010). Following the independence of Uzbekistan in 1991, cotton production remained linked to the interests of national export earnings which were cemented in a cotton procurement policy (Guadagni et al., 2005). This policy includes the determination of the area of farmland that should be cultivated with cotton. Under this *area-based setting,* farms in Uzbekistan allocate annually about half of their cropland to cotton cultivation. In addition, the *quantity-based setting* forces farmers to produce a prescribed amount of raw cotton from a given cropland. Furthermore, government purchases the entire cotton harvest from farms while offering prices usually below the potential border prices (Pomfret, 2008).

Uzbekistan's irrigated agricultural production is challenged by irrigation water availability that is predicted to decrease in the near future, e.g. due to increased water utilization in other sectors of the economy as well as in upstream countries and climate change impacts towards higher aridity (Glantz, 1999). One of the options to render agriculture more resilient to water scarcity is via the modification of the cotton procurement policy.

Various options for a procurement policy modification while aiming at higher farm revenues were previously discussed by Guadagni et al. (2005), Chertovitsky et al. (2007), Pomfret (2008), Bobojonov et al. (2010), Kienzler et al. (2011), Djanibekov et al. (2013a). However, such *ex-ante* analyses suggested mainly a shift from the area-based to the quantity-based production targets or the complete abolishment of this policy and focused in the first place on scenarios for increasing farmers' income. Table 1 presents summaries of nine selected studies on cotton procurement in Uzbekistan. While being diverse in the approaches, some studies focus on alternatives settings of cotton procurement policy, while the largest group analyzes the effects of policy liberalization. Yet, such scenarios have found hardly entrance in the cotton procurement policy most likely because they indirectly proposed neglecting cotton production targets and that in turn would introduce much uncertainty in the entire cotton value chain. The latter is sustained by the government also because it forms a social security net for a large part of the Uzbek population (Rudenko et al., 2009).

<Table 1>

This analysis, therefore, looks at options of increasing individual farm profits while concurrently ensuring the targeted levels of cotton production which could be reached by establishing tradable cotton targets between cotton-growing farms without compromising the present land and water use. We define the contractual agreements on cotton production targets between cotton-growing farms as inter-farm negotiations on additional prices paid to farmers for producing cotton for their peers such as the entire cotton production target is fulfilled and the water use rules within the system is not compromised.

2. The Quantitative Framework

A mathematical programming model was developed to analyze farm decision-making and determine an optimal production plan of each individual farm and negotiated cotton price bonuses for fulfilling the production target. In the absence of regulations on the contractual agreements between farms to trade their individual cotton production targets, we assume that each farm maximizes its profit at a given production target settings and available land and water. The mathematical formation of the model applied for each farm type[1] is:

$$max\ Z = \sum_i \sum_j c_{ij} X_{ij} \qquad (1)$$

where index j stands for crops (here cotton, winter wheat, rice and maize) produced on i types of land with different fertility or quality level. These four crops occupied more than 76% of the sown area and accounted for 82% of total irrigation water demand in the Khorezm region during 1998-2006 (OblStat, 2010). Due to a lack of detailed information on production factors it was assumed that all other inputs such as diesel, fertilizers, and labor were constant with respect to the level of crop yields. c stands for gross margin of each crop (in USD ha^{-1}), and X are the cultivated areas of each crop (in ha) on different types of land quality. Z is the total gross margin of each modeled farm type.

The model is solved subject to several constraints:

Resource endowments, according to which each modeled farm type allocates a specified area of arable land (b) with quality type i to X levels of crops j. This is described as:

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[1] Further throughout the text 'Farm type' is referred as 'Farm'.

$$\sum_j X_{ij} \leq b_i \tag{2}$$

Water availability constraint: each farm receives a specified amount of water w that can be used for irrigation of j crops at an irrigation rate k:

$$\sum_j k_{ij} X_{ij} \leq w, [\omega] \tag{3}$$

ω is a shadow price of water constraint.

The settings of cotton procurement policy contain two constraints:

A) The area of cotton cultivation should not be less than the one set by the procurement policy:

$$\sum_i X_{ij} \geq \bar{x}_j \tag{4}$$

where j = cotton and X is cotton cultivation area that should not be less than the production area $\bar{x}$ set by the procurement policy (both in ha). In our case each farm has to allocate at least half of its arable land to cotton cultivation.

