Agroforest Syst (2023) 97:319–334
https://doi.org/10.1007/s10457-021-00617-7

Agro-economy of tree wind break systems in Kyrgyzstan, Central Asia

Niels Thevs · Kumar Aliev

Received: 23 April 2020 / Accepted: 25 March 2021 / Published online: 7 May 2021

Abstract Tree wind break systems are found in many parts of the world. In particular in windy and arid regions they help to increase crop yields and reduce crop water consumption. Due to these reasons, tree wind breaks have a long tradition in Central Asia and were strongly propagated there during Soviet Union times. After the Soviet Union had disintegrated and the countries in Central Asia had become independent, energy supplies from Russia ceased and fuel wood became the primary energy source for large parts of the population, in particular rural population. Consequently, most of those tree wind breaks were cut down for fuel wood during the 1990s. Now, governments wish to restore these systems, but many farmers are skeptical about the economic returns from investment in tree wind breaks. Against this background, this study calculated revenues, costs, and profits for tree wind break systems of poplars combined with wheat, barley, corn, alfalfa, cotton, and rice in Kyrgyzstan, based on interviews and field observations. Tree wind breaks with more than one row of trees (multiple row type) did not result in financial gains for most crop tree wind break systems compared to open field conditions, while single tree wind breaks were cost-neutral or resulted in small economic gains, also under different discount rates and revenues attained from crops and trees. Among the different grid sizes, the 200 m × 200 m grid attained the highest financial surplus compared with open field conditions and other grid sizes. Thereby, effectively it is recommended to establish tree wind breaks along existing field borders or irrigation ditches while keeping an average distance between tree lines of 200 m, in order not to impede farm operations.

Keywords Agroforestry · Shelterbelt · Poplar · Irrigated agriculture · Net present value · Household interviews

Introduction

Tree wind break systems have been applied globally in agriculture since long time and constitute a wide spread agroforestry system, e.g. in the USA (Brandle et al. 2004; National Agroforestry Center 2020), Canada (Ontario Federation of Agriculture 2020), Europe (e.g. Germany (Kayser 2020) and Ukraine (EURAF 2020)), Central Asia (Missall et al. 2015; Thevs et al. 2019 and literature cited there), China (e.g. Zheng et al. 2016), Australia (Cleugh et al. 2002), Africa (e.g. Lamers et al. 1994), and Argentina (Peri

N. Thevs (✉) · K. Aliev
World Agroforestry, Central Asia Office, Toktogul Street 141, 720001 Bishkek, Kyrgyzstan
e-mail: N.Thevs@cgiar.org; niels.thevs@giz.de

N. Thevs
Gesellschaft für Internationale Zusammenarbeit (GIZ), Friedrich-Ebert-Allee 32+36, 53113 Bonn, Germany

and Bloomberg 2002). Tree wind breaks reduce wind speed resulting in lowered crop water consumption inside tree wind break systems (Alemu 2016), which are the two major biophysical effects of these systems.

Tree rows along field borders and irrigation ditches have a long tradition in Central Asia. Traditionally, those trees, mainly poplars, were planted with the intention to harvest timber, mainly for house construction. Unintentionally, those trees thus served as wind breaks as well. In Soviet Union times, tree wind break systems were largely promoted, also across Central Asia (e.g. Albenskii et al. 1972; Vasilyev 1980; Stepanov 1987; Schroeder and Kort 1989). From 1918 till 1948, the area covered by tree wind break belts increased from 130,000 ha to one million ha across Soviet Union (Kalashnikov 1969), which increased further to 2 million ha by 1967 (Danilov 1971). During Soviet Union times, tree wind breaks were planted as belts of trees rather than single tree lines (Albenskii et al. 1972; Vasilyev 1980; Stepanov 1987).

Globally, increased crop yields were reported for a wide range of tree wind break systems, whereby winter wheat, barley, rye, millet, alfalfa and hay (mixed grasses and legumes) appear to be highly responsive to protection, while spring wheat, oats and corn respond to a lesser degree. Generally, percentage yield increases due to tree wind breaks have been higher in semiarid and arid regions or in drier years compared to humid regions or moister years (Kort 1988). In particular for Central Asia, a large volume of research reported increased crop yields in tree wind break systems compared to open field conditions: Susa (1959) measured wheat yields and potato yields to be increased by 20–30% and 37% compared to open field conditions, respectively, in a tree wind break system in the Kazakh steppe. Cereal yields increased by 41% to 115% after tree wind breaks had been planted, corresponding to initial yields of 1.3 and 1.5 t/ha, which rose to 2.8 and 2.1 t/ha, respectively (Tribunskaya 1974). In Northwestern Kazakhstan, on a Kastanozem site rye and summer wheat yields rose from 0.7 t/ha to 1 t/ha and 0.5 t/ha to 0.9 t/ha, respectively, under impact of snow trap by tree wind breaks (Vorobiev and Anuchin 1985). Investigations around the city of Rostov revealed yield increases of winter and summer wheat by 22–78% by tree wind breaks (Kalashnikov 1969). In the Chuy Valley, wheat yields grew by 28% after tree wind breaks had been planted (Bulychev and Onishenko 1979).

After the Soviet Union had disintegrated and Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan gained independency, energy supply from Russia dropped sharply so that people had to shift to fuelwood as primary energy source. Trees in villages, towns, from the agricultural landscape, and forests were cut at large scale. Consequently, the countries lost most of their tree wind breaks during the early 1990s (UNECE 2019).

Today, most of the countries in Central Asia wish to restore such tree wind break systems (Republic of Tajikistan 2014; UNDP 2015a, b; SAEPF 2017; State Committee of Turkmenistan for Environmental Protection and Land Resources 2018), in order to regain the positive effects of those tree wind breaks on yields, microclimate, and water resources, but also to provide domestic wood resources to address the countries' wood demand. In an arid region, like Central Asia, where most of the agriculture depends on irrigation, reducing water consumption in agriculture through tree wind breaks is an important benefit (Thevs et al. 2019). Still, many farmers are reluctant to engage in tree wind break planting, because they are concerned that tree wind breaks will not be beneficial for farm income, as trees consume space that reduces the crop area and shade crops (Ruppert et al. 2020). Other farmers plant trees as tree rows along field borders, where trees pose the smallest impact on farm operations, in order to harvest timber in the future (authors' observation). Poplar based agroforestry systems in India were found economically more viable than corresponding crop rotations outside of agroforestry systems (Jain and Singh 2000; Dwivedi et al. 2007). There, additional income from poplars in agroforestry was stated as the main motivation to engage in agroforestry (Dwivedi et al. 2007). The Australian Windbreak Program found that tree wind breaks are either cost-neutral or lead to small financial gains (Cleugh et al. 2002).

Against the background of those contradicting findings from the literature and field observations, this study aims at comparing the economic performance of major crops in tree wind break systems versus under open field conditions. This study was carried out in Kyrgyzstan, as this country has the longest history of shifting its agriculture from a planned economy to a market economy so that undistorted market prices for crops, harvested trees, and related inputs could be revealed. Kyrgyzstan distributed cropland to households during the 1990s, whereas Uzbekistan and Turkmenistan execute state control over major crops (cotton, wheat) until today, which may result in distorted prices and costs (Wandel et al. 2011).

