

# Stochastic Economic Assessment of Afforestation on Marginal Land in Irrigated Farming System

Utkur Djanibekov · Asia Khamzina

Accepted: 7 November 2014 / Published online: 26 November 2014  
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**Abstract** We analysed the economic viability of afforestation on marginal irrigated croplands in irrigated drylands of Uzbekistan. The revenues derived from a combination of diversified agricultural production, carbon sequestration, nitrogen fixation, and avoided irrigation water use were analysed considering uncertainty associated with on-farm activities such as crop production and short-rotation forestry. At the per hectare scale variability in land-use revenues would necessitate substantial increases in carbon prices for afforestation to be as profitable as crop cultivation on marginal lands, assuming an abundant irrigation water supply. In contrast, at the farm scale the analysis results revealed that afforestation can be attractive financially even without carbon payments due to farm production constraints, variable land-use returns, and the benefits of land-use diversification. Increased carbon prices would promote carbon sequestration by motivating farmers to plant high biomass producing tree species, but would have an ecosystem service trade-off by reducing the appeal of nitrogen-fixing species that are essential for nitrogen self-sufficiency of afforestation efforts. Given the modest irrigation needs of afforestation efforts compared to the cultivation of annual crops, tree plantations could become a primary income source for farms during periods of drought. Irrigation water saved from replacing crops with trees on marginal farmland would enhance the cultivation of commercial crops on productive lands, thus increasing farm income.

**Keywords** Farm income risk · Ecosystem services · Ecosystem service trade-offs · Land-use diversification · Expected utility · Stochastic dominance

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## 1 Introduction

Unsustainable land-use practices are among the major drivers of global environmental degradation (Turner et al. 2007). 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). Approximately 20% of irrigated agro-ecosystems suffer from some level of degradation and 2,500–5,000 km<sup>2</sup> of arable land is lost annually due to excessive salinity and waterlogging (Bai et al. 2008; UNEP 2009). Introducing forestry efforts on degraded croplands may yield various ecosystem services (ES), such as reducing soil erosion, lowering shallow and saline groundwater tables, replenishing soil nutrients, improving biodiversity, and mitigating the climate change (Danso et al. 1992; Costanza et al. 1997; Guo and Gifford 2002; Jiao et al. 2012; Ninan and Inoue 2013). Rewarding the providers of these services through compliance (e.g. Clean Development Mechanisms [CDM]) or voluntary markets (e.g. Chicago Climate Exchange) could further incentivise afforestation initiatives on marginal farmland (Dobbs and Pretty 2008; Engel et al. 2008; Gong et al. 2010).

Variability in the supply of ES provided by tree plantations affects the value of those services, making it necessary to consider the different outcomes that could influence land-use decisions (Mendelsohn and Olmstead 2009; Bateman et al. 2011). However, previous studies that assessed environmentally sustainable land uses typically considered only a portion of their value (Mendelsohn and Olmstead 2009; Sijtsma et al. 2013). For instance, when assessing carbon (C) stocks resulting from forestry efforts profits were often compared to opportunity costs, such as cultivation of annual crops (e.g. Olschewski et al. 2005; Maraseni and Cockfield 2011), and only a few studies have accounted for related uncertainty and risk (e.g. Johnson et al. 2012; Knoke et al. 2011). Benítez et al. (2006) considered the opportunity costs of land-use alternatives based on analyses at the hectare level to determine conservation payment amounts for shade coffee plantations under conditions of uncertainty. That study found that the payments required preserving these land uses were greater than those estimated without considering variability of returns.

When farmers make land-use decisions within the context of a farming system, however, different values for ES provision at the farm-scale are taken into account (Knoke et al. 2009). Di Falco and Perrings (2005) argued that consideration of revenue risks at the farm level was important for estimating the full range of potential land-use benefits and costs. Supporting this argument, Johnson et al. (2012) showed that revenue fluctuations from different land uses can lead to trade-offs in the provision of ES. These trade-offs may occur when the enhancement of one ES decreases provision of another ES, often with negative consequences on rural livelihoods (Rodríguez et al. 2006). Introducing new land uses such as afforestation on marginal croplands may have negative effects on farmer incomes by exacerbating production constraints such as limited land and water availability (Cao et al. 2011). To the contrary, diversifying farm activities with forestry may provide an effective buffer against farm revenue risks due to independent income fluctuations among land uses (Baumgärtner and Quaas 2010). Hence, the implementation of forestry efforts on marginal croplands may provide various goods and services whose appropriate values under conditions of uncertainty must be identified, while considering trade-offs in supply of ES as well as the effects on agricultural land-use decisions and consequently on incomes (Van Kooten 2000; Rodríguez et al. 2006; Nijnik et al. 2013). To our knowledge there have not yet been any efforts to conduct such complex analyses within the context of irrigated crop production systems where forestry has been introduced on degraded farmland for land rehabilitation.

Few studies have addressed trade-offs in the provision of multiple ES when policies target enhancing a specific ES (e.g. [Raudsepp-Hearne et al. 2010](#); [Goldstein et al. 2012](#)). To fill these gaps we analysed afforestation initiatives on degraded irrigated croplands in Uzbekistan and revealed opportunities for C sequestration, soil nitrogen replenishment, irrigation efficiency improvement, and potential profit generation ([Khamzina et al. 2012](#); [Djanibekov et al. 2012, 2013b](#)). Considering that the returns from forestry initiatives on marginal croplands are subject to various uncertainties and may also diversify farm income, we assessed: (1) the value and trade-offs with respect to the provision of ES through afforestation efforts under uncertain revenue conditions and at different spatial scales, and (2) the effects of land-use diversification through afforestation on farm activities and income among irrigated farming systems.

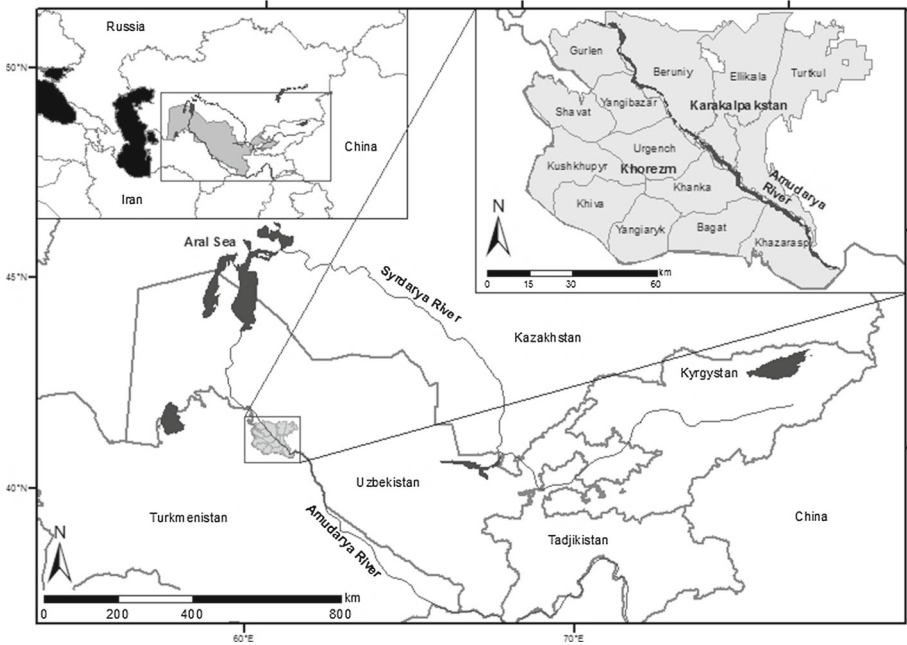
## 2 Methods

### 2.1 Study Area

The study area included the Khorezm region and three southern districts (Beruniy, Turtkul, and Ellikkala) of the Autonomous Republic of Karakalpakstan located in the lower reaches of the Amu Darya River in Uzbekistan (Fig. 1). The area has an arid continental climate with annual precipitation of about 100 mm, most of which occurs outside of the growing season; thus crop cultivation requires irrigation. Irrigated agriculture accounts for about 35 % of the regional GDP ([MAWR 2010](#)). Most agricultural producers are farmers who lease land, accounting for about 88 % of the total arable land area ([MAWR 2010](#)).