B) The average cotton yield should not be less than the target yield:

$$y_{ij} X_{ij} \geq \bar{y}_j \bar{x}_j [\gamma_{ij}] \tag{5}$$

where j = cotton, y is the yield of cotton under different irrigation regimes and soil quality. $\bar{y}$ is the target yield (both in t ha^{-1}). A shadow price of the cotton target, γ, differs across i farms.

After farm consolidation program, the size of cotton-growing farms is ca 90 ha (Djanibekov et al. 2012). We model the farms of this size as they dominate the farm structure in Khorezm by accounting for 42% of all commercial farms and occupying about 85% of total farmland in the region.

As the size of the cotton production target depends largely on the arable area of a farm, it is further assumed that the cotton production target should be at least equal to the average cotton yield in Khorezm in 1997-2009 (or 2.4 t ha^{-1}; OblStat, 2010) multiplied by the area set for cotton cultivation $\bar{x}$. In this case, the farm model determines the farm plan defined by the X land use activity for the modeled crops j subject to area b of i types of land quality, irrigation water availability w, and the cotton policy constraints $\bar{x}$ and $\bar{y}$ such that the total gross margin Z is maximized.

The model was programmed in GAMS and solved via CONOPT3 solver.

3. Tradable Cotton Targets Concept

Our idea of tradable cotton targets is based on the concept of tradable water permits that argued to be an effective and efficient market-based instrument for sustainable water user in irrigation systems where water users are physically interdependent with each other through their location in their irrigation network. Particularly, the tradable water permits produce the highest benefits in irrigated areas (i) prone to water scarcity, with (ii) arable land of diverse quality, (iii) crops heterogeneous in their technology and prices, cultivated by (iv) water users of different characteristics (cf Latinopoulos and Sartzetakis, 2013). Benefiting from the main points of this concept, our idea on improving cotton production, crop diversification and sustainable water use in Uzbekistan addresses the main properties of the cotton production target. First, the tradability of the cotton production targets heavily relies on the abolishment of the area-based production target, i.e. cotton-growing farmers can decide on which field and of what area to cultivate cotton. The only setting that is continued in here-presented concept is the quantity-based production target. Exactly, this is a lower-binding target constraint that stipulates that each farm has to deliver a certain quantity of cotton. The proposal is that a cotton-growing farmer can offer to take part or entire cotton production target from other farms based on newly negotiated top-up payment. In this way, the latter would pay the negotiated price in addition to the cotton procurement price received for cotton harvest delivered to the state ginneries. Unlike in case of tradable water permits, the trade of cotton production targets implies that the farm that takes the cotton targets from other farms receives an extra payment from the latter, i.e. opportunity cost of allocating its arable land for cotton production above the levels set by the procurement policy.

For our analysis of the shadow price of cotton (γ in eq. 5), we introduce the tradable cotton targets by abolishing the area-abased production target (eq. 4).

3.1 Assumptions

With respect to the farm types, the quantitative framework is based on two main assumptions: *Farm homogeneity.* It is assumed that the five farms are homogenous in their objective function, i.e. they are all profit maximizers, as well as they are similar in the size of their arable land and in endowments of irrigation water. In the remainder of this study, farms are

referred to as A, B, C, D, and E. We assume that the average farm has 90 ha of arable land which is based on the registration information after the land consolidation program in 2008 (cf Djanibekov et al., 2012). Each farm is endowed with 14,000 m^3 ha^{-1} of irrigation water, which is about the average annual irrigation water supply per hectare of cultivated land in Khorezm during 1998-2006, although this was not attained during the water scarce years of 2000-2001; OblSelVodHoz, 2007).

It was further assumed that each of the five modelled farms had identical cotton production targets. According to the area-based target, the cotton cultivation area in each farm should, therefore, not be less than 45 ha, while the targeted amount of cotton production should not be less than 108 t (the cotton area of 45 ha multiplied by 2.4 t ha^{-1}, which is the about the average raw cotton yield in the case study region in 1997-2009).