Study regions

This study focused on the villages between Kyzyl Ai and Chek in Bazarkorgon County (Jalalabad Region) in the Ferghana Valley as well as on the villages Temen Suu and Murake in Moskva County in Chuy Region (Fig. 1). Both study regions were chosen to represent irrigated agriculture, as country-wide most of the cropland was irrigated—939,100 ha out of a total crop land area of 1,363,800 ha as of 2017 (FAOSTAT 2020). The major crops grown in Kyzyl Ai and Chek are cotton, corn, and rice, thus reflecting major crops grown in the Ferghana Valley in Kyrgyzstan and in neighboring Uzbekistan. In Moskva County, the major crops are wheat, corn, barley, potato, and alfalfa, which represents most of Chuy Region.

The climate is continental with a rainy season in spring in both study regions. Though, Ferghana Valley is warmer than Moskva County and its rainy season is less pronounced. In both study regions, soils receive water from snow melt and rain fall in winter and spring. But, from late spring through summer crops need to be irrigated, with furrow irrigation being the main irrigation type.

Methods

In order to compare the economic performance of those major crops under open field conditions versus crops within tree wind break systems, the following two sets of calculations were done: First, revenues and costs attributed to each crop were calculated on an annual basis, discounted, and summed up over the time from tree planting till harvest to obtain the NPV for open field conditions after the formula below (Tomás et al. 2018). Secondly, tree growth and the resulting impact of that tree wind break on adjacent crops were modelled on an annual basis from tree planting until harvest. The revenues and costs attached to the investigated crops were calculated annually, too, whereby the modelled effects of the tree wind breaks were included, which will be explained below. These annual revenues and costs were discounted as well and summed up as NPV. The NPV from the trees was calculated by the annual costs attributed to the trees and the revenue at harvest, both discounted, too. Finally, that NPV from the trees and the accumulated NPV of the given crops under impact of tree wind breaks yielded the NPV of the given crop-tree wind break system (Tomás et al. 2018). In both sets of calculations, transport costs were excluded, in order to avoid biases due to different distances from markets.

Fig. 1 Map of Kyrgyzstan with the two study regions Bazarkorgon and Temen Suu/Murake

$$NPV = \sum_{t=0}^{n} \frac{(R_t - C_t)}{(1+i)^t}$$

NPV is the discounted net present value; n is the length of the rotation period from tree planting till harvest in years; t refers to a given year within the rotation period; R_t and C_t are the revenue and costs in year t; i is the discount rate. Calculations were done with discount rates of 12% and 17.5%, as the former was the lower boundary of the interest rate on agricultural loans by Ayil Bank, which has the highest penetration in rural areas of the country, while the latter was the average real interest rate from 1996 to 2017 after World Bank (2019).

Yields, revenues, and costs attributed to crops were revealed through structured household interviews in 2017. Revenues and costs attributed to trees were collected through semi-structured interviews on local wood markets in Osh, Jalalabad, and Bishkek in 2017 and 2018. All revenues, costs, and profits were recorded and calculated in Kyrgyz Som (KGS) as of 2017, which converted as 1 USD into 68.87 KGS averaged over 2017. The data on tree growth were taken from an unpublished data set of DBH (diameter at breast height) and tree height of about 1000 trees from tree wind breaks across Kyrgyzstan. Tree ages were assessed from a subset of about 200 trees through tree cores. This dataset allowed to calculate the average tree height by age and average age of diameter classes.

Revenues were the harvested crops as well as the harvested trees. Costs attributed to crops were variable costs, which included costs for soil preparation, seeds, fertilizer, plant protection, harvest, and associated costs to rent machines. As most of the farmers did not own machinery nor extra buildings for farming, fixed assets were not calculated. As none of the interview respondents mentioned costs for land (rent or taxes), such costs were not included as well. Labor was partly paid and partly unpaid family labor, but all labor was treated as paid, with KGS 750 per day, to reveal comparable results. Only water fees were included as fixed costs, because that fee had to be paid according to land size regardless of ongoing land use. Alfalfa, as a perennial crop, was assumed to be harvested in the year of seeding and during the four following years, as stated by interview respondents. Therefore, the variable costs in the four years after planting were reduced to costs for harvest, as this was the only remaining farm operation. Finally, costs attributed to tree wind breaks were costs for planting material, labor costs for planting and tree maintenance during the first and second year, and costs for tree felling for harvest.

To compare the open field conditions with tree wind break systems, hypothetical square shaped tree wind break systems were used with plot sizes of 50 m × 50 m, 100 m × 100 m, 200 m × 200 m, 400 m × 400 m, 500 m × 500 m, 750 m × 750 m, and 1000 m × 1000 m. Remnants of such nearly square shaped tree wind break arrangements with field sizes ranging from 200 m × 200 m to 500 m × 500 m still can be seen in places in Chuy Region, e.g. Karasay Batyr and Kemin (Thevs et al. 2019 and Fig. 2). Furthermore, it was assumed that the tree wind breaks surrounded the crops on all four sides. Single tree row wind breaks were calculated for the two study areas, while multiple row wind breaks only were calculated for Chuy Region, because this type of tree wind breaks was only found there, but not in the Ferghana Valley (Thevs et al. 2019).

The following assumptions were made to model the impact of tree wind breaks on crops: Tree wind breaks consume space and shade crops. Therefore, a zone with cero crop yield, which width was derived from field observations, was inserted along the tree wind breaks and crop areas as well as the harvested amount of the crops were reduced accordingly. Costs for crop cultivation were not changed to follow a conservative approach, as e.g. costs for machine rent or labor are not expected to be reduced, when the crop area shrinks by 2 or 3 m (Table 1). Wang et al. (2016) found negative impact of tree wind breaks on the first three rows of cotton next to tree wind breaks, which corresponded to an impact until 1.80 m from the tree wind break. This was confirmed by field observations during the data collection.

In most settings, tree wind breaks increase crop yields (Kort 1988). Still, in this study for each crop-tree wind break combination, calculations were done without and with crop yield increase to deliver conservative as well as optimistic NPVs. In the former, no changes in crop yield were assumed. In the latter, yield change was modelled with a function developed after Alemu (2016) and increasing tree heights from planting towards harvest time.