The major crops in the study area are cotton and winter wheat (hereafter wheat), accounting for about 40 and 25 % of the arable land respectively ([MAWR 2010](#)). Cotton and wheat cultivation are subject to a state procurement policy. According to this policy farmers must allocate about half of their land to cotton and comply with assigned production levels ([Djanibekov et al. 2013a](#)). Farmers are required to sell their entire cotton harvest to the state at lower prices than potential border market prices ([Pomfret 2008](#)). Farmers are also required to sell the state half of the wheat they produce at below local market prices, and the remainder can be traded in local markets ([Djanibekov et al. 2012](#)). Cotton and wheat production receives indirect subsidies from the state, including prioritized irrigation water provision and reduced prices for fertilizers and machinery leasing ([Djanibekov et al. 2010](#)). Most subsidies are allocated to the agricultural sector as a whole rather than to individual farmers. Other principal crops such as rice and vegetables are important cash crops, while maize is cultivated for use as livestock feed. The annual crop production cycles include cotton cultivation from March to November, wheat from October to June, rice and maize from July to September, and vegetables from April to September.

Irrigated agriculture in the study area is subject to various risks that can affect rural well-being. For example, increased variability of irrigation water supply and recurrent droughts in 2000 and 2001 have had substantial negative impacts on rural livelihoods ([Dukhovny and Ziganshina 2011](#)). Due to the downstream location of the study area there is greater uncertainty in the availability of irrigation water than in upstream areas. Yield variability also occurs as a result of pest outbreaks, crop diseases, and unfavourable weather conditions. About 20–30 % of the arable land in the region are classified as marginal ([MAWR 2010](#)) due to either inherently low suitability for farming or degradation. The low fertility of agricultural soils in the study area makes substantial inputs of fertilizers, particularly nitrogen, necessary for crop production ([Kienzler et al. 2011](#)). The crops subject to the state procurement policy—cotton



**Fig. 1** Location of the Khorezm region and southern districts of the Autonomous Republic of Karakalpakstan

and wheat—are the main crops cultivated on marginal lands (MAWR 2010), which often results in financial losses for farmers (Djanibekov et al. 2012). Farmers also face market risks due to fluctuations of agricultural commodity prices. Table 1 in Appendix 1 presents the coefficients of variation for crop yields, crop prices, irrigation water availability, and tree product prices.

## 2.2 Uncertainty of Crop and Forestry Revenues

In the analyses land-use risks were considered to be undesirable events that could negatively affect farm income (Hardaker et al. 2004). Uncertainty in farm revenues may affect farm income either positively or negatively (Hardaker et al. 2004). We used a Monte Carlo simulation to generate various parameters for irrigation water availability, and yields and prices of crop and tree products. Monte Carlo simulation is commonly applied to explore the impacts of economic uncertainty on land-use returns. This method allows the generation of a large number of different scenarios and outcomes by considering certain model values to be randomly selected with the possibility of making them correlated (Hildebrandt and Knoke 2011). To prevent biasing the simulation results a stochastic dependency among crop yields and prices and irrigation water availability were considered by assuming their joint normal distribution. The price of cotton is set by the state and was therefore considered deterministic. The wheat price used was the mean value of the market and state procurement prices. Yields of product of each tree species were pair-wise correlated (i.e. between yields of wood, foliage, and fruit) and generated with a normal distribution, whereas product prices were independently normally distributed. Given that the data for tree product yields rely on experimental forestry findings and the prices of tree products were only obtained for 1 year, we did not consider correlation between tree yields and prices, tree and crop parameters, and

tree parameters and irrigation water availability. Simulated parameters were assumed to be identically distributed therefore the outcome in one period did not influence the probability distribution in another. Since it is not possible to have negative yields, prices and irrigation water availability, their values were truncated at minimum and maximum values. Table 2 in Appendix 2 presents the correlation coefficients of observed irrigation water availability, crop prices, and yields. The correlation coefficients of tree product yields are presented in Table 3 in Appendix 2.

Given the simulated stochastic parameters, the net present value of trees and crops ( $NPV_s$ ) was estimated as follows:

$$NPV_s = \sum_{t=0}^T \frac{Y_{st} P_{st} - B_t}{(1 + d)^t} \tag{1}$$

where  $Y_{st}$  and  $P_{st}$  are values of yields and prices respectively under states  $S$ ;  $B_t$  is the cost (in USD ha<sup>-1</sup>) of land uses during period  $t$  (including land preparation, planting, maintenance, harvest, and transportation of crop and tree products), and  $d = 14\%$  is the real interest rate, which is the difference between the nominal interest rate (22%) and a consumer price index (ca. 8%; ADB, 2011) for Uzbekistan in 2009.  $Y_{st}$  includes major crop products and the share of crop by-products, such as wheat and rice straw, and cotton and maize stem. The costs were assumed to be deterministic.

### 2.3 Uncertainty in Land-Use Revenues at the Field Level

In the process of changing land-uses such as from annual crop cultivation to forestry, a farmer decides whether to invest in afforestation under  $S$  possible outcomes corresponding to different levels of returns from tree species and crops. For valuing the management practices in plantation forestry the option pricing approach has been widely applied (Hildebrandt and Knoke 2011). Plantinga (1998) identified optimal forest rotation lengths under stochastic prices, Jacobsen and Thorsen (2003) developed optimal thinning strategies for mixed-species stands under varying tree growth rates, and Leroux et al. (2009) proposed optimal biodiversity conservation policies considering the uncertainty of species densities.

In the case of newly introduced forestry systems in areas lacking in management history, the comparison of their income distributions with those of crop production systems (i.e. opportunity costs of land) should be considered first. Stochastic dominance is a suitable method for this purpose because it orders the profits of land-use activities when the preference function is unknown, ranking them in terms of the income distribution (Hadar and Russell 1971). As farmers are often risk-averse, we applied a second-order stochastic dominance (SSD) approach. According to the SSD criteria the distributions of land-use outcomes at the hectare scale were compared based upon the areas under their cumulative distribution function (Hardaker et al. 2004). We used the SSD approach to investigate the distribution of land-use income and identified the required financial support for farmer in terms of the price for tonne of sequestered CO<sub>2</sub> (tCO<sub>2</sub>) to incentivise afforestation efforts. In this case profits from afforestation would dominate the profits from annual crop cultivation, if and only if:

$$\int_{NPV_a^{min}}^{NPV_a} FNPV_a(u) du \leq \int_{NPV_c^{min}}^{NPV_c} FNPV_c(u) du \tag{2}$$

where  $NPV_a^{min}$  and  $NPV_c^{min}$  are the minimum attainable NPV of afforestation and annual crops respectively;  $FNPV_a$  and  $FNPV_c$  are the cumulative distribution functions of NPV of afforestation and annual crops respectively, and  $u$  is a variable of integration. Ranking thus includes comparison of the integrals of the cumulative distribution functions.

This approach does not account for constraints in land-use decisions; therefore the state cotton procurement policy, irrigation water availability, and land area were not considered as limiting factors. Accordingly, the SSD analysis considered crop yields at the optimal water-yield response levels.

Similar to [Olschewski and Benítez \(2005\)](#), in cases where the returns from afforestation is lower than those from crops the minimum payment levels per tCO<sub>2</sub> ( $P_s^{tCO_2}$ ) required to motivate farmer to shift from annual crop cultivation to forestry on marginal land were calculated as follows:

$$P_s^{tCO_2} = \frac{NPV_{sc} - NPV_{sa}}{\sum_{t=0}^T Y_{st}^{tCO_2} (1+d)^{-t}} \quad (3)$$

In Eq. 3 the value of  $P_s^{tCO_2}$  depends on the yield and price variability of crops and trees, reflected in  $NPV_{sc}$  and  $NPV_{sa}$  respectively, and on the variability of tCO<sub>2</sub> sequestration determined by species-based variability in tree growth. According to the SSD approach we assumed that in order to justify the conversion of marginal croplands to tree plantations when the returns on afforestation efforts are lower than those from crops, therefore the price for sequestered tCO<sub>2</sub> needs to reach the level at which returns are at least equal. Due to the lack of information on revenue correlations between crop and tree products, the range of NPVs (i.e. from the minimum and maximum  $NPV_c$  and  $NPV_a$  values) were used to determine the prices for tCO<sub>2</sub> that would incentivise afforestation initiatives on marginal croplands. We did not attempt to estimate the value of N<sub>2</sub>-fixation by tree plantation species under revenue uncertainty because markets and a general awareness of this ES are lacking.