The prospects of contractual agreements between cotton-growing farms were analyzed under the assumption of complementarity. This means that each farm could complement another in exchanging land quality and making joint decision in water use. Therefore, we assumed that the crop yield response to the irrigation rate w of the four modeled crops was similar across the modelled farms (see Table A in the Appendix). Hence, it was assumed that factors other than water which could affect crop yields, such as farm management, timing of irrigation or capital endowment, were of less importance than irrigation rate. Hence, water-yield matrices had been introduced for each type of land quality based on the official irrigation norms for the study region Khorezm (MAWR, 2001). The different land quality types were used to depict the heterogeneity in the modeled situation. Therefore the farm lands had been classified into three levels of quality: low, medium and high. Accordingly, the model determines an optimal farm plan and the total production quantities of the four crops with respect to the area of crop cultivation and crop yield. Consequently, the farm plan describes what volume of irrigation water to apply per hectare of sown cropland.

Each farm faces similar exogenous prices for inputs and output. The direct and indirect costs included in the model are related to the production of crops (Table B in the Appendix). Thus gross margins vary with respect to crop yield depending on water application levels.

Farm heterogeneity. It was assumed furthermore that farms are heterogeneous in quality (fertility) of their land (Table 2).

<Table 2>

The farm heterogeneity in land quality can reflect social differences among members (power, networking) and/or financial resources (e.g., access to credit). It was assumed that such differences in land quality affect farmers' decisions on land and water use for crop cultivation to achieve the highest possible gross margins. The proportion of the assumed land types with respect to quality is close to the distribution of arable lands with the different *bonitet* scales where poor quality lands comprise 20%, average quality lands 43%, and high quality land 37% of total arable land in Khorezm (OblSelVodHoz, 2007).

3.2 Scenario Settings

Scenarios of water availability within a range from 50% to +50% of normal water availability during the vegetation period have been simulated including modification of the cotton policy. For the tradable cotton targets, we identify the least cotton 'bonus' price, i.e. the difference between the shadow price of the quantity-based cotton constraint (eq. 5) and the procurement price. For this, we assumed that farms are free in deciding the size and location of cotton cultivation area, but have to deliver the total predetermined amount of cotton. When farms decide on their production plans individually, the area-based setting of cotton production target (eq. 4) is removed from the model, while the quantity-based setting (eq. 5) is kept for each farm at the level of 108 t of cotton. By running the simulations we identify the shadow price of eq. 5 by running simulation scenario for each farm for the range of water availability levels. This provides us with the set of the minimum 'bonus' price for cotton under which farms would trade cotton among each other.

4. Results and Discussion

At the current stage of our study we present the following results of our attempt to develop the model for simulation of the inter-farm cotton tradable targets:

The test of the water availability within the range from -50% to +50% of normal water availability level during the vegetation season shows that when the cotton area-based setting (eq. 4) is relaxed farmers would have sufficient flexibility in their decision making to operate even at the lowest level of water availability (i.e., -50%) and fulfill the quantity-based cotton target by increasing cotton yield (Fig. 1), and reducing its cultivation area. This is different when the eq. 4 is kept as part of the model definition, namely, the model produces infeasibility results with this constraint.

<Fig. 1>

Fig. 2 shows that the move from -50% to +50% of irrigation water availability during the vegetation seasons would come at cost of maize production, that in turn farmers would opt during the water scarcity. Yet, in water abundant situations, maize would be substituted by rice cultivation. Both crops are cultivated in the study region as a second crop after winter wheat.

<Fig. 2>

The minimum bonus price graph (Fig. 3) presents the smallest value of shadow prices of quantity-based target (eq. 5) among the five modelled farms. It shows that some farms would opt for the production of one more additional ton of cotton when its procurement price is increased by almost 47% (this is of course, given the assumption of relaxed area-based setting, eq. 4). With the increasing water availability, the minimum price level would also increase, indicating for increased opportunities for cultivating the higher value crops. For policymakers, when the cotton tradable targets are being considered, this may imply that rather flexible mechanisms of cotton 'bonus' price negotiations should be introduced that reflect the situation with the variability of irrigation water during the vegetation season.