Yields, revenues, and costs attributed to crops and trees were kept constant for all calculations, as no solid trend across a wider range of crops and trees was

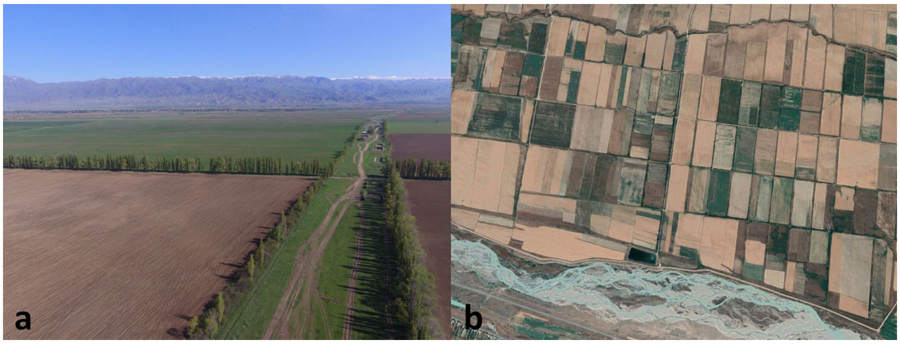

Fig. 2 Tree wind breaks in Chui Valley. **a** poplar tree wind break, Kemin, Chuy Region (photo: N. Thevs), **b** tree wind break structure, Karasay Batyr, Chui Valley

Table 1 Zone from crop field lost due to tree wind break with different tree ages

Tree age	Width single row tree wind break (m)	Width multi row tree wind break (m)
< 2	1	7.5
3	2	8.5
4–10	3	9.5
> 11	5	11.5

The widths listed here refer to one field, i.e. half of the total width occupied and impacted by a tree wind break

visible from the literature. Still, the calculations explained above were repeated with different crop and tree revenues as input for a selection of tree wind break systems as a sensitivity analysis, In order to illustrate possible effects of changes of crop and tree revenues on the NPVs of the different crops and tree wind break systems.

Results

The household interviews revealed that field sizes were generally smaller in Bazarkorgon than in Chuy Region (Table 2). The revenue per hectare was highest for rice and cotton (170,129 KGS/ha and 107,789 KGS/ha, respectively), both grown in Bazarkorgon, in the Ferghana Valley. The second highest revenues were attained by corn grown in Bazarkorgon with 66,717 KGS/ha and in the Chuy Valley with 69,750 KGS/ha (Table 3). Only those revenues of rice and cotton translated into high profits; and accordingly rice yielded the highest profit of all crops—66,360 KGS/ha—followed by cotton with 35,047 KGS/ha. In contrast to its fairly high revenue, the profit of corn grown in Bazarkorgon was negative (− 903 KGS/ha) and the lowest of all crops, as costs exceeded the revenue. In Chuy Region, costs attributed to corn did not exceed revenue, and there corn yielded the highest profit (21,440 KGS/ha), followed by wheat and barley (Table 3). Farmers did not report specific crop rotations, but rather followed expected market prices or family driven demands.

Most farmers rented machines for farm operations, whereby this rent included the labor of the machine driver and fuel. These machine costs were also applied for the few farmers, who used their own machines, as a correct depreciation calculation was not possible with the given data. In Chuy Region, such machine services were more wide-spread and cheaper than in Bazarkorgon, and in general, the share of manual labor was higher in Bazarkorgon compared to Chuy Region. Also, field sizes in Bazarkorgon were smaller than in Chuy Region (Table 2), which made manual farm operations more feasible than in on the larger field sizes in Chuy Region. This was confounded, as in Bazarkorgon it was mainly the farmers with field sizes below average, who relied on manual labor.

Table 2 Crop areas, yields, and selling prices of the major crops as of 2017 as revealed by the farm interviews

Crop	Crop area (ha)	Crop yield (kg/ha)	Selling price (KGS/kg)	N
Bazarkorgon				
Cotton	0.9 ± 0.4 (0.1–1.4)	2757 ± 732 (1667–4000)	39 ± 2 (35–42)	10
Rice	1.0 ± 1.1 (0.1–4)	4823 ± 1747 (2500–7667)	35 ± 7.6 (20–50)	11
Corn	0.4 ± 0.2 (0.2–1)	5217 ± 2530 (1000–10,000)	13 ± 3.1 (9–19)	11
Chuy region				
Wheat	15.4 ± 23 (0.1–70)	2686 ± 619 (2500–4550)	11 ± 1.4 (10–15)	11
Barley	3.3 ± 3.5 (1–15)	2778 ± 1432 (1500–7833)	9 ± 0.5 (8–10)	16
Corn	1.7 ± 0.6 (1–2)	10,625 ± 3125 (7500–13,750)	6 ± 0 (6–6)	3
Alfalfa	3.7 ± 4.7 (1–15)	4796 ± 2408 (255–10,200)	4.6 ± 0.8 (1.9–6.5)	25

Numbers are given as average ± standard deviation. Minimum and Maximum values are given in brackets

Table 3 Farm level cost, revenue, and profit calculation for the major annual crops investigated (reported in values of 2017)

Crop	Cotton	Rice	Corn in Bazarkorgon	Corn in Chuy Region	Barley	Wheat
Revenue per hectare (KGS/ha)	107,789	170,129	66,717	63,750	25,392	29,550
Costs of seeds pro ha (KGS/ha)	5052	5943	868	2750	5171	3684
cost for fertilizer (KGS/ha)	7218	18,029	7126	5373	619	4000
Costs for pesticides (KGS/ha)	1517	3469	1950	1950	783	783
Direct costs (costs for seeds, fertilizer, pesticides) (KGS/ha)	13,786	27,441	9944	10,073	6573	8467
Machine rent (KGS/ha)	12,537	9658	14,166	15,500	6750	5376
Labor costs per man day (KGS)	750	750	750	750	750	750
Labor costs for whole season from soil preparation to harvest (KGS/ha)	45,404	65,136	42,463	16,112	8451	8610
Contribution margin (KGS/ha)	36,061	67,893	146	22,065	3618	7096
Water fee (KGS/ha)	1014	1533	1048	625	324	281
Profit from production process (crop) (KGS/ha)	35,047	66,360	− 903	21,440	3294	6815

The major difference in the cost structure between Bazarkorgon and Chuy Region was the substantially higher labor costs in Bazarkorgon compared to Chuy Region. This difference was in particular striking for corn, as labor costs for corn in Bazarkorgon summed up to 42,463 KGS/ha, in contrast to only 16,112 KGS/ha in Chuy Region. During the interviews, farmers in Bazarkorgon explained that they were sowing, applying fertilizer and pesticides, and sometimes harvesting manually, as machines were not always available and renting was costly to farmers there. Also, irrigation absorbed a high amount of labor. So, the amount of labor days attributed to corn was much higher in Bazarkorgon compared to Chuy Region. Labor costs of cotton and rice cultivation were high, too, as the former was harvested manually, while other farm operations, except for pesticide application, were done by machines. The latter was harvested by combine-harvesters though, but sowing as well as applying fertilizer and pesticides were done manually. Field sizes of rice and corn fields were smaller than half a hectare, rice field sizes even went down to 15 m × 15 m fields, which also explained the high share of manual labor associated to those two crops.

Costs attributed to alfalfa cultivation were described as follows: The soil was prepared at machine costs of 1400 KGS/ha, including furrows for later irrigation, followed by seeding through a seeding machine at costs of 1100 KGS/ha. Most respondents did not apply any fertilizer, while only a few of them applied manure, and no pesticides were used. Alfalfa was harvested twice a year by mowing machine at costs of 1200 KGS/ha. As alfalfa is a perennial crop, it has been harvested for five years, before another crop followed or alfalfa was planted again.

