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ECONOMIC ANALYSIS OF AFFORESTATION OF MARGINAL CROPLANDS IN UZBEKISTAN

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1 ABSTRACT

Irrigated agricultural production in Uzbekistan is threatened by the impacts of land degradation, irrigation water scarcity and climate change. The conversion of marginal croplands to tree plantations is an option for rehabilitation of nutrient-depleted cropland soils, saving of irrigation water, carbon sequestration, and improving population welfare. The economic benefits and impacts of tree planting on marginal croplands, and policies that may facilitate the adoption of this land use are not well known. We employed various methods at different scales to investigate economically viable options of afforestation on marginal croplands on example of irrigated drylands of Uzbekistan. This includes analyzing the impacts of afforestation supported by the carbon (C) sequestration reward on the rural livelihoods. At field level (one hectare), the stochastic dominance analysis was employed to investigate the financial attractiveness of afforestation on marginal farmlands under uncertainty. At the farm level, the expected utility method was employed to analyze effects of this land use change on farm incomes. To consider the bimodal structure of agriculture in Uzbekistan, the stochastic dynamic farm-household model was developed. The results indicate that due to benefits from non-timber products, afforestation is a more viable land use option on marginal lands than crop cultivation. Allowing the exemption of marginal lands from cotton cropping in favor of tree planting would incentivize afforestation. At the same time, the field level analysis indicates that due to variability in returns a substantial increase in C prices would make afforestation as financially attractive as crops on marginal lands. However, when considering uncertainties in land use returns at the whole farm level, afforestation would occur without the C incentives due to improved irrigation water use efficiency and reduced revenue risks through land use diversification. Through the considered farm-household wage-labor relationship, the benefits of afforestation on marginal croplands at farm would be also transferred to rural smallholders employed at this farm. This would mainly result from improved payment structure by tree products, particularly fuelwood and foliage for livestock fodder.

2 INTRODUCTION

Cropland degradation reduces agricultural production, costing about 400 billion USD annually on a global scale and affecting 1.5 billion people (Lal, 1998; Bai et al., 2008). In Uzbekistan, almost half of the arable land is saline and about 25% are classified as marginal, i.e., generating low profits for farmers from crop cultivation (MAWR, 2010; Djanibekov et al., 2012). Afforesting marginal croplands can increase the productive potential of land and contribute to climate change mitigation, efficiency of irrigation water use, and rural incomes (Djanibekov et al., 2012; Khamzina et al., 2012). Payments for such environmental services (PES) to the providers of these services through compliance (e.g., Clean Development Mechanism (CDM)) or voluntary markets could further incentivize afforestation on degraded croplands (Engel et al., 2008; Pagiola, 2008).

Various effects of environmental sustainable land use, e.g., afforestation on marginal croplands, and variability in its value necessitates considering different scales and outcomes that could influence land use decisions (Mendelsohn and Olmstead, 2009). However, previous studies assessing environmental sustainable land uses usually addressed one aspect and scale, and underlined thereby only a portion of its actual value. For instance, previous research compared opportunity costs of farm forestry with pasture and crop cultivation, to estimate returns from land use and derive PES (e.g., Olschewski et al., 2005; Djanibekov et al., 2012), and only a few have accounted for uncertainties and risks affecting decisions of land users (e.g., Knoke et al., 2011). At the same time, as land users make decisions in a farm system context, different effects can be investigated at such scale. The farm-scale analysis can capture land use diversification options, where strategies combining several land uses, e.g., tree plantations and crops, with independent revenue fluctuations may become an effective buffer against revenue risks. Yet, few studies have considered various returns of afforestation at farm level (e.g., Knoke et al., 2011; Castro et al., 2012). In addition, on larger scale, the economy-wide impacts of afforestation have been analyzed (e.g., Glomsrød et al., 2011; Paul et al., 2013). However, planting trees on marginal farmlands may change rural economy relationships (Djanibekov et al., 2013b). In most of the post-Soviet countries agricultural production is organized in a bimodal agricultural system, that comprises large-scale commercial farms with external economies of scale occurring through advantages in accessing inputs, credits and markets, and rural households/smallholders, whose incomes are limited to sales of their surplus crops and employment at large-scale farms (Lerman et al., 2004). Hence, introducing new land use policies in such a bimodal agricultural system would impact the rural population by altering employment structure on commercial farms. In contrast to previous studies, an explicit consideration of different scales (i.e., field, farm, and bimodal agricultural system), uncertainties in land use returns, and impacts of afforestation of marginal croplands on various rural population groups would help to address the multidimensional impacts on rural livelihoods. Thus, the study aimed to: (1) assess the monetary value of environmental services of tree plantations, e.g., carbon (C) sequestration within the framework of CDM, under uncertainty; (2) identify risk managing options of afforesting marginal croplands; and (3) analyze the direct and spillover effects of land use change to afforestation on rural livelihoods.