## 2.4 Farm Land-Use Planning

The SSD approach can be used for ordering risky choices in farm activity and for identifying appropriate environmental payment levels according to the opportunity cost of land. However, SSD lacks discriminatory power and neglects total farm income and land-use trade-offs, and consequently may result in weak conclusions with respect to the implementation of environmentally sustainable land uses ([Hardaker et al. 2004](#)). Introducing an innovative land use involves changes in farm planning that are conditional upon resource availability and production trade-offs. Frequently used farm-level approaches that consider uncertainty include mathematical programming models such as the mean-variance, minimization of total absolute deviations, and expected utility models ([McCarl and Spreen 1997](#); [Hardaker et al. 2004](#); [Hildebrandt and Knoke 2011](#)). The mean-variance approach considering revenue uncertainty at the farm level was used to develop strategies for conservation of wildlife-friendly shade coffee production ([Castro et al. 2013](#)). [Teague et al. \(1995\)](#) used the target minimization of total absolute deviations approach to assess the environmental outcomes associated with agricultural production practices and concluded that the deterministic environmental risk measures might ignore significant probabilities of exceeding an environmental standard. The main disadvantage of these two approaches is that the mean is considered as the relevant target and risk is quantified as the magnitude of deviation from this target ([Berg and Schmitz 2008](#)). Several other studies have analysed the downside risk (i.e. lower than expected profits) mitigation options at the farm level (e.g. [Sakong et al. 1993](#); [Manfredo and Leuthold 2001](#); [Femenia et al. 2010](#)). However, the land-use activities may have both positive and negative impacts on farm income ([Graveline et al. 2012](#)).

Another approach that is frequently applied in farm economic models to address both the positive and negative effects on farm income is expected utility  $E(U)$ . The  $E(U)$  method assumes that the utility of farm profits from all land uses ( $NPV_s^{FARM}$ ) can be calculated

based on the expected distribution of land-use revenues and the degree of risk aversion ( $r$ ). We applied a  $E(U)$  model that included different states of nature through a Monte Carlo simulation and considered two scenarios: (1) business-as-usual (BAU); subject to the state cotton procurement policy, and (2) afforestation of marginal croplands. The negative exponential utility function was expressed as follows:

$$MaxE(U) = \sum_{s=1}^S U \left( NPV_s^{FARM}, r \right) \pi(P_s) = 1 - e^{-rNPV_s^{FARM}} \tag{4}$$

where  $U$  is the utility function evaluated for the selected risk aversion  $r$  values with respect to the expected NPV from the land uses and  $\pi(P_s)$  is the probability for the states of nature  $S$  in the Monte Carlo simulation; where each outcome has the same probability. This approach allows uncertainty to be represented by differentiating various states of nature whose utility sums to 1.

Ordering each outcome by utility values would be the same as ordering them by certainty equivalents (CE) (Lien et al. 2007). The CE expresses values in monetary terms which indicate the certain amount of return rated by a decision maker under risky conditions (Hardaker et al. 2004):

$$CE = U^{-1}(NPV_s^{FARM}, r) \tag{5}$$

Following Arrow (1971) we assumed that the constant absolute risk aversion level ( $r$ ) would remain constant when land-use profits change. The  $r$  values were estimated with respect to the NPV of the risk-neutral farmer ( $NPV^{neutral}$ ) within a range of risk aversion coefficients  $rr$  (ranging from 0.5 to 4 for the hardly and extremely risk-averse farmer respectively) following Anderson and Dillon (1992), and as we used the NPV of farm the  $r$  values do not change every year:

$$r = \frac{rr}{NPV^{neutral}} \tag{6}$$

A mixed cotton-grain farming system was analysed because of its numeric and spatial dominance in the study area (MAWR 2010). It was assumed that farmer had 100 ha of arable land ( $q$ ), of which 1 ha are highly productive, 20 ha are good productive, 56 ha are fair productive, and 23 ha are marginal. These lands ( $X$ ) were allocated to either crops or trees ( $j$ ). The distribution of land productivity classes corresponds to that reported in the Khorezm region in 2005 (Khorezm Region Land Cadastre 2006). Crops could be cultivated regardless of land productivity, whereas afforestation was restricted to marginal lands:

$$\sum_j X_j \leq q_j \tag{7}$$

The mean irrigation water availability for farm was assumed to be 1,200,000 m<sup>3</sup> annually based on MAWR (2010). With respect to the irrigation water availability constraint, farmer allocated irrigation water to arable lands ( $X$ ) with crops and trees ( $j$ ) at respective irrigation rates ( $k$ ) that should not exceed the variable water supply to the farm ( $w_s$ ):

$$\sum_j kX_j \leq w_s \tag{8}$$

The state cotton procurement policy was incorporated into the model using two constraints. Under the BAU scenario (1) at least 50 % of farmland ( $X$ ) was allocated to cotton cultivation ( $F$ ) according to the area-based target (Eq. 9), and (2) cotton production for the entire farm

should not be less than the amount set by the state ( $ST$ ), i.e. 120 t, according to the quantity-based production target (Eq. 10). In the afforestation scenario the cotton production area was not fixed, yet the same quantity-based production target remained:

$$X_j \geq F_j \quad \text{where } j \text{ includes only cotton} \quad (9)$$

$$\sum Y_{sj} X_j \geq ST_j \quad \text{where } j \text{ includes only cotton} \quad (10)$$

In order to determine the payment level for sequestered tCO<sub>2</sub> required to incentivise afforestation on marginal croplands a sensitivity analysis was applied by changing the price of tCO<sub>2</sub> under five scenarios: no value, 4.76 [the value for temporary Certified Emission Reductions of CDM in 2009 from [Hamilton et al. \(2010\)](#)], 20, 70, and 120 USD t CO<sub>2</sub><sup>-1</sup>. The sensitivity analysis included 5 and 20 % interest rates in addition to the 14 % real interest rate to reveal the impacts of discounting on the optimal allocation of farm land uses.

## 2.5 Data Sources

Survey of 160 farms were conducted in the study area from June 2010 to March 2011 to collect data on farm sizes, crop cultivation areas, input and output prices, production practices and costs, labour requirements, and transportation costs. The prices of crop and tree products were based on weekly market monitoring during the same period. In addition, data from local statistical departments were collected for the 2001–2009 period to capture the variability of crop yields, crop prices, and irrigation water availability ([MAWR 2010](#); [State Statistical Committee of Uzbekistan 2010](#)).

Yields of cotton, wheat, rice, maize, and vegetables were estimated based on a water-yield response function using official irrigation rate recommendations for the four classes of cropland productivity, (i.e. marginal, fair, good, and high) ([MAWR 2001](#); [Land Resources 2002](#)). According to these specifications rice yields are similar for all land productivity classes, varying only with the amount of irrigation water applied. Based on the water-yield response functions achieving optimal yields require annual water inputs of 5,980 m<sup>3</sup> ha<sup>-1</sup> for cotton, 5,380 m<sup>3</sup> ha<sup>-1</sup> for wheat, 26,590 m<sup>3</sup> ha<sup>-1</sup> for rice, 5,300 m<sup>3</sup> ha<sup>-1</sup> for maize, and 8,600 m<sup>3</sup> ha<sup>-1</sup> for vegetables ([MAWR 2001](#)).