Tree development and economy of trees

The tree heights and the modelled yield increases are shown in Table 4. The highest crop yield increases were found for the grid size of 100 m × 100 m, which are 10.8% to 13% compared to crops without tree wind breaks. The selling prices of poplar trees varied depending on size, age, and quality, like straightness, number of branches, and being free of fungi infection in the stem wood. Trees traded for timber were classified by wood traders according to their diameter (Table 5). Trees with diameters smaller than 22 cm were only traded in villages among farmers. Despite the demand and high prices for trees with diameters of 35 cm and more, respondents during farm interviews said that most trees from tree wind breaks were harvested at an age of 12 to 15 years. Thereby, younger trees were more likely to be cut, fi there was immediate demand for money or wood.

The average age of both classes 22–27 cm and 27–35 cm was 13 years (Table 5). Still, the average of selling prices for trees of those two classes, 2425 KGS per tree (Table 6), was attributed to 15 year old trees, because farmers and wood traders associated those two classes with a tree age of around 15 years. Trees in Chuy Region had an average age of 16 years across all three classes from 15 to 35 cm diameter. Still, a selling price of 1250 KGS per tree, as for the smallest trading class, was used for further calculations (Table 6), as wood trading and working was less common in Chuy Region compared to the Ferghana Valley. The costs related to trees are given in Table 7. Those costs were the same in both study regions.

The single row tree wind breaks had a tree density of 116 tree per 100 m (Table 6), which was the average across all single row tree wind breaks from which trees had been measured in the two study regions. The minimum and maximum tree density per 100 m were 100 trees and 125 trees, respectively, in that type of tree wind break. The tree density of 200 trees per 100 m and width of the multiple row tree wind break was taken from an example in Karasay Batyr (Fig. 2), a village in the Chuy Valley in Kazakhstan, about 150 km east of Temen Suu and Murake. There, tree wind breaks from Soviet Union times are still fairly well preserved (Fig. 2), which consist of two rows of *Populus alba* with tree spacing of 1 m within rows and 6.5 m distance between rows (Strenge et al. 2018).

NPV of crop-tree wind break systems

At a discount rate of 12%, wheat, barley, and alfalfa, together with single row tree wind breaks in Chuy Region, attain higher NPVs, even without assuming increased crop yields due to impacts of tree wind breaks (Table 8). Those three crop-tree wind break systems showed highest NPVs when tree wind breaks

Table 4 Tree heights and resulting impact on crop yields as modelled after Alemu (2016)

Tree age (years)	Corresponding tree height (m)	Yield increase for the whole field plot surrounded by tree wind breaks (%)						
		Grid size of tree wind breaks (m)						
		50	100	200	400	500	750	1000
4	7.7	12.8	10.8	5.7	2.9	2.4	1.6	1.2
5	9.6	11.1	12.3	6.9	3.6	2.9	2.0	1.5
7	12.5	8.5	13	8.7	4.6	3.7	2.6	1.9
9	14.6	6.7	12.8	10	5.3	4.3	3.1	2.2
11	16.3	5.2	12.4	10.9	5.9	4.8	3.4	2.5
13	17.8	4	11.9	11.5	6.4	5.2	3.7	2.7
15	19	3.2	11.4	12	6.8	5.5	3.9	2.9

The crop yield increases are expressed in percent

Table 5 Trading classes of poplars and selling prices as revealed during interviews with wood traders and farmers

Trade class	Diameter of stem (cm)	Selling price (KGS)	Average age ± standard deviation	
			Bazarkorgon	Chuy Region
1	10–15	500	11 ± 2.1	15.4 ± 3.1
2	15–22	1000–1500	12 ± 2.9	16.1 ± 3
3	22–27	2000	13 ± 3.8	16.5 ± 1.2
4	27–35	2000–3700	13 ± 3.9	16.7 ± 1.8
5	> 35	4000	17 ± 1.7	23 ± 13.4

The average ages and standard deviations per trading class were calculated from the trees measured during 2016 to 2018

Table 6 Characteristics of the different tree wind breaks: tree density, rotation time, selling price per tree

Feature of tree wind break	Ferghana Valley	Chuy Region single row	Chuy Region multirow
Tree density per 100 m tree wind break	116	116	200
Rotation time (years)	15	16	16
Selling price per tree after rotation (KGS)	2425	1250	1250

Table 7 Costs attributed to planting, maintenance, and harvest of tree wind breaks

Cost item	Costs (KGS)
Procurement of saplings (per one sapling)	20
Delivery of saplings for 100 m tree wind break	500
Labor costs for planting and maintenance of tree wind break for 100 m tree wind break	4500
Harvest costs per 100 m tree wind break	2250

were arranged in a 50 m × 50 m grid as single row wind breaks. NPVs of those three crop-tree wind break systems were 62%, 146%, and 41% above the NPVs of wheat, barley, and alfalfa, respectively, without tree wind breaks. The larger the tree wind break grid sizes became, the more the NPVs decreased, but did not fall behind the NPV by crops without tree wind breaks (Table 8). The NPV of corn in Bazarkorgon turned from negative to positive values, after it was combined with tree wind breaks. Only the largest tree wind break grid sizes of 750 m × 750 m and 1000 m × 1000 m resulted in negative NPVs, though still being larger than the NPV of corn without tree wind breaks. Cotton together with single row tree wind breaks attained higher NPVs compared to cotton without tree wind breaks, while the combination of rice with tree wind breaks resulted in lower NPVs than rice alone (Table 8). Under an assumption of increased crop yields, all crops together with single row tree wind breaks attained higher NPV compared to the corresponding crops without tree wind breaks, except for corn in Chuy Region with a 50 m × 50 m tree wind break grid size (Table 9).

When multiple row tree wind breaks were introduced, only barley and alfalfa together with tree wind breaks showed higher NPVs than crops under open field conditions (Table 8). When increased crop yield due to tree wind breaks were assumed, also wheat tree wind break systems showed increased NPVs compared to open field conditions (Table 9).

In most crop-tree wind break combinations, the costs incurred by crop cultivation and tree planting and maintenance did not exceed the revenues from the crop in the year of tree planting. Only, if 50 m × 50 m

Table 8 NPV per ha of major crops and crops with wind breaks after given rotation times at a discount rate of 12%

Tree wind break crop system	Net present value (NPV) of crops and tree wind break crop systems after given tree harvest time (1000 KGS/ha)							
	No tree wind break	Grid size of tree wind breaks [m]						
		50	100	200	400	500	750	1000
Bazarkorgon								
Single row tree wind breaks, tree harvest after 15 years								
Cotton	267	316	289	278	272	271	270	269
Rice	506	*467*	*483*	*493*	*500*	*501*	*503*	*503*
Corn	− 6.9	99	45	19	6	3	− 0.2	− 1.9
Chuy region								
Single row tree wind breaks, tree harvest after 16 years								
Wheat	53	86	69	61	57	56	55	55
Barley	26	64	44	35	30	29	28	28
Corn	167	*150*	*157*	*162*	*165*	*165*	*166*	*166*
Alfalfa	65	110	87	75	70	69	68	67
Multiple row tree wind break, tree harvest after 16 years								
Wheat	53	*63*	51	50	51	51	52	52
Barley	26	55	34	28	27	26	26	26
Corn	167	*21*	*77*	*118*	*142*	*147*	*154*	*157*
Alfalfa	65	113	84	73	68	68	67	66

No yield increase was assumed under impact of wind breaks. NPV is given in 1000 KGS/ha in values of 2017. Cells in italic indicate NPVs of the crop tree wind break systems lower than NPVs of the corresponding crops without tree wind breaks

and 100 m × 100 m tree wind breaks were combined with barley or wheat, the costs incurred by crop cultivation, tree planting, and tree maintenance would exceed the revenue in the year of tree planting. The revenue of crops in the year of tree planting always exceeded costs, when tree wind break grids of 400 m × 400 m and larger were used.