<Fig. 3>

In the absence of the simulated scenario of tradable cotton targets, the farmers have to cope with individually-set production targets. The result can be that farmers achieve low cotton yields, fail the production target, and make economic losses. The simulation exercises show that a modification in the cotton procurement policy, particularly the introduction of 'market-based' instrument for contracting other farmers at a negotiated 'bonus' price, can generate additional economic incentives for farmers to improve cotton yield, as well as to increase the scope for crop diversification and sustainable water use. Particularly, these benefits would be stronger in the areas that comprise heterogeneous farms, diverse cropping options and technologies (e.g., conventional vs innovative). The trade in cotton targets would also allow the farms to benefit from characteristics of their land and location to irrigation canal. In contrast to individually-set production targets, the analyzed situation would involve higher

direct economic benefits both for farms producing cotton and those that could reduce their cotton area in favor of high value crops. Other attributes of the object of contractual arrangement (i.e., cotton targets) can affect its sustainability. In addition to the material interest, the redesign of the cotton policy can serve a policy-imposed incentive for farmers to establish a platform for trading cotton targets and to ensure its economic and institutional sustainability. The already existing land lease penalties shared by each participating farm for failing to deliver the production targets can act as an enforcement mechanism and increase the farms' 'commitment' to deliver the target and to pay for the offered cotton-production service in time. Of course, such contractual arrangements would require well-established regulations, e.g. on the tradable target contract design, or on the process of resolving disputes between involved farms. For instance, would a farmer who produces cotton for his peers and receives for this an extra payment be responsible alone for failing the cotton production target? It is obvious that in the irrigation system as in Khorezm, farmers are interdependent in their water use and land allocation decisions. Although the simulation exercise does not consider this, the shared responsibility for delivered cotton would minimize the risks particularly in situation when cotton-free farms would opt for the cultivation of more water-intensive crops (e.g., rice) and, thus, compromise the availability of irrigation water to cotton-service providing farms, as a result leading to the failure of the cotton production target. The understanding of distinct 'soft' features of social interaction and modes of rural livelihoods in Uzbekistan, such as trust, norms and networks, that farmers face in their daily lives and which shape their selfish or reciprocal behavior towards contractual agreements, are important to understand the existing prerequisites that can trigger and sustain the tradable cotton target arrangements. It is when the cotton policy modification options are offered, the farms would receive an incentive to engage in the new mode of cotton production. The top-down decision to modify the cotton policy and introduce new regulations to prevent evasions from the contractual arrangements can form farmers' beliefs in the sustainability of this mechanism. In this respect, the availability of information that such cotton policy changes can produce a better outcome for each contracted party as well as the information how the disputes are to be resolved can affect the farmers' decision to participate and determine the levels of trust with their contracted peers.

5. Conclusions and Further Model Development

According to the results of our study on the tradable cotton targets as a solution for improving the cotton production and crop diversification in Uzbekistan, the current design of cotton policy can be modified by introducing windows for more flexible decision making of cotton-growing farms. However, the mechanism that would ensure the tradability of cotton targets should also incorporate the farms' freedom in negotiating the 'bonus' prices for transferring cotton targets among each other. This is necessary at least to ensure the responsiveness of cotton producers to the fluctuations of irrigation water supply.

The next step of the model development would be the integration of the eq. 6 into the Farm Level Economic Ecological Optimization Model (FLEOM), a bio-economic model developed in the GAMS environment at the scale of a water user association (WUA) in a ZEF/UNESCO research project (www.khorezm.zef.de), led by Center for Development Research (ZEF) of the University of Bonn. At the core of FLEOM is a linear programming model that maximizes profits over seven modeled cotton-grain growing farms with a size range from 83 ha to 161 ha. Each farm is characterized by the soil quality of its fields and the distance to irrigation canals. The model database comprises agronomic and socio-economic characteristics of crops and farms, and was presented in detail in Sommer et al. (2010) and Djanibekov et al. (2013a).

For the solution over the negotiated price for tradable cotton targets, we are planning to use Multiple Optimization Problems with Equilibrium Constraints (MOPEC) as proposed by Britz et al. (2013). We find this approach particularly relevant for our case when each individual farm transfers its cotton production target with its peers for a negotiated bonus price. This approach as opposed to commonly used (non-)linear programming approaches would allow us to account for simultaneous simulation of 'independent optimization' decisions by the several modelled farms while maintaining their interdependence in newly introduced equation of tradable cotton targets. Since MOPEC allows to 'express spatial externalities resulting from asymmetric access to water use' (Britz et al., 2013), the updated version of FLEOM would allow to take into consideration the spatial characteristics of the modelled seven farms in terms of distance of their fields to main irrigation canal as well as their physical interdependences through water use from the same irrigation canal. The proposed solution over tradable cotton targets is illustrated in Fig. 4, where p_c stands for bonus price of transferred cotton target.

<Fig. 4>

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Table 1: Overview of selected studies on cotton procurement policy in Uzbekistan.