Information on product yields from afforestation with *Elaeagnus angustifolia* L., *Populus euphratica*, Oliv. and *Ulmus pumila* L. species and associated forestry practices over a 7-year period were obtained from a field trial on degraded cropland in the Khorezm region ([Khamzina et al. 2008](#)). The experimental tree plantations received 1,600 m<sup>3</sup> ha<sup>-1</sup> of irrigation water annually for the first 2 years after planting and thereafter relied on groundwater. The nitrogen (N) requirements of tree plantations were satisfied through biological nitrogen fixation (N<sub>2</sub>-fixation) by *E. angustifolia* (i.e. a supporting ES) and the uptake of leached fertilizers from groundwater. Over time the N<sub>2</sub>-fixation by *E. angustifolia* enhanced soil fertility of degraded cropland ([Khamzina et al. 2009](#)). The value of N input through N<sub>2</sub>-fixation over a 7-year period was calculated based on the price of an equivalent amount of ammonium nitrate fertilizer, which is commonly applied to annual crops in the study area ([Kienzler et al. 2011](#)). We used the local price of ammonium nitrate (154 USD t<sup>-1</sup>) and its nitrate share (33 %) to calculate a value of 467 USD t<sup>-1</sup> for fixed N. We also considered the regulating service (i.e. CO<sub>2</sub> that is sequestered in the above- and below-ground woody biomass) and provisioning services (i.e. fuelwood, foliage used as livestock fodder, and edible fruit of *E. angustifolia*). The percentage of C in stems, twigs and coarse roots ranged 44–47 % based on the analysis of finely ground plant samples using an elemental analyser. The C stocks for plantations were then computed based on the observed values of woody biomass and stand density and



subsequently converted into CO<sub>2</sub> by applying a factor of 3.67. As leaf fodder is not marketed in the study area its value was derived from the crude protein content and market price of dry alfalfa. The 7-year forestry rotation period was considered a sufficient amount of time for generating a harvestable supply of goods and services from tree plantations on marginal lands. The forestry rotation period of 7 years also reflects existing land tenure constraints in Uzbekistan, which presently limit long-term investments in forestry.

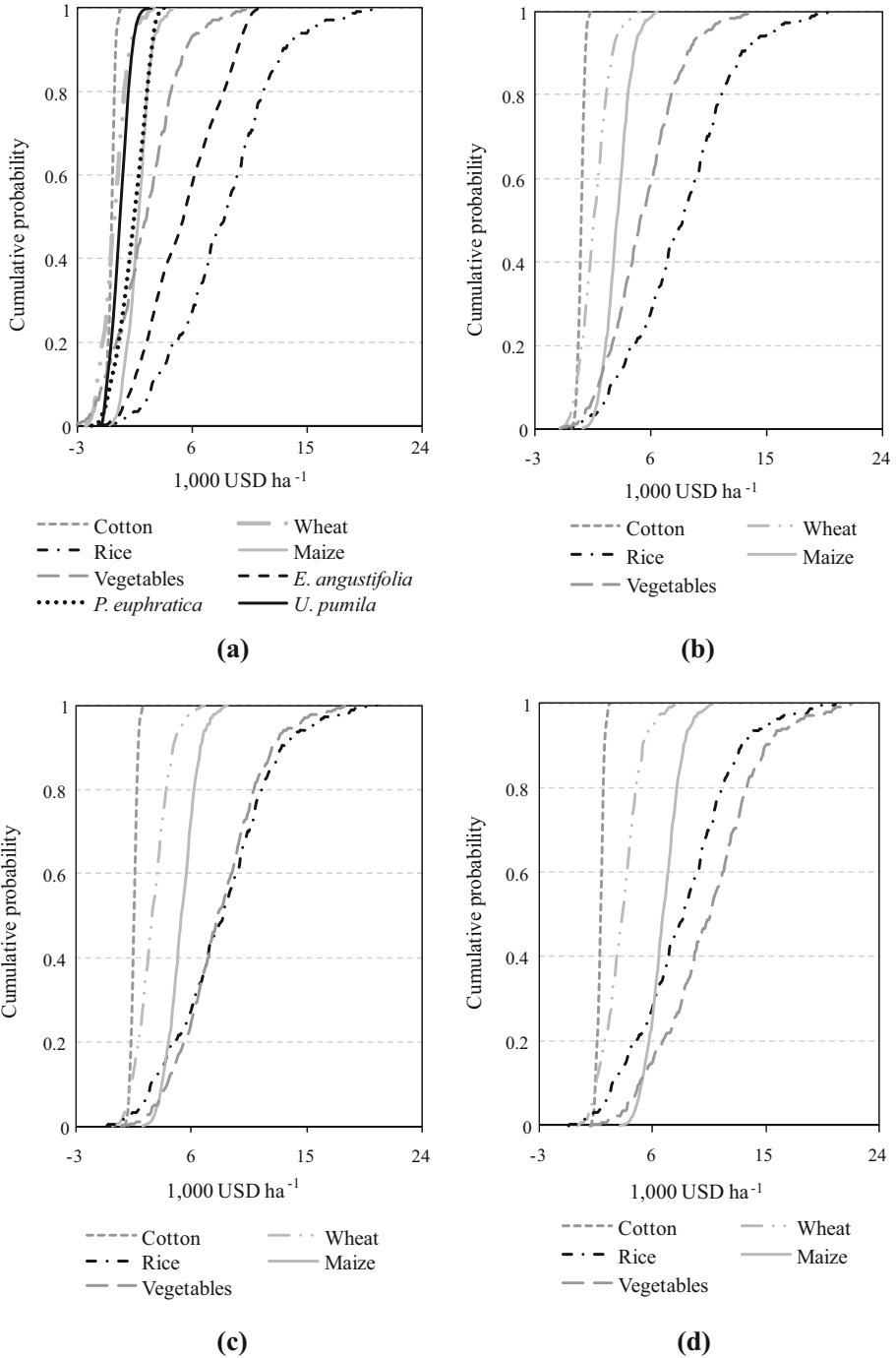
### 3 Results

#### 3.1 Uncertainty in Net Present Value of Land Uses

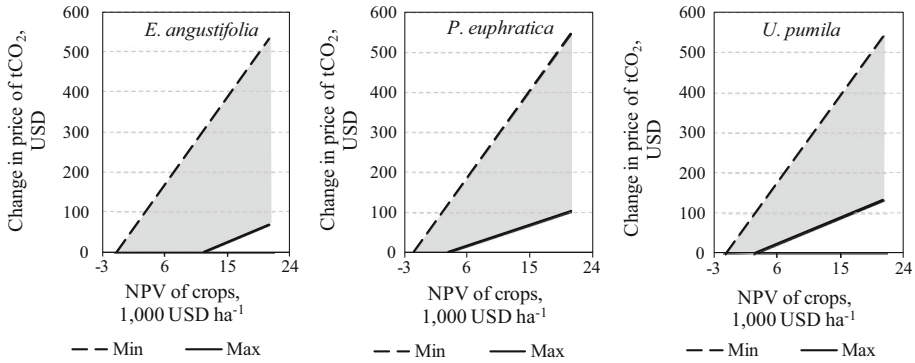
The stochastic simulation of annual cropping and short-rotation forestry allowed us to identify land-use options that were mutually exclusive, as well as the most and least risky land-use options (Fig. 2). The NPV range for crops was from  $-2,971$  to  $20,424$  USD ha<sup>-1</sup> for marginal lands, and from  $-588$  to  $21,753$  USD ha<sup>-1</sup> for highly productive lands. Due to the state procurement policy cotton was the least risky crop, with most of the associated risk stemming from yield variability. For example, the NPV of cotton production over 7 years ranged from  $-1,041$  to  $346$  USD ha<sup>-1</sup> on marginal lands. The NPV of wheat was also relatively stable because half of wheat harvests are purchased by the state at fixed prices. Rice had the highest NPV among all crops on marginal lands, with values ranging from  $-500$  to  $20,500$  USD ha<sup>-1</sup>, however, to achieve optimal yield levels rice production required the largest irrigation inputs ( $26,590$  m<sup>3</sup> ha<sup>-1</sup> year<sup>-1</sup>). On fair productivity soils rice outperformed other crops, whereas both vegetables and rice dominated on good productive lands, and on high productive areas vegetables performed best. Rice and vegetables had the greatest variability of NPV among the crops considered. For instance, the cumulative probability function for rice indicated a 20% chance of the NPV being lower than  $4,650$  USD ha<sup>-1</sup>, a 40% chance of being lower than  $7,300$  USD ha<sup>-1</sup>, a 60% chance of being lower than  $9,500$  USD ha<sup>-1</sup>, and an 80% chance of being lower than  $11,500$  USD ha<sup>-1</sup>. The high variability of NPV was due to the values of the coefficients of variation and correlation of the simulated parameters. [Bobojonov and Aw-Hassan \(2014\)](#) also found high variability of crop gross margins, which can be exacerbated further due to the effects of climate change.