This picture changed with a discount rate of 17.5%. Under the assumption that tree wind breaks do not result in any increase of crop yields, crops without tree wind breaks performed better than all the corresponding crop-tree wind break systems (Table 10). The only exception was corn in Bazarkorgon combined with single row tree wind breaks. In contrast, when crop yield increased due to tree wind breaks were assumed, the single row tree wind break systems with corn in Bazarkorgon and barley as well as alfalfa in Chuy Region attained higher NPVs than the corresponding crops without tree wind breaks. The single row tree wind break systems with cotton and rice in Bazarkorgon as well as wheat in Chuy Region resulted in higher NPVs at grid sizes of 100 m × 100 m and larger. Corn in Chuy Region had to be combined with tree wind breaks of grid sizes of 200 m × 200 m and larger to result in slightly higher NPVs than corn under open field condition. The multi row tree wind break systems yielded lower NPVs than the corresponding crops across all grid sizes (Table 11).

The NPV calculations were repeated for the 200 m × 200 m single row tree wind break systems combined with cotton and wheat, respectively, whereby revenues from crops and trees were altered (Tables 12 and 13). Also, crop yield increase due to the impact of tree wind breaks was assumed here. Overall, the assumed crop revenue changes influenced the resulting NPVs much stronger than changes in revenues from trees. But, the 200 m × 200 m tree wind break system yielded higher NPVs compared to the corresponding crops regardless of discount rate, crop, or tree revenue. Conversely, in the wheat tree wind break system (single row, 200 m × 200 m) under 17.5% discount rate, without yield increase by tree wind breaks, and without any changes in crop revenues, the selling price of a single poplar tree had to

Table 9 NPV per ha of major crops and crops with wind breaks after given rotation times at a discount rate of 12%

Tree wind break crop system	Net present value (NPV) of crops and tree wind break crop systems after given tree harvest time (1000 KGS/ha)							
	No tree wind break	Grid size of tree wind breaks (m)						
		50	100	200	400	500	750	1000
Bazarkorgon								
Single row tree wind breaks, tree harvest after 15 years								
Cotton	267	345	337	315	293	288	282	278
Rice	506	512	559	552	532	527	522	517
Corn	− 6.9	117	75	42	19	14	7.3	3.5
Chuy region								
Single row tree wind breaks, tree harvest after 16 years								
Wheat	53	94	83	72	63	61	59	57
Barley	26	71	56	44	35	34	31	30
Corn	167	*167*	187	185	177	176	173	172
Alfalfa	65	115	96	83	74	72	70	69
Multiple row tree wind break, tree harvest after 16 years								
Wheat	53	67	61	59	57	56	55	55
Barley	26	58	43	36	31	30	29	28
Corn	167	*29*	*99*	*139*	*154*	*157*	*161*	*162*
Alfalfa	65	116	91	79	72	71	69	68

Yield increase was assumed under impact of wind breaks (see method section). NPV is given in 1000 KGS/ha in values of 2017. Cells in italic indicate NPVs of the crop tree wind break systems lower than NPVs of the corresponding crops without tree wind breaks

climb up to 1800 KGS, before that given tree wind break system reached the same NPV as wheat without tree wind breaks.

Discussion

The interviews revealed a general picture that farms in Bazarkorgon have smaller land plots, are less mechanized, and less market oriented (except for cotton) than farms in Chuy Region. This picture is in line with the findings of Ruppert et al. (2020) and applies in general for southern versus northern Kyrgyzstan (WFP 2020).

Crop yields as stated during interviews are in the range of FAOSTAT (2020) and national statistics (National Statistical Committee of the Kyrgyz Republic 2020). If farmers responded that they used fertilizer, they exclusively used nitrogen fertilizer, which matched with FAOSTAT (2020). All farmers irrigated their crops, which also corresponded with statistics, as country-wide 68% of the total crop land area was irrigated in 2017 (FAOSTAT 2020).

Selling prices of barley and wheat by the interviews were the same as producer prices after FAOSTAT (2020). The selling price of corn by farmers in Bazarkorgon was close to FAOSTAT (2020), while it was much lower in Chuy Region. This might be explained, as corn in the south of Kyrgyzstan is used as food, whereas farmers in Chuy Region sell it mainly as fodder, which results in lower prices. Furthermore, farmers in Chuy Region are more likely to compete with large scale producers in neighboring Kazakhstan than farmers in the south of the country, because transport between northern and southern Kyrgyzstan is still an effort due to long road connections through high mountain areas. The rice selling prices as given by interview partners (Table 2) were only about half of the producer prices by FAOSTAT (2020). An explanation for this difference might be that interview partners in this study produced rice mainly for self-consumption and therefore do not meet the

Table 10 NPV per ha of major crops and crops with wind breaks after given rotation times at a discount rate of 17.5%

Tree wind break crop system	Net present value (NPV) of crops and tree wind break crop systems after given tree harvest time [1000 KGS/ha]							
	No tree wind break	Grid size of tree wind breaks [m]						
		50	100	200	400	500	750	1000
Bazarkorgon								
Single row tree wind breaks, tree harvest after 15 years								
Cotton	214	*192*	*202*	*208*	*211*	*212*	*212*	*213*
Rice	406	*320*	*360*	*382*	*394*	*396*	*399*	*401*
Corn	− 5.5	15	3.5	− 1.3	− 3.5	− 3.9	− 4.4	− 4.7
Chuy region								
Single row tree wind breaks, tree harvest after 16 years								
Wheat	42	*34*	*38*	*40*	*41*	*41*	*42*	*42*
Barley	20	*16*	*18*	*19*	*20*	*20*	*20*	*20*
Corn	133	*88*	*110*	*121*	*127*	*128*	*130*	*131*
Alfalfa	50	51	*50*	*50*	*50*	*50*	*50*	*50*
Multiple row tree wind break, tree harvest after 16 years								
Wheat	42	*− 9.8*	*10*	*25*	*33*	*35*	*37*	*39*
Barley	20	*− 17*	*− 3.1*	*7*	*14*	*15*	*17*	*18*
Corn	133	*− 41*	*33*	*80*	*106*	*111*	*118*	*122*
Alfalfa	50	*28*	*35*	*42*	*46*	*47*	*48*	*48*

No yield increase was assumed. NPV is given in 1000 KGS/ha in values of 2017. Cells in italic indicate NPVs of the crop tree wind break systems lower than NPVs of the corresponding crops without tree wind breaks

requirements for rice traded on larger markets and do not attain prices as farmers that are specialized on rice.

