Article

Adoption of Sustainable Land Uses in Post-Soviet Central Asia: The Case for Agroforestry

Utkur Djanibekov [1],*, Grace B. Villamor [2], Klara Dzhakypbekova [3], James Chamberlain [4] and Jianchu Xu [5]

[1] Institute for Food and Resource Economics (ILR), University of Bonn, Meckenheimer Allee 174, Bonn 53115, Germany

[2] Center for Development Research (ZEF), University of Bonn, Walter-Flex-Str. 3, Bonn 53113, Germany; gracev@uni-bonn.de

[3] Agricultural Sciences and Resource Management in Tropics and Subtropics, University of Bonn, Nussallee 1, Bonn 53115, Germany; klara.dzhakypbekova@uni-bonn.de

[4] Research Forest Products Technologist, Forest Service, Southern Research Station, FIA, 1710 Research Center Drive, Blacksburg, VA 24060, USA; jchamberlain@fs.fed.us

[5] World Agroforestry Centre—East and Central Asia, c/o: Kunming Institute of Botany, Kunming 650201, China; j.c.xu@cgiar.org

* Correspondence: u.djanibekov@ilr.uni-bonn.de; Tel.: +49-228-73-2892

Abstract: We examine constraints and opportunities to enhance adoption of agroforestry for ecosystem and livelihood improvement in post-Soviet economies, using Central Asian countries as examples. Using a coevolutionary socio-ecological systems framework, we describe how development efforts, especially agricultural policies, under centrally planned regimes and under transition to market economies have changed environmental conditions, and how they affect peoples' welfare. We then discuss agroforestry as a sustainable land use practice to address these issues. We present regional-specific and -suitable agroforestry practices, and discuss their potential. We found that legacies from the previous period of central planning shape current land uses, institutions, infrastructure and decisions of farmers, and constrain development of agroforestry. By identifying opportunities and constraints of agroforestry, we provide recommendations for enhancing the use of agroforestry in Central Asia.

1. Introduction

From 1922 until independence in 1991, the national economic policies in Central Asia (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan) were dominated by the centrally planned Soviet economy that considered the agricultural sector as the backbone of the region. With the collapse of the Soviet Union, the economies of the Central Asian countries (CAC) began transitioning to market-based economies. This transition is not complete [1], as each country experiences different issues. Planned increases in agricultural output during the Soviet Union shaped current environmental conditions. For example, agricultural intensification resulted in substantial amount of degraded lands [2] with the lowest on-farm tree cover and biomass carbon globally [3]. Further, expansion of irrigation to support production of strategically important crops for the state resulted in a decline of the Aral Sea [4]. As a result of unsustainable agricultural practices, the ecological conditions of the CAC are deteriorating and decreasing the welfare of the people [2].

Identifying sustainable land use practices for the region, while considering previous and current economic policies and ecological conditions, is imperative to sustainable development of the CAC.

Agroforestry (integration of trees on farms) is adaptable to farmers' needs, the landscape and local environment and may be suitable in the CAC [5–7]. Other practices include conservation agriculture [8,9], water-wise technologies [10] and improved crop rotation methods [9]. Diversifying farming systems through agroforestry provides possibilities to rehabilitate degraded landscapes, address biodiversity loss, climate change adaptation and mitigation, while supplying diverse products for consumption and income [6,11–13]. However, agroforestry is low priority among policy and decision makers in the CAC [5,7]. Previous studies analyzed the potential of agroforestry for certain countries or provinces in the CAC by conducting field experiments, and policy and economic analyses (e.g., see [6,12–18]). Past studies did not assess barriers and options to enhance adoption of diverse agroforestry practices considering the context of the whole CAC. The adoption and expansion of agroforestry in the CAC requires understanding the complex interactions between social and ecological systems to provide insights for interventions to enhance the mutual benefits of the systems [19].

To understand adoption of agroforestry in the CAC we adapted the framework of coevolution of social and ecological systems, where two systems interact, create feedback and evolve over time [20]. We use this framework to understand the influence of interdependencies between two systems and dependencies on current land uses and adoption of agroforestry in the CAC. For this study we reviewed interdisciplinary scientific studies from Soviet Union archives and studies published since independence. The objectives of this study are to: (1) describe agroforestry in the CAC, and its potential for expansion; (2) investigate how previous and current economic developments may affect adoption of agroforestry; and (3) develop policy recommendations to provide an enabling environment for adoption of agroforestry.

## 2. Methods and Conceptual Framework

This study relies on the review of 95 interdisciplinary scientific studies from Soviet Union archives and studies published since independence. A total of 38 peer-reviewed journal articles and 57 other scientific studies were analyzed to assess historical developments of land uses and agroforestry practices in the CAC. Scientific publications concerning land use and agroforestry for the post-independence period were obtained using Google Scholar (scholar.google.com), whereas literature published during the Soviet Union era was obtained from the archives of research institutes and university libraries in Uzbekistan and Kyrgyzstan.

For the analysis of the literature, we relied on a coevolutionary socio-ecological systems framework [19,21]. This framework argues that social processes create ecological outcomes that feedback into the evolutionary process and the two systems have reciprocal influences [22]. Interactions of these systems are influenced by temporal and spatial scales and coevolution occurs when changes in one system diffuse impacts on the other systems [21]. Socio-ecological systems are path dependent where past changes influence the current state of these systems [22]. Legacies from the past impact the course of evolution of systems [23]. Shaped over time, social and ecological systems may create a situation called lock-in. Accordingly, lock-in arises because of path dependency where legacies impact current socio-ecological systems such as current technologies, practices and policies that limit the adoption of new technologies, practices and polices because the systems that evolved lack flexibility needed to encourage adoption [24–26].