In Fig. 2a the NPV curve of *E. angustifolia* is to the right of the curves of all other crops except rice, indicating that the cultivation of this tree species would generate greater NPVs than other crops on marginal lands. The NPV of *E. angustifolia* over 7 years ranged from  $-962$  USD ha<sup>-1</sup> to  $11,634$  USD ha<sup>-1</sup>. The NPV of *E. angustifolia* was the highest and most variable among the tree species due to the annual production of fruits. Afforestation with *U. pumila* yielded the least NPV and had the least variability of returns among tree species. For instance, the NPV of *U. pumila* had a 20% chance of being lower than  $-350$  USD ha<sup>-1</sup>, a 40% chance of being lower than  $120$  USD ha<sup>-1</sup>, a 60% chance of being lower than  $650$  USD ha<sup>-1</sup>, and an 80% chance of being lower than  $1,000$  USD ha<sup>-1</sup>. In the deterministic analysis the NPV results were  $5,516$  USD ha<sup>-1</sup> for *E. angustifolia*,  $1,459$  USD ha<sup>-1</sup> for *P. euphratica*, and  $477$  USD ha<sup>-1</sup> for *U. pumila* ([Djanibekov et al. 2012](#)). The deterministic analysis NPV results for crops on marginal lands were  $-330$  USD ha<sup>-1</sup> for cotton,  $-74$  USD ha<sup>-1</sup> for wheat,  $8,369$  USD ha<sup>-1</sup> for rice,  $1,800$  USD ha<sup>-1</sup> for maize, and  $561$  USD ha<sup>-1</sup> for vegetables.

For crops that were more profitable on marginal lands than trees, suitable tCO<sub>2</sub> payment levels for incentivising afforestation could be identified. To derive tCO<sub>2</sub> payment levels with the SSD approach we considered a range of values that would make the NPV of afforestation



**Fig. 2** Stochastic dominance of the net present value over 7 years of both trees and crops on marginal lands (a), and only crops on fairly (b), good (c), and highly (b) productive lands. *Note* Revenues from the payments for sequestered tCO<sub>2</sub> are not considered



**Fig. 3** Prices of tCO<sub>2</sub> under variability of the net present value (NPV) over 7 years of trees and crops on marginal lands. *Note* Min is the price of tCO<sub>2</sub> based on the lowest simulated net present value of the respective tree species; Max is the price of tCO<sub>2</sub> based on the highest simulated net present value of the respective tree species

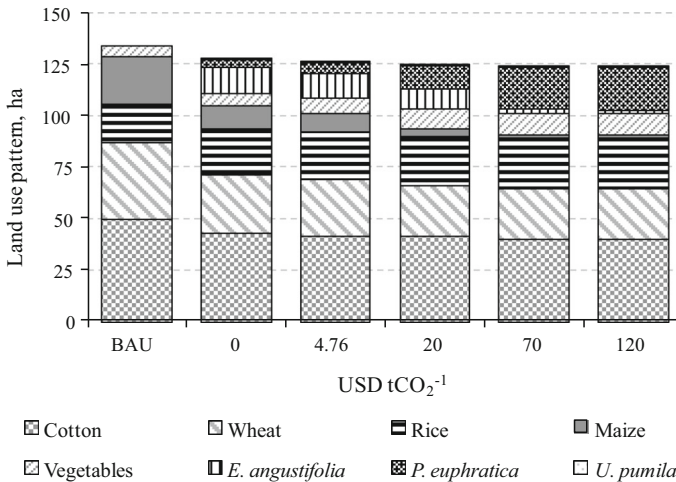
equal to the opportunity cost (i.e. the NPV of other land uses) (e.g. shaded areas in Fig. 3). Depending on the variability of returns from crop cultivation and considering the greatest NPV of tree plantations, the tCO<sub>2</sub> payment levels may need to reach 68 USD tCO<sub>2</sub><sup>-1</sup> for *E. angustifolia*, 103 USD tCO<sub>2</sub><sup>-1</sup> for *P. euphratica*, and to 133 USD tCO<sub>2</sub><sup>-1</sup> for *U. pumila*. In the most extreme case of forestry having the least NPV due to low yields and market prices of tree products and crop cultivation having the greatest NPV, the tCO<sub>2</sub> payment level would have to be raised considerably to make afforestation financially attractive. For example, in the case of afforestation with *U. pumila*, which had the lowest NPV among trees; to justify replacing the crop with the highest NPV (i.e. rice) on marginal lands the monetary value of tCO<sub>2</sub> would need to reach 540 USD.

### 3.2 Land-Use Diversification and the Provision of Ecosystem Services

Prior to initiating afforestation on marginal cropland, it is important to assess the resulting trade-offs from this land-use conversion in the context of the entire farm system for balancing the demands for goods and services (Johnson et al. 2012). Under the assumption of deterministic returns in the BAU scenario with a 14 % discount rate the crop area on 100 ha would be 50 ha for cotton, 32 ha for wheat, 26 ha for rice, 19 ha for maize, and 2 ha for vegetables. In the afforestation scenario, tree plantations of *E. angustifolia* would account for 18 ha and the areas allocated for cotton, wheat, and maize production would be reduced to 41, 30, and 2 ha, respectively. In contrast, rice and vegetable production areas would increase to 30 and 4 ha, respectively.

We initially determined land-use NPVs for a risk-neutral farmer to derive the risk aversion level of farmer. Over 7 years the NPV for this risk-averse farmer reached 353,000 USD. Consequently, considering constant absolute risk aversion levels the estimated risk aversion levels of farmer ranged from 0.000014 to 0.000011. To simplify the interpretation of the results we focused on the model output at the highest extreme 0.000011 risk aversion level under the current real interest rate of 14 %.

In the BAU scenario the extremely risk-averse farmer would prioritize achieving the cotton production target (Fig. 4). The land-use pattern under conditions of uncertainty would differ from the results achieved without the uncertainty analysis. The area of crops with high and variable NPV would be lower than under the deterministic analysis, whereas the opposite

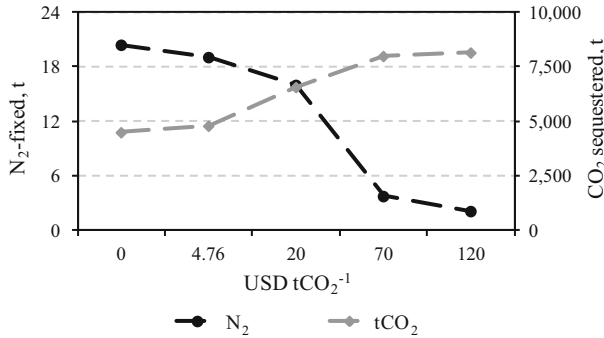


**Fig. 4** Land use pattern of extremely risk-averse farmer under scenarios of business-as-usual (BAU) and afforestation with different prices of tCO<sub>2</sub>

would be observed for less NPV varying crops. A similar trend of land-use was observed for the hardly risk-averse farmer, however, crop production would account for another 2.5 ha relative to the extremely risk-averse farmer due to the lower susceptibility to risk of the production system. Under both risk aversion levels rice would be the major crop cultivated on marginal lands due to the assumption of uniform irrigation-yield response among land productivity classes.