The DBH values of poplar trees found in this study were lower than in planting experiments in Central Asia (Ghan et al. 1961; Yakovleva 2003), Canada (Petersen et al. 1996), or India (Rizvi et al. 2011). That might be due to the more intense management and protection of trees in such experiments compared to the tree wind breaks in agricultural landscapes. Furthermore, the subtropical climate in India with a longer vegetation period than the study areas of Kyrgyzstan allows higher growth rates.

The tree wind break systems with multiple tree rows only attained higher NPVs than the crops under open field conditions, when combined with alfalfa and barley under the assumption pf a discount rate of 12% (Tables 8 and 9). In contrast, single row tree wind break systems showed higher NPVs in most crop tree wind break combinations even without assuming yield increase due to the effects of tree wind breaks, rendering the single row tree wind breaks more attractive than the multiple row type.

The discount rate had a dramatic effect on the results, as at the higher discount rate of 17.5% tree wind break systems only were able to increase their NPVs over open field conditions, when yield increases due to tree wind breaks were assumed (Tables 10 and 11). Also, the differences between NPVs by tree wind breaks systems and open field conditions shrunk substantially compared to the lower discount rate of 12%, which underlines that the effect by trees on the total NPV of such tree wind break systems is largely driven by the discount rate followed by potential yield increases due to tree wind breaks. Ayil Bank, for example, asks the lower interest rates the larger the loan requested. Therefore, a higher discount rate used in this study reflects the situation in Bazarkorgon in the southern part of Kyrgyzstan, as farm sizes are smaller, farm income is lower (National Statistical Committee of the Kyrgyz Republic 2020), and consequently loans would be smaller compared to Chuy Region in the north of the country. Still, at a discount rate of 17.5% tree wind breaks remain more profitable than crops under open field conditions, if we include indirect

Table 11 NPV per ha of major crops and crops with wind breaks after given rotation times at a discount rate of 17.5%

Tree wind break crop system	Net present value (NPV) of crops and tree wind break crop systems after given tree harvest time [1000 KGS/ha]							
	No tree wind break	Grid size of tree wind breaks [m]						
		50	100	200	400	500	750	1000
Bazarkorgon								
Single row tree wind breaks, tree harvest after 15 years								
Cotton	214	*213*	235	232	225	223	220	219
Rice	405	*353*	413	422	416	414	412	410
Corn	− 5.5	28	24	14	5	3	0.5	− 1.1
Chuy Region								
Single row tree wind breaks, tree harvest after 16 years								
Wheat	42	*40*	47	47	45	44	44	43
Barley	20	21	26	25	23	23	22	22
Corn	133	*101*	*130*	136	136	135	135	134
Alfalfa	50	55	57	55	53	52	52	51
Multiple row tree wind break, tree harvest after 16 years								
Wheat	42	*− 7*	*17*	*31*	*37*	*38*	*40*	*40*
Barley	20	*− 14*	*2.9*	*13*	*17*	*18*	*19*	*19*
Corn	133	*− 35*	*48*	*94*	*114*	*117*	*123*	*125*
Alfalfa	50	*30*	*40*	*46*	*48*	*49*	*49*	*50*

Yield increase was assumed under impact of wind breaks (see method section). NPV is given in 1000 KGS/ha in values of 2017. Cells in italic indicate NPVs of the crop tree wind break systems lower than NPVs of the corresponding crops without tree wind breaks

Table 12 NPV per ha of cotton without tree wind breaks and with 200 m × 200 m single row tree wind breaks under cotton revenues changed by + 20% and − 20% and under altered revenues from poplar trees

Discount rate 12%	No tree wind break	Poplar price KGS 2000	Poplar price KGS 2425	Poplar price KGS 3000
Cotton yields increase by 20%	432	469	479	493
Cotton yields decrease by 20%	103	141	151	165
No yield change	267	305	315	329
Discount rate 17.5%	**No tree wind break**	**Poplar price KGS 2000**	**Poplar price KGS 2425**	**Poplar price KGS 3000**
Cotton yields increase by 20%	346	359	364	371
Cotton yields decrease by 20%	83	96	102	109
No yield change	214	227	233	240

Yield increase was assumed under impact of wind breaks (see method section). NPV is given in 1000 KGS/ha in values of 2017

benefits by tree wind breaks, such as increased crop yields (as introduced above) and a reduction of crop water consumption (Thevs et al. 2019).

At a discount rate of 17.5% and assumption of crop yield increases, the highest NPVs were attained by single row tree wind break systems of grid sizes of 100 m × 100 m with cotton, wheat, barley, and alfalfa. With regard to rice and corn in Chuy Region, tree wind break grid sizes had to be changed to 200 m × 200 m to yield highest NPVs. At the lower discount rate of 12%, the 200 m × 200 m tree wind break systems yielded highest NPVs, when combined with rice in

Table 13 NPV per ha of wheat without tree wind breaks and with 200 m × 200 m single row tree wind breaks under wheat revenues changed by + 20% and − 20% and under altered revenues from poplar trees

Discount rate 12%	No tree wind break	Poplar price KGS 1000	Poplar price KGS 1250	Poplar price KGS 1500
Wheat revenues increase by 20%	99	112	118	123
Wheat revenues decrease by 20%	7	20	26	31
No revenue change	53	66	72	77
Discount rate 17.5%	**No tree wind break**	**Poplar price KGS 1000**	**Poplar price KGS 1250**	**Poplar price KGS 1500**
Wheat revenues increase by 20%	79	81	83	86
Wheat revenues decrease by 20%	5.6	7.9	10	13
No revenue change	42	44	47	50

Yield increase was assumed under impact of wind breaks (see method section). NPV is given in 1000 KGS/ha in values of 2017

Bazarkorgon and corn in Chuy Region, which were the most profitable crops in both study regions, respectively.

When combined with crops that yielded low profits (e.g. corn in Bazarkorgon or barley in Chuy Region), the tree wind break systems with small grid sizes (50 m × 50 m or 100 m × 100 m) attained the highest NPVs at a discount rate of 12%, which resulted in a higher contribution to NPV by the trees. But, if farmers were to change their crops, such tree wind break systems also should remain profitable if combined with higher value crops. Low income crops (barley and wheat) with tree wind breaks cause an economic loss in the year of tree planting, when combined with dense tree wind break grids. This may render tree planting unattractive for farmers. Planting of wood lots also too often faces the problem that land users do not receive short-term income, but have to wait until the time of tree harvest for their revenues. Tree wind break systems of grid sizes of 200 m × 200 m and larger do offer the advantages from trees, i.e. income, yield increase, and reduced crop water consumption (Thevs et al. 2019), while maintaining short-term income also during the year of tree planting.