3 METHODS

3.1 Study area

The case study area is the Khorezm region and southern districts of the Autonomous Republic of Karakalpakstan, namely Beruniy, Turtkul and Ellikkala, located in the lowlands of the Amu Darya River, Uzbekistan. The area is characterized by an arid climate with an annual precipitation of about 100 mm that occur mostly outside of the crop growing season making crop cultivation feasible only through irrigation. Irrigated agriculture accounts for about 35% of region's GDP. The main agricultural producers are commercial farms (hereafter referred to as farms) and semi-subsistence smallholders/rural households. The land use decisions of farms are mainly determined by possible returns from land uses, policy settings, and market and production conditions. At the same time, farmers lack flexibility in land use decisions, as they follow the cotton state procurement policy, according to which (1) about 50% of the farmland have to be allocated to cotton cultivation, and (2) expected yield targets based on soil productivity scale have to be achieved (Djanibekov et al., 2013a). Half of the winter wheat (hereafter referred to as wheat) production at farm is purchased below local market prices (Djanibekov et al., 2012). Smallholders are the smallest agricultural producers in Uzbekistan (posses 0.2 ha), that produce for own consumption, and whose incomes are limited to sales of crop surplus and employment at farms (Djanibekov et al., 2013c). Production decisions of smallholders are also driven by their food consumption, amount of income available and income sources. Cotton and wheat are the major crops cultivated, including on marginal lands as this is imposed due to the state procurement policy. Crops such as rice and vegetables are vital to farmers for income and smallholder consumption, while maize is used as livestock feed (Djanibekov et al., 2013b).

Agricultural production is subject to various risks affecting rural livelihoods. For instance, over the last decades irrigation supplies varied between 5,500 and 21,000 m^3 ha^{-1} $year^{-1}$ (MAWR, 2010). The underdeveloped infrastructure, fluctuation of irrigation water availability, and lack of insurance options result in a high variability of crop prices. Yields are uncertain as a result of irrigation water variability, crop diseases and unfavorable weather conditions. Due to inherently low suitability for farming or degradation (Dubovyk et al., 2013) about 20–30% of arable lands in the study area are marginal (MAWR, 2010), which mainly belong to farms, and crop cultivation on such lands result in economic losses (Djanibekov et al., 2012). Although such marginal croplands can be afforested with certain tree species that provide both environmental and economic benefits (Djanibekov et al., 2012; Khamzina et al., 2012) currently farmers are not practicing such a land use change, due to prohibitive policies, ongoing farmland consolidation that restrains interest in long-term land use investments and the lack of knowledge among farmers about potential benefits and management activities of tree plantations (Kan et al., 2008).

3.2 Data sources

160 farms and 400 smallholders were surveyed during June 2010 and March 2011 to obtain information on their demographic composition, cropping pattern, input and output prices, crop production technologies and costs, and consumption structure. Prices of commodities were also monitored through weekly market surveys. The input costs, which included expenditures for saplings and seeds, field preparation, labor, machinery, fertilizers, transaction costs for market access, and transportation, were reported in Djanibekov et al. (2012). Transaction costs that may incur from land use change are those related to the preparation of arable farmland for afforestation such as machinery costs for proper leveling and labor costs related to digging holes for tree planting, as well as fees related to the official registration of the land use change. Besides, as

in the study we considered an afforestation activity within the framework of CDM we included transaction costs to cover the costs of CDM project design document preparation, validation, registration, monitoring and verification.

Quantity and quality of products of the three tree species recommended for afforesting marginal croplands, including *Elaeagnus angustifolia* L., *Populus euphratica* Oliv., and *Ulmus pumila* L., were collected from an afforestation study conducted in 2002- 2009 (Khamzina et al., 2008, 2009). The plantations were irrigated at rates of 1,600 m^3 ha^{-1} $year^{-1}$ during the first two years. From 2005 onwards, irrigation was stopped and trees relied entirely on the shallow and saline groundwater. Hence, soil properties, irrigation water availability and groundwater table are important biophysical inputs needed for conducting afforestation on marginal croplands in the region (Khamzina et al., 2012). The study included temporary Certified Emission Reduction (tCER) (1 ton of CO_2 content in above- and below-ground wood biomass) within the framework of Clean Development Mechanism (CDM), fruits, fuelwood, and leaves as fodder. Five crops were considered, i.e., cotton, wheat, rice, maize, and vegetables, as well as their by-products, i.e., cotton stem, wheat and rice straw, and maize stem. Crop yields are responsive to irrigation application (requirements lay between 5,300 and 26,500 m^3 ha^{-1} $year^{-1}$ depending on crop) and land productivity.