Farmer who is flexible with respect to their land-use decisions (afforestation scenario) would have substantially different land-use compositions depending on their risk aversion levels, which could be explained by the cotton procurement policy and land-use diversification through afforestation. To mitigate risks to their incomes farmer would choose to plant all three tree species. As a result of afforestation on marginal croplands the cultivation area of rice and vegetables on productive land would increase relative to the BAU scenario. These land-use changes can be explained by the relatively modest irrigation requirements of trees (Khamzina et al. 2008), allowing farmer to divert more water to more productive croplands. When we included 5% discount rates in the uncertainty analyses the farm land use pattern included 41 ha of cotton, 26 ha of wheat, 24 ha of rice, 6 ha of maize, 7 ha of vegetables, 13 ha of *E. angustifolia*, 6 ha of *P. euphratica*, and 0.2 ha of *U. pumila*. At the 20% discount rate the land-use composition was similar for annual crops and the tree plantation area was reduced to 16 ha, and dominated by *E. angustifolia*. Hence, even at the higher discount rate afforestation on marginal croplands over 7 years would remain a financially preferable option for farmer.

Tree production on marginal croplands would likely be attractive to farmer even without tCO<sub>2</sub> payments due to relatively high returns from other products (i.e. fuelwood, fruit, leaves as fodder). *E. angustifolia* would be the most attractive tree species at tCO<sub>2</sub> price level of up to 20 USD, whereas *U. pumila* would be the least attractive under all tCO<sub>2</sub> price levels. At 20 USD tCO<sub>2</sub><sup>-1</sup> *P. euphratica* would occupy the largest area on marginal lands due to its greater woody biomass production and thus C sequestration, which consequently would reduce the preference for *E. angustifolia*. For instance, at 120 USD tCO<sub>2</sub><sup>-1</sup> the model showed that *P. euphratica* would be planted on 22 ha by the hardly risk-averse farmer and on 21 ha by extremely risk-averse farmer, whereas the area planted with *E. angustifolia* would be 0.1 and 1.2 ha for the respective risk-averse farmer. Increases in tree plantation area would occur



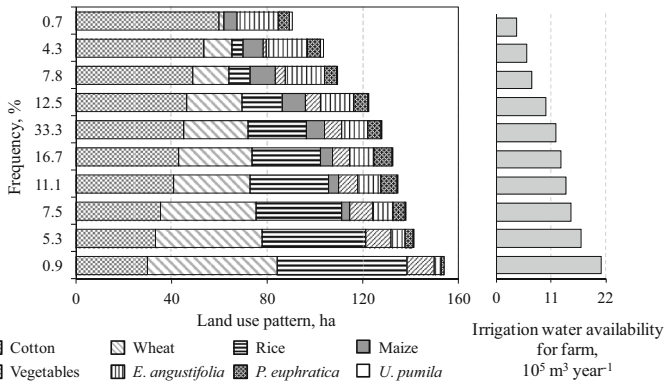
**Fig. 5** Tradeoffs between ecosystem services of CO<sub>2</sub> sequestration and biological nitrogen fixation (N<sub>2</sub>-fixation) in extremely risk-averse farm under scenario of afforestation with different prices of tCO<sub>2</sub>

at the expense of maize cultivation, which would nearly cease at tCO<sub>2</sub> payments above 70 USD.

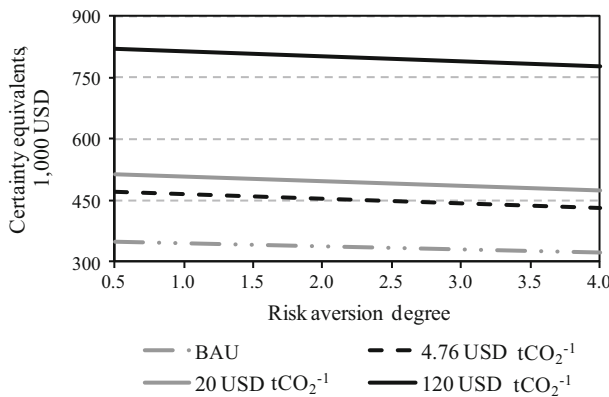
Increased tCO<sub>2</sub> payments would not only lead to the expansion of tree plantations on marginal croplands, but also to enhanced CO<sub>2</sub> sequestration and changes in the provision of other ES (i.e. replenishment of ecosystem N stocks by *E. angustifolia*). Based on N<sub>2</sub>-fixation rates of *E. angustifolia* the amount of N generated through afforestation (without the tCO<sub>2</sub> payment incentive) would reach 20.4 t over 7 years (Fig. 5), with a value of 5,669 USD that would have been required for an equivalent amount of ammonium nitrate to maintain tree plantations on marginal lands. Increasing tCO<sub>2</sub> payments would likely lead to a reduction in the N contribution because the area planted with *E. angustifolia* would be reduced in favour of non-N<sub>2</sub>-fixing *P. euphratica*, which sequesters more C. For instance, at 4.76 and 120 USD tCO<sub>2</sub><sup>-1</sup> the cumulative amounts of soil nitrogen would reach 19.1 and 2.1 t, respectively, with expected monetary values of 5,291 and 572 USD respectively over the 7-year period. This would lead to trade-offs in supply of ES because, even though *P. euphratica* is able to partially satisfy its N needs through uptake of fertilizers leached into the groundwater from neighbouring crop production, the N<sub>2</sub>-fixation capability of *E. angustifolia* was an important factor for the N self-sufficiency of the afforestation system (Khamzina et al. 2009).

### 3.3 Uncertainty of Irrigation Water Supply

In irrigated agricultural settings increased irrigation use efficiency at the farm level following the introduction of tree plantations could mitigate income risks stemming from reductions in irrigation water supplies. Figure 6 presents land-use pattern of the extremely risk-averse farmer based on a tCO<sub>2</sub> price level of 4.76 USD under various levels of irrigation water availability at the farm level. In the below average irrigation water availability scenario (i.e. below 12,000 m<sup>3</sup> ha<sup>-1</sup> year<sup>-1</sup>) trees are preferable over crops on marginal lands, in contrast to adequate water supply scenarios. Recurrent droughts, expressed in the model with a simulated water availability minimum of 4,000 m<sup>3</sup> ha<sup>-1</sup> year<sup>-1</sup> at a frequency of occurrence of about 1 %, would likely enhance the attractiveness of afforestation on all marginal croplands for the extremely risk-averse farmer at 4.76 USD tCO<sub>2</sub><sup>-1</sup>. In this case the species land use pattern would include *E. angustifolia* on 17.1 ha, *P. euphratica* on 4.7 ha, and *U. pumila* on 1.2 ha. Most farmland would be cultivated with cotton in order to fulfil the state quantity-based production target. Due to lower cotton yields under the water



**Fig. 6** Frequency of land use pattern under different levels of irrigation water availability for extremely risk-averse farmer under scenario of afforestation with tCO<sub>2</sub> price of 4.76 USD

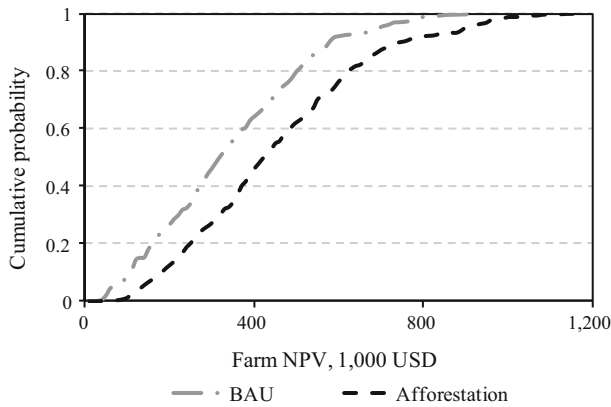


**Fig. 7** Farm certainty equivalents over 7 years at different risk aversion levels under scenarios of business-as-usual (BAU) and afforestation with different prices of tCO<sub>2</sub>

scarcity scenario the cotton production target of 120 t would require enlarging the cotton cultivation area. In the ample irrigation water scenario (i.e. 21,000m<sup>3</sup> ha<sup>-1</sup> year<sup>-1</sup> with a 1% frequency of occurrence), afforestation would be justifiable on around 4.5 ha of marginal lands, mostly with *E. angustifolia*. In this extreme scenario, rice, wheat, and vegetables would occupy the largest areas, thus reducing the area of maize cultivation and the likelihood of afforestation.