Author (year)	Scenarios analyzed	Main conclusions
Pomfret (2000)	A simple partial equilibrium of Uzbek cotton market to explain its difference from the basic dual-pricing model, e.g. China. Dual-pricing and price liberalization.	Cotton procurement policy causes major economy-wide distortions, deters output growth, diversification and innovation adoption in agriculture.
Guadagni et al. (2005)	Cost-benefit analysis to estimate explicit/implicit subsidies and taxes to cotton producers. Abolishment of cotton targets, liberalization of cotton marketing and exports.	Cotton tax makes 30% of farmer's gross cotton revenues and creates disincentives in cotton production.
Chertovitsky et al. (2007)	Cost-benefit analysis of abolishing the area-based production target.	If the procurement policy is modified (not abolished) 3-6% of farmland occupied by cotton can be used for other purposes without affecting the production values assigned by the cotton target.
Rudenko et al. (2009)	Cotton value chain analysis of changes along the supply chain.	Structural changes and alternative and liberalized marketing channels for raw cotton can improve revenues for cotton-growing farmers.
Bobojonov et al. (2010)	A static stochastic optimization model. Liberalization of cotton production.	Liberalization of cotton production would increase crop diversification and farm income.
Kienzler et al. (2011)	Agronomic and economic analysis of N-fertilizer application to cotton.	Farmers follow recommended N-fertilizer application norms, but tend to under-apply fertilizer for cotton.
MacDonald (2012)	Estimation of a nominal rate of assistance	Cotton taxation offsets subsidies for cotton farms, and total net taxation increased after 2008, coincided with lower cotton yields.
Djanibekov et al. (2013b)	Dynamic farm-household model to analyze a scenario of liberalization of the procurement policy for marginal crop lands	Diverting marginal croplands from cotton production to tree plantations would improve farm and household revenues as well as reduce the pressure on irrigation water resources.
Djanibekov et al. (2013a)	A bio-economic model of several cotton producers to simulate various adjustments in the procurement policy, including a scenario of the cotton policy abolishment.	The abolishment of cotton policy is the most economically attractive option among all possible modifications; yet it may increase pressure on irrigation water resource (e.g., in Khorezm it can lead to increase in rice cultivation area). Supplementing mechanism is necessary.

Table 2: Distribution of land of different quality in A-E modeled farms, ha.

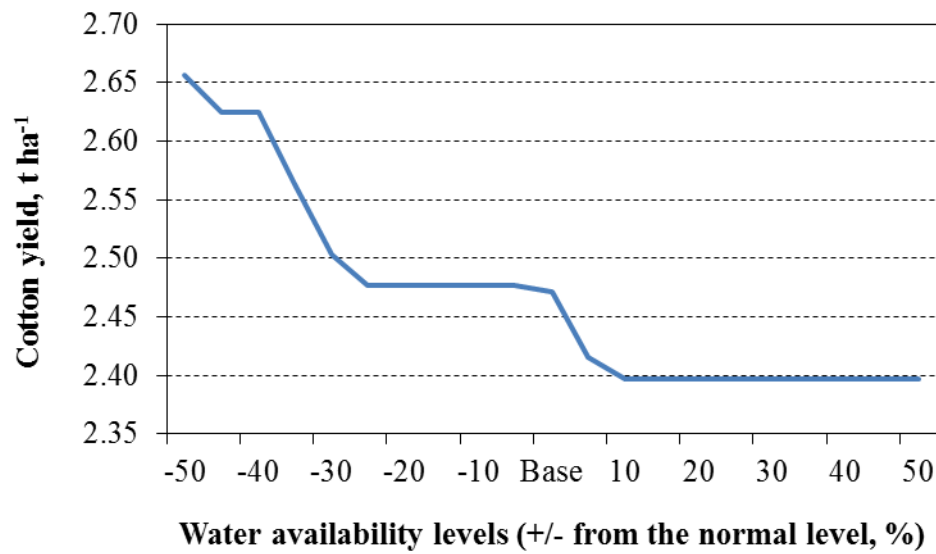| Land quality	Farms				
	A	B	C	D	E
High	65	55	30	15	5
Average	25	30	45	50	40
Low	0	5	15	25	45