3.3 The models

To investigate the multidimensional aspects of afforestation on marginal croplands three approaches were used: (1) at the field scale (one hectare) the stochastic dominance (SD) analysis was applied to analyze variability in revenues of crops and tree species on marginal lands, and compare them in terms of the distribution of outcomes; (2) at the whole-farm level the expected utility (EU) approach was used to estimate the farm profit depending on the distribution of the profit and the risk mitigating option of afforestation; and (3) as the afforestation on marginal farmlands would impact not only farmers that planted trees but also would have spillover effects on rural households that are employed at these farms, the stochastic dynamic farm- household model was built to capture the interdependencies between these two actors through wage-labor relations (i.e., agricultural contracts). For all these three approaches Monte Carlo simulation was applied to generate variability of yields and prices of crop and tree products, and irrigation water availability. Covariance between yields and prices of crops, and irrigation water availability, as well as between yields of tree products were considered. In the SD and EU approaches, the net present values (NPV) were calculated over seven years using the discount rate of 14%. Within the SD and EU approaches the price for tCER was derived. To derive tCER prices with the SD approach, we considered a range of values that would make the NPV of afforestation equal to its opportunity cost (i.e., NPV of crops). In the farm-household model one farm and three heterogeneous groups of smallholders were considered, which differ with respect to income and expenditure sources (the description of the deterministic farm-household model is presented in Djanibekov et al. (2013b)). It was assumed that smallholder groups 1, 2 and 3 consisted respectively of 10, 6 and 4 households. The farm-household model covered 28 years and assumed three seven- year tree plantation rotations without a discount rate. In the EU and farm-household models, to address the reluctance level of land users to accept a bargain with uncertain incomes rather than another bargain with more certain but lower incomes the risk aversion degrees were considered. To simplify the interpretation of the findings the extremely risk aversion degree was presented. Based on the observed conditions in the study area, in the EU and farm-household model a total area of 100 ha was assumed, of which 23 ha are marginal, 56 ha are fairly, 20 ha are good, and 1 ha is highly productive. The average irrigation water availability in these two models was assumed to be 12,000 m^3 ha^{-1} $year^{-1}$. In the EU and farm-household models two scenarios were simulated: (1) business-as-usual (BAU) scenario assumed existing cotton policies, i.e., 50% of farmland was allocated for cotton with a production target of 2.4 t ha^{-1} $year^{-1}$; and (2) afforestation scenario assumed that farmers can plant trees on marginal croplands, and without fixing the cotton cropping area but the same yield targets as in the BAU.

4 RESULTS

4.1 Uncertainty in net present value of land uses

The NPV for crops varied between -2,971 and 20,424 USD ha^{-1} on marginal lands (Fig. 1a). The lowest NPV over seven years on marginal cropland were of cotton, ranging between -1,041 and 346 USD ha^{-1}. Rice had the highest returns on marginal cropland assuming an irrigation input of 26,500 m^3 ha^{-1} to achieve its maximum yield. Due to the relatively high NPV ranging between -900 and 11,700 USD ha^{-1}, investments in *E. angustifolia* would be more preferred on marginal lands than cotton, wheat, maize and vegetables. Returns of *P. euphratica* and *U. pumila* species were higher than those of cotton and wheat.

In those cases where the NPV of crops were higher than trees, suitable price levels of tCER for incentivizing tree farming were estimated that would foster more environmentally sustainable land uses (areas between the lines of the respective tree species in Fig. 1b). Depending on the variable returns from crop cultivation and considering the highest NPV of trees, the tCER prices would need to increase up to 68 USD $tCER^{-1}$ for *E. angustifolia*, 103 USD $tCER^{-1}$ for *P. euphratica*, and to 133 USD $tCER^{-1}$ for *U. pumila*. When tree plantations generate the lowest profits owing to low yields and market prices of tree products, while cropping, in contrast, generates the highest profits, the tCER price would have to be substantially raised to make afforestation financially attractive, i.e., up to 540 USD $tCER^{-1}$.