### 3.4 Farm Income

The estimated profits of the risk-averse farmer (i.e. CE values) differed between the BAU and afforestation scenarios. CE values decreased as risk aversion level increased (Fig. 7). The lower values implied that more risk-averse farmer would select land uses that avoid losses. In the BAU scenario the NPV of the hardly risk-averse farmer would be around 350,000 USD over the 7-year period, whereas the extremely risk-averse farmer would have an NPV of 325,000 USD. The afforestation scenario with a tCO<sub>2</sub> price of 4.76 USD would yield higher incomes of about 470,000 and 435,000 USD for the hardly and extremely risk-averse



**Fig. 8** Cumulative distribution of the net present value (NPV) over 7 years of extremely risk-averse farmer under scenarios of business-as-usual (BAU) and afforestation with  $t\text{CO}_2$  price of 4.76 USD

farmer respectively. These greater CE values for the afforestation scenario were a result of increased profits from both forestry on marginal lands and increased cultivation of high NPV rice and vegetables on productive lands. At 120 USD  $t\text{CO}_2^{-1}$  the resulting total farm NPV almost doubled compared to the current  $t\text{CO}_2$  value (i.e. 4.76 USD  $t\text{CO}_2^{-1}$  per temporary Certified Emission Reduction). In such a scenario most of the farm profits would be derived from the unrealistically high  $t\text{CO}_2$  payments.

Uncertainty of land-use returns would lead to considerable variation of farm income (Fig. 8). For example, the extremely risk-averse farmer engaged in BAU practices on marginal lands would have NPVs ranging from 15,000 to 930,000 USD over the 7-year period. The lowest NPV would be caused by reductions in crop yields and prices, and irrigation water availability. In contrast, the afforestation scenario exhibited higher NPVs ranging between 80,000 and 1,170,000 USD for the extremely risk-averse farmer. Under this scenario, in the case of the highest NPV level (i.e. 1,170,000 USD) income would be primarily derived from crop cultivation. Tree product yields and prices were independent from crop yields and prices, therefore increase in tree product yields and prices would lead to higher NPVs as well.

## 4 Discussion

### 4.1 Value of Ecosystem Services

The value of ES provided from afforestation is not fully understood as the valuation approaches used might not capture the full range of ES or the necessary values that would incentivize the adoption of such environmentally sustainable land use (Mendelsohn and Olmstead 2009; Bateman et al. 2011). Even the market value of the most tradable ES, C stocks, is not fully determined and ranges from 0.65 to 50 USD  $t\text{CO}_2^{-1}$  (Peters-Stanley et al. 2012). For example, Chakraborty (2010) found that existing market  $t\text{CO}_2$  payments for forestry were sufficient to motivate afforestation, whereas Tal and Gordon (2010) found that increases in  $t\text{CO}_2$  payments were required to incentivise afforestation. In our study we considered afforestation in irrigated agricultural settings under revenue uncertainty on a per hectare scale and found that the current payment level (4.76 USD  $t\text{CO}_2^{-1}$ ) in the compliance market (i.e. via CDM) may need to be increased by 115 times (i.e. up to 540 USD  $t\text{CO}_2^{-1}$ ) to motivate farmer towards afforestation on marginal croplands. Sequestered carbon units are unlikely to

sell at such high payment levels. However, the analysis at the field level (i.e. stochastic dominance) lacks discriminatory power with respect to farm production, whereas the land-use decisions of farmer are made in consideration of the entire farming system context. [Castro et al. \(2013\)](#) found that ES payments derived by accounting for the entire farm were almost half of the values based on the opportunity cost of land uses. This is likely due to capturing the farm production constraints and effects of land-use diversification in order to hedge income risks of land uses ([Baumgärtner and Quaas 2010](#); [Knoke et al. 2011](#)). Our analysis at the whole farm level also provided a broader overview of the valuation of tCO<sub>2</sub> sequestered in woody biomass, while considering various correlated uncertainties that affect farm activities. The expected utility model results at the entire farm scale suggested that tCO<sub>2</sub> payments would not be necessary to incentivise afforestation. Such payments are useful, however, for enhancing the appeal of afforestation in areas where it is not currently practiced ([Kallis et al. 2013](#)). Consideration of the long-term economic and environmental impacts of afforestation may reveal greater benefits due to enhanced production, land rehabilitation and gradual C sequestration if forestry activity continued beyond the 7-year period contemplated in our study.

At the same time, high value payments to enhance a particular ES may result in negative effects on the provision of other ES. For example, [Goldstein et al. \(2012\)](#) found that land-use decisions intended to enhance C storage in Hawaii had water quality trade-offs and that land uses intended to improve the integrity of the ecosystem had financial trade-offs. A key principle of ES management is that they are interdependent and can be thought of as different components of a greater bundle of ES ([Raudsepp-Hearne et al. 2010](#)). In our study increased tCO<sub>2</sub> values resulted in a trade-off between C sequestration, a climate change mitigation ES, and N<sub>2</sub>-fixation, a supporting ES that improves soil fertility ([Jiao et al. 2012](#); [Ninan and Inoue 2013](#)). As the tCO<sub>2</sub> value increases, the attractiveness of tree species with a higher C sequestration potential would be preferred over N<sub>2</sub>-fixing species. The production of maize—which is the primary livestock feed in the region—would likewise be reduced. ES trade-offs may occur when interactions among ES are neglected ([Ricketts et al. 2004](#)), when information on their function is incomplete ([Smith et al. 2012](#)), or when they have no markets and/or established monetary values ([Rodríguez et al. 2006](#)). Given the interrelationships between C sequestration, which has an established market value, and N<sub>2</sub>-fixation, which does not have explicit monetary value, evaluation of the impacts of afforestation on poor agricultural soils requires consideration of both ES in order to develop efficient land-use policies. Overall, understanding of the social and ecological drivers and feedbacks are needed for developing appropriate policies and land-use practices in multiple ES situations, and hence their trade-offs and synergies, ([Raudsepp-Hearne et al. 2010](#)), and on investments in ecological restoration and sustainable land-use practices ([de Groot et al. 2010](#); [Villamor et al. 2014](#)).

#### 4.2 Risk Managing Instrument

Irrigated agricultural production in drylands can be subject to various uncertainties ([Anderson and Dillon 1992](#)). In contrast to the deterministic model results, incorporating uncertainty into our analyses showed that land uses that generate high returns, but that also exhibit high variability may be less attractive than lower return alternatives that are more stable. These uncertainties affect rural livelihoods and their interactions (i.e. covariate risks), further exacerbating those effects. According to [Berg and Kramer \(2008\)](#) and [Hardaker et al. \(2004\)](#), risk management instruments that can be implemented by farmers include on-farm (i.e. diversification, holding reserves) and market-based (i.e. insurance, risk transfer via contracting)



options. Many of these instruments are difficult to implement in a developing country context because of transitional/unstable policies, weak institutions, poorly defined property rights, undeveloped markets, and a lack of relevant knowledge among farmers (Anderson 2003; Velandia et al. 2009). One suitable risk management strategy is combining multiple land uses that have little or no correlation in terms of revenue fluctuation, such as trees and annual crops (Knocke et al. 2009). Babu and Rajasekaran (1991) in the case of India found that the introduction of tree plantations into irrigated agricultural systems can reduce the negative impacts of revenue risks associated with crop cultivation. Mills and Hoover (1982) argued that the USA farmers who invested in forestry initiatives benefited from the diversification because there was little correlation between forestry and other land uses. Baumgärtner and Quaas (2010) found that with increasing risk levels farmers would be more likely to diversify land uses and thus enhance the provision of ES. The concurrent consideration of a diversity of farming activities is important for evaluating the sustainability of land-use practices (Knocke et al. 2011). By capturing the variability of crop and tree product prices and yields, as well as irrigation water availability at the farm level, our study constitutes one of the first steps in addressing various correlated uncertainties when evaluating land uses in irrigated drylands. The farm model (expected utility) results showed that establishing tree plantations on marginal croplands could represent an effective strategy for managing risks associated with reduced availability of irrigation water and low crop prices and/or yields. For instance, during drought years tree plantations would likely occupy a larger area of farm relative to other crops, exceeded only by cotton. Although state procurement prices for cotton and wheat reduce farmer's exposure to price variability of these crops, such policies lead to little or no financial returns from marginal lands, making forestry a more attractive land-use option there.