Fig. 1. Cotton yields with respect to the level of water availability, t ha^{-1}.
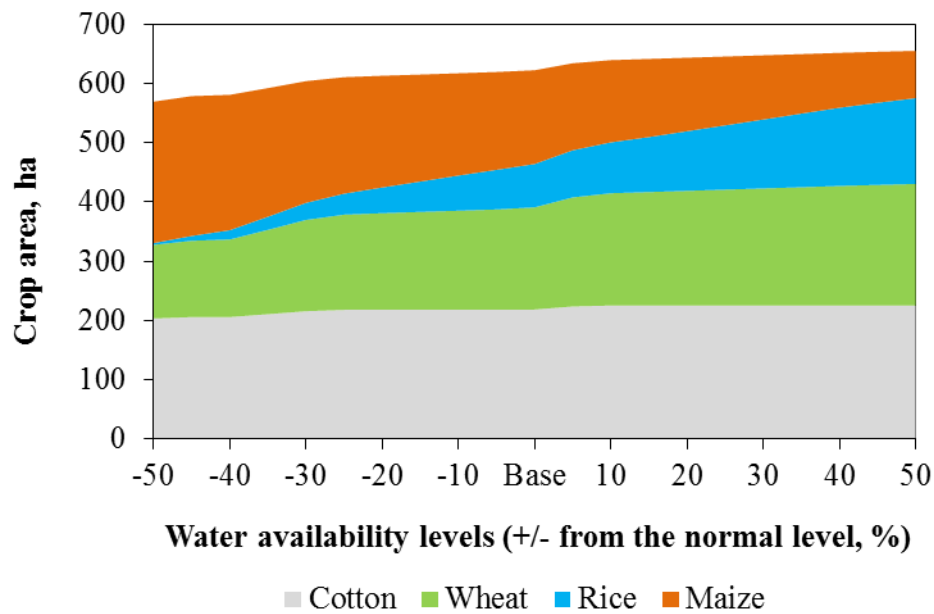

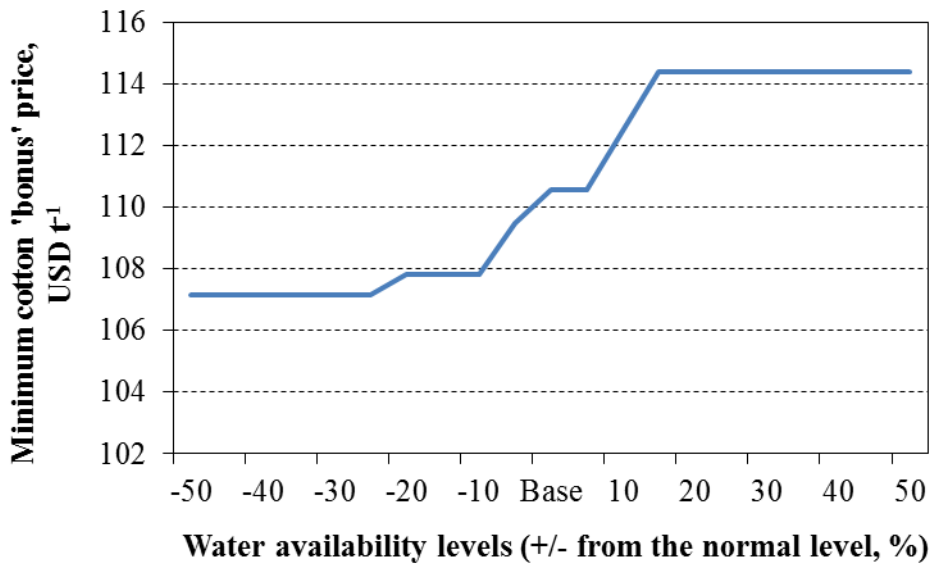Fig. 2. Crop area under different water availability levels, ha.