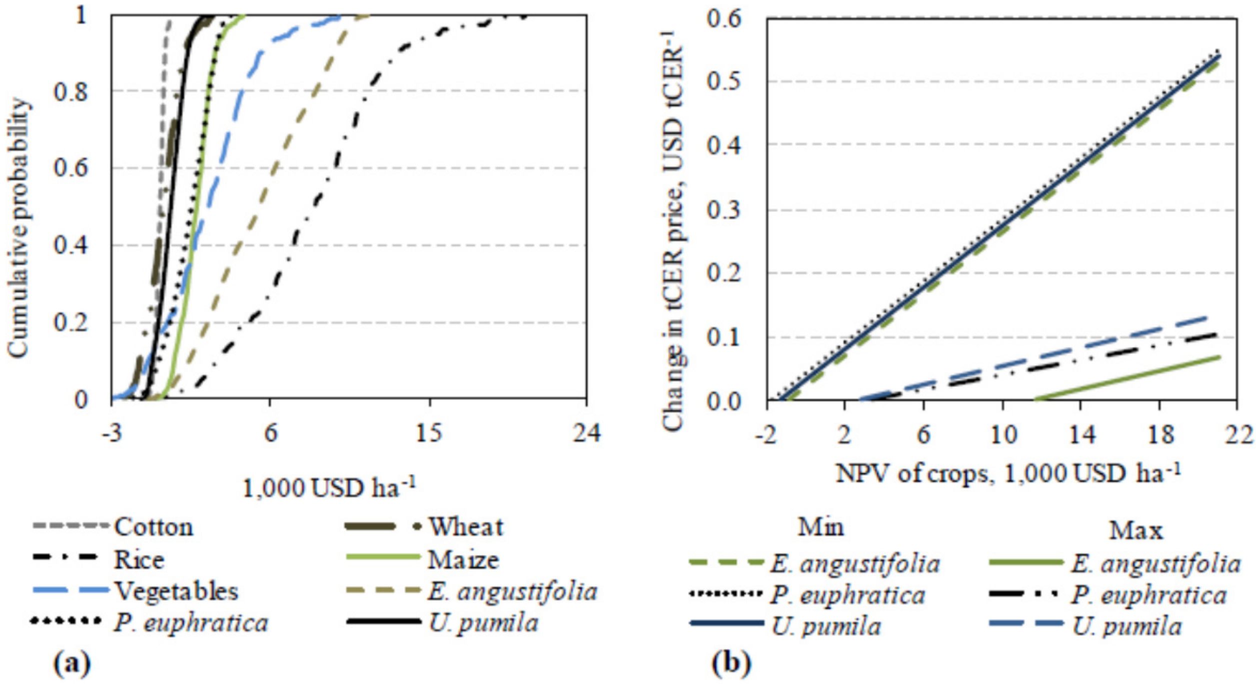

Fig.1: Stochastic dominance of trees and crops on marginal lands (a), and prices of temporary Certified Emission Reduction (tCER) under uncertainty of the net present values (NPV) of trees and crops over seven years (b).

Note: Min is the tCER price based on simulated lowest NPV of the respective tree species; Max is the tCER price based on simulated highest NPV of the respective tree species.

4.2 Land use diversification and farm income

Uncertainties in land use returns would affect farm activities. Using the EU approach, due to uncertainties in yields and prices of crops, and irrigation water availability, as well as the state procurement policy, in the BAU case, mainly cotton and wheat would be cultivated at farm (Fig. 2a). Not the entire farmland area would be cropped since about 2.5 ha of the arable land would be left fallow due to perceived revenue risk aversion. In the afforestation scenario, the flexibility of cotton procurement policy (removal of area-based target and remain only the output-based target) would lead to afforestation on marginal croplands. Planting trees on marginal croplands would increase the opportunity for cropping the most profitable crops, i.e., rice and vegetables, due to supplying irrigation water unused at afforested plots to these water demanding crops. Under the current tCER price level (4.76 USD $tCER^{-1}$) *E. angustifolia* would be the preferred choice on marginal lands. An increase in tCER revenues could enhance the preference for planting *P. euphratica*, owing to its increased biomass increment over time at the expense of the *E. angustifolia* area. In addition, the area of maize and wheat would decline as the price for tCER increases.