As the 200 m × 200 m gridded tree wind break systems combine a number of advantages, the sensitivity analysis was performed on those systems (Tables 12 and 13). That analysis revealed that the tree wind break systems delivered higher NPVs than crops under open field conditions under a wide range of crop or tree revenues. These systems also react more on changes in crop revenues than on tree revenues so that a certain resilience regarding farm income can be attributed to the trees.

Azarov et al. (2019) investigated trends of prices of a number of commodities in the context of Kyrgyzstan's accession to the Eurasian Economic Union in 2015. They found that e.g. prices for potatoes and hay are likely to increase. In contrast, barley prices were foreseen to decrease due to imports of cheaper barley from Russia. This logic might apply for wheat and wood as well. On the other side, transport of wood from Russia to Kyrgyzstan is costly, in particular to the south, which makes domestic timber competitive. Often it is claimed that poplar wood has properties inferior to pine, which is the bulk of imported wood. But technological innovations in the field of engineered wood products of recent years opened new applications based on poplar wood, as listed in Isebrandt and Richardson (2014) and van Acker et al. (2020) and specified for beam structures by Monteiro et al. (2020), which makes poplar wood competitive and eventually an attractive commodity to be grown by farmers in tree wind breaks or other agroforestry systems. Strelkovskii et al. (2020) built a number of scenarios on development pathways for Kyrgyzstan. Half of their development pathways result in industrialization, which would reduce the overall importance of agriculture and possibly a shift to higher value commodities, while the other development pathways result in economic stagnation of the country, which would not lead to increase of prices for agricultural products. Thereby, the former set of scenarios would create a favorable environment for innovative wood products, while the latter would by an environment within which small scale wood working may remain important.

After all, cooperation among neighboring farmers is key to establish tree wind break systems, as tree wind breaks along borders between fields of different land owners may impact those land owners differently and benefits need to be shared. Lack and unwillingness to cooperate was reported by Ruppert et al. (2020) as a major obstacle against tree wind breaks. In contrast, farmers in Bazarkorgon study area planted trees on individual initiative to harvest them also for their individual profit, but this was done in coordination and in agreement with neighbors. In practice, there tree wind breaks were not established in square shaped patterns, as was used for sake of calculations here, but trees were planted along existing field boundaries or boundaries of groups of field plots to minimize the impact on crop field plots. For such situations, this paper would inform farmers to plant tree wind breaks along existing borders while keeping average distances of 200 m between tree wind breaks.

In Chuy Region, in particular around Bishkek, there is a trend towards increasing farm and field plot sizes (personal communication, N. Thevs and K. Aliev, 2020), which would allow to integrate tree wind breaks to capture the monetary revenue and benefits with regard to water consumption by tree wind breaks, while not intersecting field plots of different land owners.

Conclusion

In this study, revenues, costs, and profits were calculated for tree wind break systems of poplars combined with wheat, barley, corn, alfalfa, cotton, and rice, being major crops in Kyrgyzstan. This study focused on Chuy Region and the Ferghana Valley as two major agricultural production regions of the country. Tree wind breaks with more than one row of trees (multiple row type) did not result in financial gains for most crop tree wind break systems compared to open field conditions, while in general, it can be concluded that single tree wind breaks of this study are cost-neutral or result in small economic gains, even under a range of discount rates and revenues attained from crops and trees. Ongoing technological innovations on products from poplar wood, which could be applied in countries like Kyrgyzstan or neighboring countries, well may render poplar wood from tree wind break systems more and more competitive, which would increase the economic viability of tree wind breaks compared to crops grown under open field conditions. Among the different grid sizes, the 200 m $\times$ 200 m grid attained the highest financial surplus compared with open field conditions and other grid sizes. Thereby, effectively it is recommended to establish tree wind breaks along existing field borders or irrigation ditches while keeping an average distance between tree lines of 200 m, in order not to impede farm operations. Such tree wind break arrangement also would make cooperation between neighbors easier, compared to very dense tree wind break grids, which would cut through field plots, as can be seen in the study region Bazarkorgon.

Acknowledgement This study was undertaken with support from the Federal Ministry of Economic Cooperation and Development of Germany (BMZ), through the Advisory Service on Agricultural Research for Development (BEAF) under Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), Germany. BMZ funded a research grant of 100,000 EUR. Niels Thevs' position as an integrated expert at the World Agroforestry Center as well as the sap flow equipment and the climate stations were co-funded by BMZ as part of the Center for International Migration and Development (CIM) program. Students, who contributed to collect data, were funded by DAAD programs Promos and East Partnerships and by ASA (Invent), respectively. We thank the land owners and village administrations in the study sites for their support and permission to work on their land. Furthermore, we thank the reviewers for their valuable comments.

References

Albenskii AV, Kalashnikov AF, Ozolin GP, Nikitin PL, Surmach GP, Kulik NF, Senkevich AA, Kasyanov FM, Pavlovskii ES, Roslyakov NV (1972) Agroforestry melioration. Lesnaya promyshlennost, Moscow

Alemu MM (2016) Ecological benefits of trees as windbreaks and shelterbelts. Int J Ecosyst 6:10–13

Azarov A, Maurer MK, Weyerhaeuser H, Darr D (2019) The impact of uncertainty on smallholder farmers' income in Kyrgyzstan. Agric Rural Dev Trop Subtrop 120:183–195. https://doi.org/10.17170/kobra-20191127816

Brandle JR, Hodges L, Zhou XH (2004) Windbreaks in North American agricultural systems. Agrofor Syst 61:65–78

Bulychev A, Onishenko L (1979) Field protective forest lines and their effectiveness in Chuy Valley. Kyrgyzstan, Frunze

Caborn JM (1957) Shelterbelts and microclimate. Forestry Commission Bulletin No. 29. Edinburgh

Cleugh HA, Prinsley R, Bird PR, Brooks SJ, Carberry PS, Crawford MC, Jackson TT, Meinke H, Mylius SJ, Nuberg IK, Sudmeyer RA, Wright AJ (2002) The Australian

National Windbreaks Program: overview and summary of results. Aust J Exp Agric 42(6):649–664

Danilov G (1971) Protective forest stands and system of cultivation. Lesnaya Promyshlennost, Moscow

Dwivedi RP, Singh KKR, Rizvi RH, Chauhan J (2007) Socioeconomic analysis of agroforestry systems in western Uttar Pradesh. Indian Res J Ext Edu 7:18–22

EURAF (2020) Agroforestry in Ukraine. https://euraf.isa.utl.pt/countries/ukraine. Assessed 3 Apr 2020

FAOSTAT (2020) http://www.fao.org/faostat/en/#data. Assessed 15 Mar 2020

Ghan PA, Djanaeva VM, Karafa-Korbut IG, Krivosheeva LS, Kunchenko AI, Orlova NI, Protopopov GF, Prutenskii DI, Tkachenko VI (1961) Trees and shrubs of Kyrgyzstan. Academia NAUK Kyrgyz SSR, Frunze

Isebrands JG, Richardson J (2014) Poplars and Willows-Trees for Society and the Environment. FAO CABI

Jain SK, Singh P (2000) Economic analysis of industrial agroforestry: poplar (*Populus deltoides*) in Uttar Pradesh (India). Agrofor Syst 49:255–273