Despite the potential for afforestation of marginal croplands as a risk management option, this land use still entails investment risks for farmer. In the context of transitional economy countries like Uzbekistan farmer's decisions regarding investments in long-term land uses are constrained by frequent changes in agricultural (e.g. farmland consolidation and restructuring) and state procurement policies (Lerman 2008). In addition, there is uncertainty in terms of the profitability of afforestation initiatives due to pest or disease outbreaks, fire, losses from illicit wood or tree product harvest, as well as fluctuating ES payment levels that may result in trade-offs with respect to their provision or economic performance and decreased interest among both farmers and buyers (Chee 2004; Metzger et al. 2006; Bateman et al. 2011).

#### 4.3 Rural Incomes

Policies addressing the land management options for improving ES must seek mechanisms for incentivising land users through improving their livelihoods. There is no consensus, however, on the outcome of such activities. Some studies have found that the implementation of forestry ES projects/policies may incur high costs or have negative impacts on livelihoods, whereas others have found improved welfare and environmental conditions. For example, Dhakal et al. (2012) found that forest policies can have negative repercussions on household income and employment, and widen inequality within Nepalese communities. Glomsrød et al. (2011) predicted that the implementation of CDM forestry efforts in Tanzania would benefit the wealthiest members of society and thus be ineffective for poverty reduction and generating income in rural areas. To the contrary, Gong et al. (2010) and Zhang et al. (2006) reported that reforestation efforts on 4,000 ha of degraded lands as part of a watershed management project in the Pearl River Basin of China contributed to farm incomes, with 75 % of the derived

financial benefits stemming from employment, 15 % from fuelwood harvest, and 10 % from C credits. Nijnik et al. (2012) showed that large-scale multipurpose tree plantations established on marginal croplands in Ukraine can contribute to climate change mitigation, soil erosion prevention, and income generation.

Likewise, afforestation on marginal croplands in the study area that we examined would generate greater farm profits relative to the cultivation of conventional crops. Compliance with only the state's quantity-based cotton production target rather than both the quantity and area-based targets would allow greater flexibility of farmer's land-use decision making and, in turn, improve agricultural diversification and producer incomes. In addition, the lower irrigation water requirements of tree plantations relative to crops would allow farmers to direct water that would otherwise have been used on marginal lands to be supplied to crop production on more productive lands, and as a result enhance grain and vegetable production, which can improve food consumption and livelihoods.

## 5 Conclusions

The provision of both ES and income from afforestation on degraded croplands under conditions of revenue uncertainty could be enhanced by properly valuing the ES provided by afforestation. We found that the application of different methods at different scales may reveal contrasting outcomes. According to the results of the field-level analysis (SSD approach) substantial additional financial support (e.g. through greater tCO<sub>2</sub> payments) could be necessary to incentivise afforestation on marginal croplands under conditions of revenue uncertainty. In contrast, the farm-scale analysis (expected utility approach), which captured crop production risks and the effects of land-use diversification, revealed that afforestation was likely to be an attractive land-use option even in absence of a financial incentive. Our results indicate that high tCO<sub>2</sub> payments could lead to trade-offs in the provision of other ES and thus reduce the ecological benefits of afforestation. Payments for ES should be defined at levels that support a balanced provision of multiple ES, such as C sequestration and N<sub>2</sub>-fixation. Adjusting the cotton procurement policy to a quantity-based production target only might be an effective strategy for stimulating afforestation initiatives on marginal croplands. In addition, such a modification of the cotton procurement policy would allow farmers to diversify their livelihood activities and hence mitigate risks to their income. The risks considered in this study, however, only affect farm revenue and do not influence probability distribution of revenue in other periods, thus inclusion of the variability of input costs and risk dynamics over time may change the model outcomes. These would require consideration of the different afforestation management practices that can be captured by the option pricing models.

**Acknowledgments** We appreciate the support of the Robert Bosch Foundation for enabling this study within the framework of the German-Uzbek Agroforestry project. The support of the ZEF/UNESCO program in the Khorezm Region of Uzbekistan is gratefully acknowledged. We also thank the International Postgraduate Studies in Water Technologies (IPSWaT), and the Dr. Herman Eiselen Doctoral Program of the Foundation fiat panis for the financial support during the doctoral studies of the first author.

## Appendix 1

See Table 1.

**Table 1** Coefficients of variation of crop yields and prices, irrigation water availability, and tree product prices

Parameters	Coefficient of variation
<i>Crop yields (tha<sup>-1</sup>)</i>	
Cotton	0.16
Wheat	0.15
Rice	0.22
Maize	0.16
Vegetables	0.11
<i>Crop prices (USD t<sup>-1</sup>)</i>	
Wheat	0.57
Rice	0.40
Maize	0.40
Vegetables	0.20
<i>Irrigation water availability (m<sup>3</sup> ha<sup>-1</sup>)</i>	
Irrigation water availability (m <sup>3</sup> ha <sup>-1</sup> )	0.25
<i>Tree product prices (USD t<sup>-1</sup>)</i>	
Fuelwood of <i>E. angustifolia</i>	0.11
Fuelwood of <i>P. euphratica</i>	0.10
Fuelwood of <i>U. pumila</i>	0.12
Leaves of <i>E. angustifolia</i>	0.10
Leaves of <i>P. euphratica</i>	0.13
Leaves of <i>U. pumila</i>	0.12
Fruits ( <i>E. angustifolia</i> )	0.08

Source: Adapted from MAWR (2010), Statistical Committee of Khorezm (2010), and own observations  
Coefficients of variation of crop yields and prices, and irrigation water availability are for the period 2001–2009. Coefficients of variation of tree product prices are for 1 year based upon weekly observations between June 2010 and March 2011. The price of cotton is state determined, thus its price variability was not considered. Variability in the price of the state purchased wheat was not considered

## Appendix 2

See Tables 2 and 3.

**Table 2** Correlation matrix of crop yields and prices, and irrigation water availability between year 2001 and 2009

	Yield					Prices				
	Cotton	Wheat	Rice	Maize	Vegetables	Wheat	Rice	Maize	Vegetables	Irrigation supply
<i>Yield</i>										
Cotton	1.00									
Wheat	0.59	1.00								
Rice	-0.02	0.45	1.00							
Maize	0.70	0.84	0.53	1.00						
Vegetables	0.17	0.64	0.61	0.53	1.00					

**Table 2** continued

	Yield					Prices				
	Cotton	Wheat	Rice	Maize	Vegetables	Wheat	Rice	Maize	Vegetables	Irrigation supply
<i>Prices</i>										
Wheat	0.35	0.70	0.02	0.48	0.66	1.00				
Rice	0.07	0.54	-0.03	0.19	0.67	0.02	1.00			
Maize	0.64	0.86	0.25	0.72	0.67	0.48	0.19	1.00		
Vegetables	-0.18	-0.58	-0.60	-0.69	-0.12	0.66	0.67	0.67	1.00	
Irrigation supply	0.03	0.14	0.74	0.42	0.03	-0.49	-0.58	-0.19	-0.67	1.00

*Source:* Adapted from MAWR (2010), Statistical Committee of Khorezm (2010), and own observations. Correlation of crop yields and prices, and irrigation water availability are for the period 2001–2009. The price of cotton is set by the state, thus its price correlation was not considered. Variability in the price of the state purchased wheat was not considered

**Table 3** Correlation matrix of tree product yields and services over 7 years since afforestation

	Wood	Leaves	Fruits	N <sub>2</sub> -fixation
<i>E. angustifolia</i>				
Wood	1.00			
Leaves	0.65	1.00		
Fruits	0.50	0.53	1.00	
N <sub>2</sub> -fixation	0.52	0.79	-0.04	1.00
<i>P. euphratica</i>				
Wood	1.00		n.a.	n.a.
Leaves	0.93	1.00	n.a.	n.a.
<i>U. pumila</i>				
Wood	1.00		n.a.	n.a.
Leaves	0.83	1.00	n.a.	n.a.

N<sub>2</sub>-fixation is the biological nitrogen fixation  
n.a. not applicable

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