These land use changes would impact the income of farmer. In the afforestation scenario, establishing tree plantations on marginal lands would lead to gains varying between 60,000 and 1,170,000 USD, with tCER payments of 4.76 USD (Fig. 2b). In comparison, the returns of farmer following conventional land use practices on marginal lands would range from 15,000 to 930,000

USD over seven years. In addition to returns from tree plantations, the increase in farm income was caused by the expanded area of the most profitable crops – rice and vegetables. The lowest income would be caused by reductions in yields, prices, and irrigation water availability.

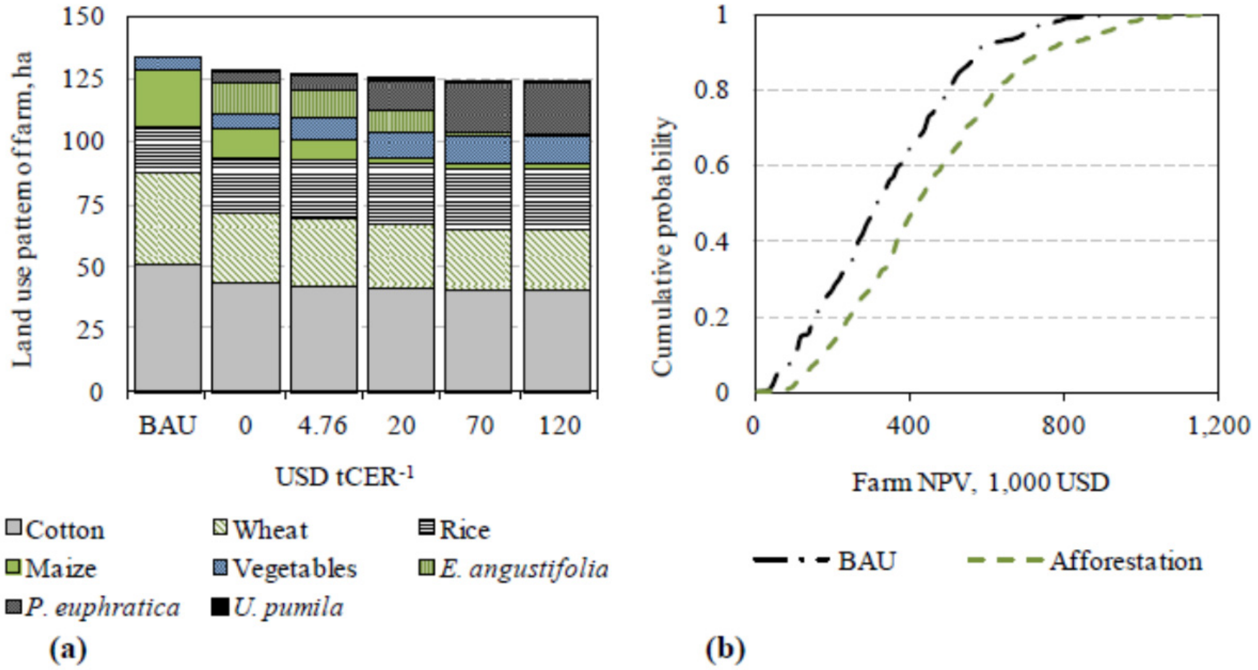

Fig. 2: Farm land use pattern (a) and cumulative distribution of the net present value (NPV) over seven years (b) in business-as-usual (BAU) and afforestation scenarios.

Given the reliance of tree plantations on the shallow groundwater (Khamzina et al., 2012), afforestation could be an option to secure farm production in years of irrigation water scarcity. The model results indicate the inclination of farmer for afforesting marginal cropland, to mitigate the income risk due to the reduced water supplies (Fig. 3). When assuming an annual lowest irrigation water availability of 4,000 m^3 ha^{-1} $year^{-1}$, marginal croplands would be entirely afforested and *E. angustifolia*, *P. euphratica*, and *U. pumila* would be planted on 17, 4.5 and 1.5 ha respectively, and the remaining farmland would be mainly cultivated with cotton (on about 70 ha) to fulfill the state production policy. At the average level of irrigation water availability, i.e., 12,000 m^3 ha^{-1} $year^{-1}$, the area of *E. angustifolia*, *P. euphratica* and *U. pumila* would be 11.1, 5.6 and 0.1 ha respectively. In the scenario of abundant irrigation water availability, i.e., 21,000 m^3 ha^{-1} $year^{-1}$, about 8 ha of marginal lands would be afforested whilst the rest would be allotted to rice and wheat.