Kalashnikov A (1969) Field protective forest lines and their influence on the yield. Ryazan Regional Printing House, Ryazan

Kayser B (2020) Hecken als Ertragsfaktor. http://www.agroforst.de/3-ertragshecken.html. Assessed 3 Apr 2020

Kort J (1988) Benefits of windbreaks to field and forage crops. Agr Ecosyst Environ 22(23):165–190

Lamers JPA, Michels K, Vandenbeldt RJ (1994) Trees and windbreaks in the Sahel: establishment growth nutritive and calorific values. Agrofor Syst 26:171–184

Missall S, Welp M, Thevs N, Abliz A, Halik Ü (2015) Establishment and maintenance of regulating ecosystem services in a dryland area of central Asia illustrated using the Kökyar Protection Forest Aksu NW China as an example. Earth Syst Dyn 6:359–373

Monteiro SRS, Martins C, Dias AMPG, Cruz H (2020) Mechanical performance of glulam products made with Portuguese poplar. Eur J Wood Wood Prod 78:1007–1015

National Agroforestry Center (2020) Windbreaks. U.S. Department of Agriculture. https://www.fs.usda.gov/nac/practices/windbreaks.php. Assessed 2 Apr 2020

National Statistical Committee of the Kyrgyz Republic (2020) Open data. http://www.stat.kg/en/opendata. Accessed 07 Apr 2020

Ontario Federation of Agriculture (2020) Best management practices field windbreaks. http://www.omafra.gov.on.ca/english/environment/bmp/AF167.pdf. Assessed 2 Apr 2020

Peri PL, Bloomberg M (2002) Windbreaks in southern Patagonia Argentina: a review of research on growth models windspeed reduction and effects on crops. Agrofor Syst 56:129–144

Peterson EB, Peterson NM, McLennan MS (1996) Black cottonwood and balsam poplar managers. Handbook for British Columbia. Ministry of Forests Canada

Republic of Tajikistan (2014) Fifth national report on preservation of biodiversity on the Republic of Tajikistan. National Center on Biodiversity and Biosafety of the Republic of Tajikistan (NCBB). Dushanbe. https://www.cbd.int/doc/world/tj/tj-nr-05-en.pdf

Ruppert D, Welp M, Spies M, Thevs N (2020) Farmers' perceptions of tree shelterbelts on agricultural land in rural Kyrgyzstan. Sustainability 12:1093. https://doi.org/10.3390/su12031093

SAEPF (State Agency of Environment and Forests Kyrgyzstan) 2017 Biodiversity conservation priorities of the Kyrgyz Republic till 2024. https://www.cbd.int/doc/world/kg/kg-nbsap-v3-en.pdf

Schroeder WR, Kort J (1989) Shelterbelts in the Soviet Union. J Soil Water Conserv 44:130–134

State Committee of Turkmenistan for Environmental Protection and Land Resources (2018) National Forest Program. http://turkmenistan.gov.tm/?id=3309. Assessed 25 Jan 2018

Stepanov AM (1987) Agroforestry melioration in irrigated lands. Agropromizdat Moscow

Strelkovskii N, Komendantova N, Sizov S, Rovenskaya E (2020) Building plausible futures: scenario-based strategic planning of industrial development of Kyrgyzstan. Futures 124:102646. https://doi.org/10.1016/j.futures.2020.102646

Strenge E, Thevs N, Aliev K, Eraaliev M, Lang P, Baibagysov A (2018) Water consumption of populus alba trees in tree shelterbelt systems in Central Asia—a case study in the Chui Valley, South Eastern Kazakhstan. Central Asian J Water Res 4:48–62. https://doi.org/10.29258/CAJWR/2018-RI.v4-1/48-62.eng

Susa NI (1959) Agroforestry melioration. Governmental Publishing House for Agriculture, Moscow

Thevs N, Gombert AJ, Strenge E, Lleshi R, Aliev K, Emileva B (2019) Tree wind breaks in Central Asia and their effects on agricultural water consumption. Land 8:167–183. https://doi.org/10.3390/land8110167

Tomás A, Palmer JHN, Graves A, Garcia de Jalón S, Burgess PJ (2018) Integrating a financial module in the web-ecoyield-safe model for bioeconomic assessment of agroforestry ecosystems. In: 4th European agroforestry conference—agroforestry as sustainable land use, 28–30 May 2018, Nijmegen, The Netherlands

Tribunskaya V, Kostina N, Sherbakova L, Astafiev N (1974) Agro-economic effectiveness of shelterbelts. Lesnaya Promyshlennost, Moscow

UNDP (2015a) Concept for conservation and sustainable use of the biological diversity of the Republic of Kazakhstan until 2030. Astana. http://www.fhc.kz/conventions/files/kz-nbsap-rus.pdf

UNDP (2015b) Fifth National Report of the Republic of Uzbekistan on Conservation of Biodiversity. https://www.cbd.int/doc/world/uz/uz-nr-05-en.pdf

UNECE (2019) Forest Landscape Restoration in the Caucasus and Central Asia—challenges and opportunities. Background paper for the Ministerial Roundtable on Forest Landscape Restoration in the Caucasus and Central Asia, 21–22 June 2018, Astana, Kazakhstan. http://www.unece.org/fileadmin/DAM/timber/publications/DP-72-flr-cca-en.pdf

Van Acker JCR, Jiang X, Bulcke J (2020) Innovative approaches to increase service life of poplar lightweight hardwood construction products. Current topics and trends on durability of building materials and components. https://www.scipedia.com/public/Acker_et_al_2020a

Vasilyev ME (1980) Melioration through forests and harvest. Kainar, Almaty

Vorobiev G, Anuchin N (1985) Forest encyclopaedia. Soviet Encyclopaedia, Moscow

Wandel J, Pieniadz A, Glauben T (2011) What is success and what is failure of transition? A critical review of two decades of agricultural reform in the Europe and Central Asia region. Post-Commun Econ 23(2):139–162

Wang SH, Zhang LZ, Zhang DS, van der Werf W, Evers JB, Sun HQ, Su ZC, Zhang SP (2016) Density responses and spatial distribution of cotton yield and yield components in jujube (*Zizyphus jujube*)/cotton (*Gossypium hirsutum*) agroforestry. Eur J Agron 79:58–65

WFP (World Food Program) 2020. WFP Kyrgyz Republic Country Brief. https://docs.wfp.org/api/documents/WFP-0000113476/download/?_ga=2.268292878.1698452485.1586425537-188563853.1586425537. Assessed 15 Mar 2020

World Bank (2019) Real interest rate (%)—Kyrgyz Republic. https://data.worldbank.org/indicator/FR.INR.RINR?locations=KG. Assessed 15 Dec 2020

Yakovleva N (2003) Quality and productivity of domesticated poplar hybrids in Kyrgyzstan. Ilim, Bishkek

Zheng X, Zhu JJ, Xing ZF (2016) Assessment of the effects of shelterbelts on crop yields at the regional scale in Northeast China. Agric Syst 143:49–60