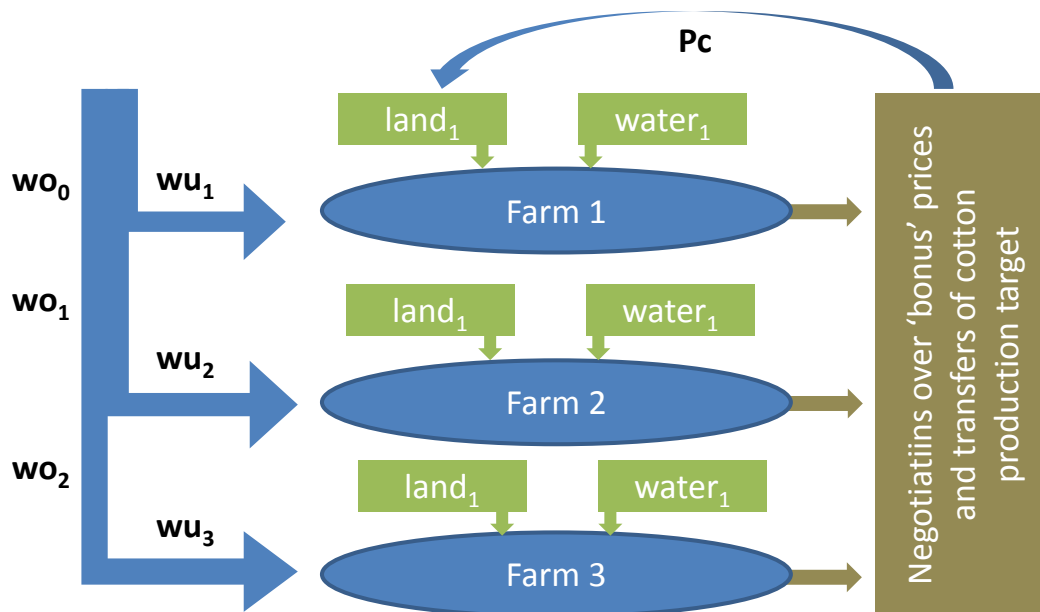Fig 3. Minimum 'bonus' price for inter-farm traded cotton under different water availability levels, USD t^{-1}.

Fig. 4. Illustration of the model of tradable cotton targets

Source: Modified based on Britz et al. (2013).

Appendix

Table A: Crop yield response to the of irrigation water application, t ha^{-1}.

Crops	Land quality	Technical optimal (TO) irrigation rate, m^3 ha^{-1}	Crop yields (t ha^{-1}) at irrigate rate w relative to the technical optimal irrigation rate						
			TO=40%	TO=50%	TO=60%	TO=70%	TO=80%	TO=90%	TO=100%
	High		0.6	1.0	1.4	2.1	2.9	3.2	3.6
Cotton	Average	5,612	0.4	0.7	1.0	1.5	2.1	2.3	2.6
	Low		0.3	0.5	0.7	1.1	1.5	1.7	1.8
	High		2.7	3.8	4.9	5.6	6.3	6.5	6.7
Wheat	Average	3,881	1.9	2.8	3.5	4.0	4.5	4.7	4.8
	Low		1.4	2.0	2.5	2.8	3.2	3.3	3.4
	High		1.2	2.1	3.0	3.5	4.0	4.2	4.3
Rice	Average	28,216	0.8	1.5	2.1	2.5	2.9	3.0	3.1
	Low		0.6	1.1	1.5	1.8	2.0	2.1	2.2
	High		2.7	4.2	5.7	6.5	7.4	7.5	7.6
Maize	Average	5,311	1.9	3.0	4.0	4.6	5.1	5.3	5.5
	Low		1.3	2.1	2.8	3.3	3.6	3.8	3.9

Source: Based on MAWR (2001).

Table B: Crop budgets.

Crops	Land quality	Max. yield, t ha^{-1}	Price, USD t^{-1}	Revenue from byproducts, USD ha^{-1}	Labor costs, USD ha^{-1}	Fertilizer costs, USD ha^{-1}	Machinery costs, USD ha^{-1}	Other costs, USD ha^{-1}	Max. gross margin, USD ha^{-1}
Cotton [a]	High	3.6	227	106	290	146	132	66	228
	Average	2.6	227	77	290	146	132	66	-13
	Low	1.8	227	54	290	146	132	66	-194
Wheat [b]	High	6.7	168	219	62	138	100	147	886
	Average	4.8	168	158	62	138	100	147	513
	Low	3.4	168	112	62	138	100	147	233
Rice	High	4.3	1,249	141	271	207	648	504	3,835
	Average	3.1	1,249	101	271	207	648	504	2,305
	Low	2.2	1,249	72	271	207	648	504	1,157
Maize	High	7.6	227	307	89	121	90	107	1,622
	Average	5.5	227	222	89	121	90	107	1,059
	Low	3.9	227	157	89	121	90	107	631

Note: [a] the price of cotton is the procurement price.

[b] wheat price is an average of the procurement and market prices.