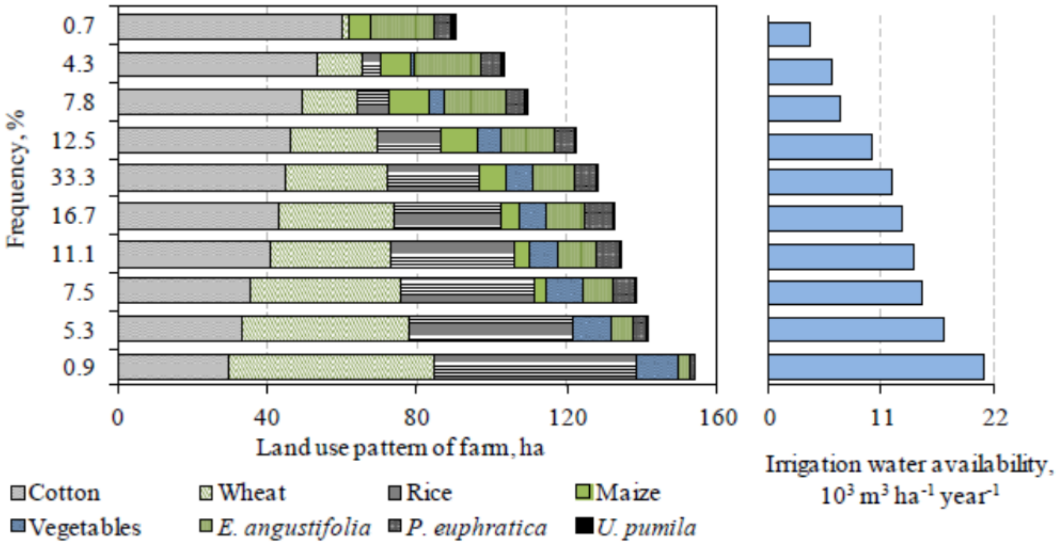

Fig. 3: Frequency of land use pattern of farm under different levels of irrigation water availability in the scenario of afforesation.

4.3 Spillover effects in the bimodal agricultural system

Introducing afforestation on marginal farmland would affect not only farm decisions but also the smallholders employed at such farm due to the existing wage-labor relationships. In the BAU scenario, cotton and wheat are dominating crops, and wheat would be rotated with rice and maize (Fig. 4a). The main crops cultivated by smallholders, would be wheat followed by rice and vegetables. In the afforestation scenario, the area of rice and vegetables would increase by about 40%, whilst cotton area would reduce by about 10% as a result of flexibility in the cotton procurement policy. The area allocated to wheat and maize would be smaller than in the BAU. The main trees planted in the afforestation scenario would be *E. angustifolia* followed by *euphratica* and *U. pumila*. The clear-cut of trees in year 21 would once again trigger changes in land use pattern. Accordingly, the cotton area policy would be restored and the area of this crop would occupy half of the farmland. The area of wheat and maize would also increase. Consequently, the area of the most profitable and irrigation demanding crops, i.e., rice and vegetables, would decline. In year 27, the land use pattern in the afforestation scenario would be similar as to the one observed in the BAU scenario.

These land use changes affected farm demand for labor services. According to the afforestation scenario, in the years of afforesting marginal lands, i.e., years one, eight and fifteen, and harvest, i.e., years seven, fourteen and twenty one, the employment of smallholders by farms would increase. In between these activities the employment at farm would reduce because of decreased labor demands, and consequently payments to smallholders would be lower than in the BAU. The inclusion of tree products in the payment structures would differ from year to year, as opposed to the BAU. In the afforestation scenario, the value of land allotted to remunerate the smallholder labor would decrease during the tree plantation period, gradually increasing after the tree harvest and reaching the level of the BAU scenario from year 27 onwards (Fig. 4b). Tree products would be one of the largest payments after land, with a fuelwood share of 20%, tree foliage of 3% and fruits of 4% of the total payment value over this period. In the BAU scenario, the main payment would remain as land, followed by grains and cotton stem. The least remuneration would be in the form of cash, because of its necessity to operate farms.

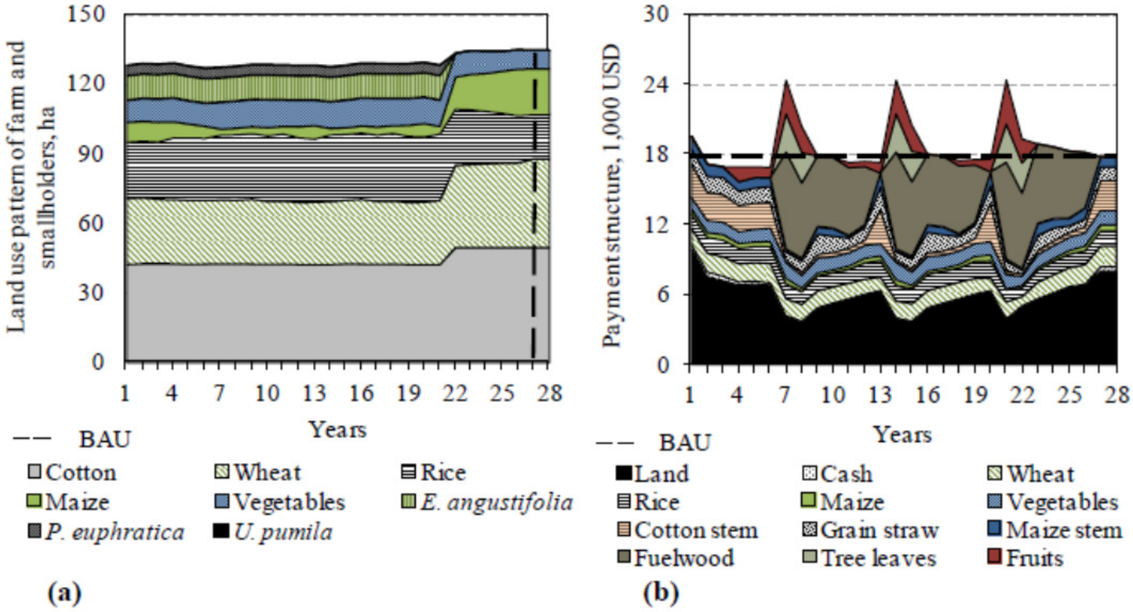

Fig. 4: Land use pattern of both farm and smallholders (a) and payments from farm to smallholders (b) over 28 years in business-as-usual (BAU) and afforestation scenarios.

4.4 Impact on rural livelihoods

Afforestation on marginal farmland would affect the incomes of farm and smallholders and would differ over the years (Fig. 5a and b). In this land use scenario the total farm income over 28 years would bypass the income in the BAU case by about 600,000 USD. This is caused by shifts in the cropping pattern towards the high-return crops such as rice and vegetables. Moreover, non-timber products, i.e., fuelwood, tree leaves, fruits and tCER, would generate revenues of around 630,000 USD over 28 years.

Due to the heterogeneity of smallholders' characteristics, their incomes would differ, and the largest one observed in group 2 (about 1,400 USD). Since less labor would be required at farm between the years of plantation establishment and harvest, the incomes of smallholders employed at farm would decrease. During those periods the incomes in total would be lower by about 5,000 USD than of the BAU case. The most affected smallholder type would be group 3, because of the high dependency of these household members on activities at farm. However, the harvest of tree plantations would substantially increase their incomes. Moreover, during the initial years after the cessation of the afforestation, namely years 22 to 26, the incomes of smallholders would be larger than under the BAU scenario. This is owing to the labor demanding activities at farm, as well as reduced energy and fodder expenditures by smallholders as a result of receiving fuelwood and tree leaves as payment in kind. A storage by farmer of tree foliage and fuelwood and their annual inclusion in the payment structure can substitute or complement respectively grain straw as fodder, and coal and liquefied petroleum gas (LPG) as domestic energy products beyond the duration of afforestation activity. The largest positive effect would relate to smallholders that largely depend on farming activities, i.e., group 3, for whom the total income over 28 years would increase by around 8% compared to the BAU scenario. As for groups 1 and 2, their incomes over 28 years would increase by 5% and 3% respectively, in contrast to the BAU case. The return to cropping on marginal lands after year 21 would eventually bring down the incomes of farm and smallholders to the levels in the BAU scenario.

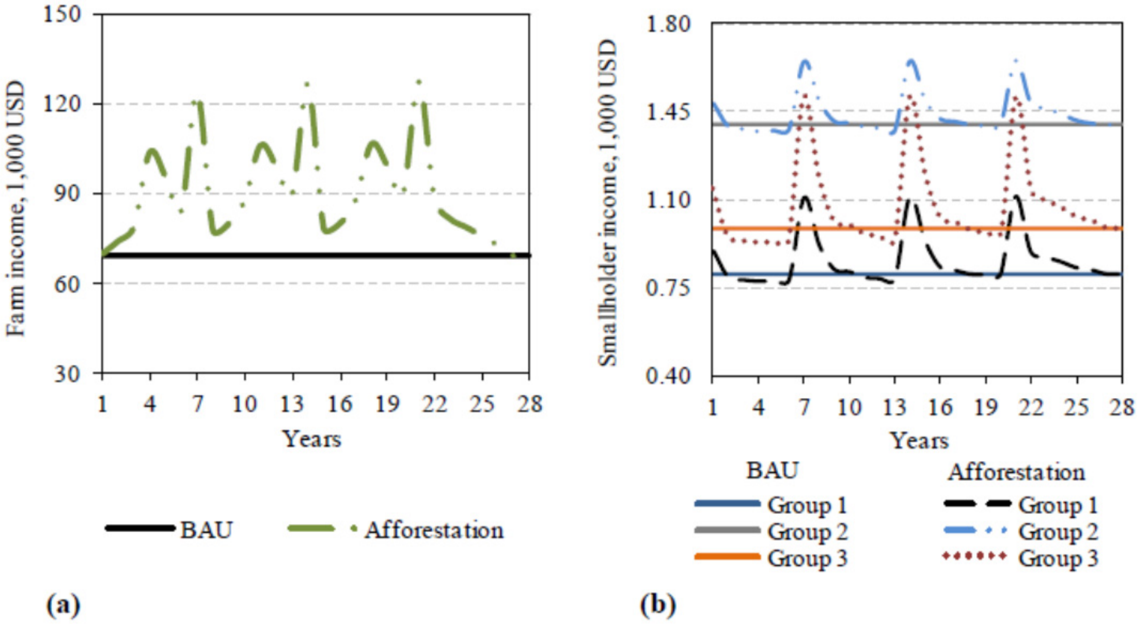

Fig. 5: Incomes of farmer (a) and individual smallholder per group (b) over 28 years in business-as-usual (BAU) and afforestation scenarios.

5 CONCLUSIONS

When considering uncertainties in land use revenues at the field level (i.e., one hectare) the current tCER prices of 4.76 USD requires an increase up to 120 times. This is hardly to be expected to implement, and thus would argue against an afforestation. At the same time, appropriately identifying the PES and scale of benefits reflect important issues. The findings showed, in addition, that an analysis at the whole farm level when afforestation of marginal croplands, rather than the field level alone, would lead to more realistic tCER prices, which may initiate land use changes to tree plantations, when considering various uncertainties affecting the farm revenues. This is because land use diversification through afforestation can be an option for farmers in order to hedge land use revenue risks. Hence, the diversification of land uses in farming could necessitate only minor adjustment of PES prices to initiate environmentally sustainable land uses. Besides, the flexibility in the cotton procurement policy, according to which farmers can decide the area of cotton cultivation and only have to deliver the state-determined production target, can be decisive for initiating afforestation on marginal croplands.

Moreover, the model findings illustrate that tree plantations could become the main income source when assuming decreased irrigation water availability and/or low crop prices and yields, reducing the repercussions of revenue risks. Due to the independent revenues of trees and crops, a farmer would select different tree species to diversify land uses. The lesser irrigation water demand of tree plantations compared to crops would allow a more efficient use of irrigation water, with that not used on marginal lands supplied to more productive croplands, and when using this would enhance grain and vegetables production. During water scarce years and when the irrigation water availability is lower than the average level, the afforestation practices would represent one of the main land uses on the farm, apart from cotton production.

The existing interdependencies in the bimodal agricultural system indicate that due to afforestation on marginal farmland not only the income of farmers adopting this land use would be impacted but also the income of smallholders employed at these farms. The annual change in working hours and inclusion of new tree products into the payment structure would diversify farm payments, and affect rural incomes. Given that afforested marginal croplands require less labor than crops between periods of tree plantations establishment and harvest, smallholders' employment on the farm would decline and consequently reduce their incomes. However, during the establishment and harvest of tree plantations the farm remuneration to smallholders would increase and outweigh the losses in previous years. This change is primarily caused from an increased employment at farm and the improved structure of agricultural contracts when including fuelwood and tree leaves into the structure of payments in kind. The inclusion of fuelwood and leaves as fodder in the farm payments has the potential to reduce the domestic energy and feed expenditures of rural households. Overall, the afforestation of marginal croplands in a bimodal agricultural system of Uzbekistan should be supplemented by additional policy measures to support smallholders' livelihoods during the periods of decreased demand for labor at farms due to the afforestation.

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