There is a need to consider coevolutionary systems in the CAC with a long-term perspective that recognizes the importance of history in creating and constraining land use practices. We identify key social (economic) and ecological changes during the Soviet Union era and the transition period, showing the interactions between the systems, and agroforestry practices. In analyzing socio-ecological coevolution, we consider that the process may occur at different spatial scales, from the entire Central Asian region to specific provinces. Changes may also occur at different levels within the social system, from the state (e.g., policies developed by ministries, and institutions) to the farmers. Our description of different scale interactions (i.e., temporal and spatial) is limited to available literature, and for that reason detailed analysis of socio-ecological coevolutions at various scales may be absent.

In our study, social change has occurred through agricultural developments that influence the economies of the CAC, observed through contribution of agriculture to the GDP and employment [27,28]. The main agrarian changes in policies, institutions, infrastructure, markets, and farmers' practices and perceptions in the CAC during the Soviet Union and transition period are considered major drivers of social change. To identify key ecological changes, we consider the repercussions of agricultural developments on natural resources and the environment. We analyze how the social system since the Soviet Union era has affected natural ecosystems (i.e., land, water, forest and biodiversity), and how feedback from these systems has shaped present socio-ecological systems (Figure 1).

In analyzing adoption of agroforestry, we consider interrelated processes between social and ecological systems [29]. Adoption of agroforestry practices is path dependent on interactions of socio-ecological systems, which shaped current conditions for land use practices [30]. We show that agroforestry may be more suitable for certain areas and limitations at different scales may constrain its adoption. In identifying factors that may limit agroforestry we propose recommendations to enhance the adoption of this land use.
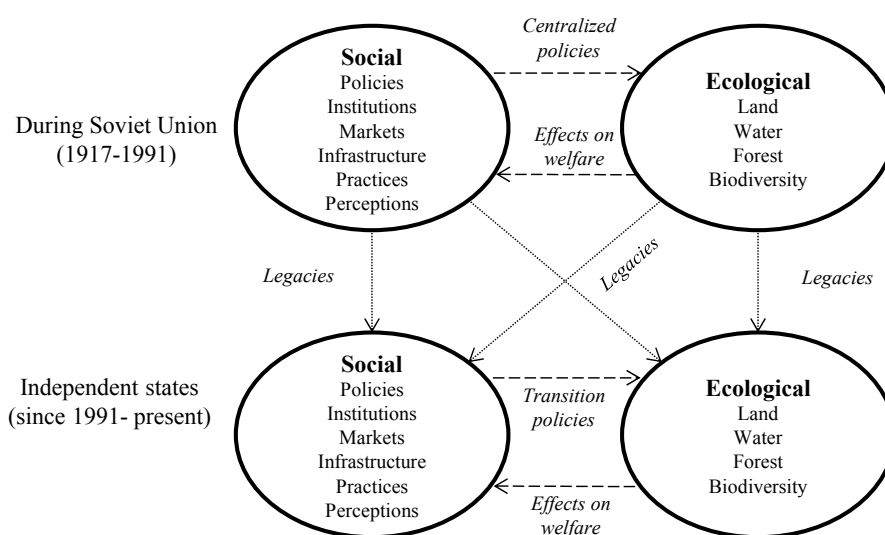
Figure 1. Coevolutionary socio-ecological systems framework of the study. Note: Dashed lines correspond to interactions between social and ecological systems, and round dotted lines correspond to systems inherited from the Soviet Union.

3. Social and Ecological Changes

3.1. Social Changes

Developments during the Soviet Union: Economic policies of the countries that now make up Central Asia were centralized during the Soviet Union era (1922–1991). The CAC were part of an integrated economy, which was oriented towards the needs of the overall Soviet economy. Economic policies were designed such that each republic contributed a set of commodities, for which they had a supposed comparative advantage, and each was dependent on commodities produced by other Soviet Union Republics.

The agricultural sector was considered the backbone of production. [31]. Each republic specialized in the production of specific commodities (i.e., Kazakhstan in grain, Kyrgyzstan in maize, alfalfa and sheep, and Tajikistan, Turkmenistan and Uzbekistan in cotton and karakul sheep) [27]. Accordingly, the agricultural sector in the region was modernized to increase output of these commodities (e.g., developing seed and fodder varieties, new livestock breeds, machineries and crop management practices) [32]. Infrastructure and institutions were owned by the state and linked to state target production policies [33]. Prices of all commodities were controlled by the state [33]. Moreover,

the increase in agricultural production was based primarily on increasing the land area and the use of water for irrigation. For example, the region experienced rapid transformation from steppe to cropland [34], cultivating a substantial area of rainfed crops. The supply of irrigation expanded [35] and since the second half of the 20th century the amount of irrigated land has almost tripled [4]. The number of irrigation canals and the quantity of water withdrawn from rivers for irrigation increased substantially, although many of the irrigation systems were poorly designed and much of the water was wasted [4]. Crop yields increased due to intensification and agricultural developments. By the mid-1970s, cotton yields in Uzbekistan were the highest (3 tons per hectare) among major cotton producing countries in the world [36].

Present developments: The republics that now constitute the CAC became independent countries in 1991. The five CAC have become more socio-economically differentiated as their governments introduced national policies for transition to a market-based economy. Agriculture is still important in the CAC (Table 1), which range from moderately to highly agrarian societies. For example, the share of agriculture in the GDP of Kazakhstan is 5%, whereas in Tajikistan's it is 27% [28]. Agrarian changes included land reforms that dismantled *sovkhozes* and *kolkhozes* (i.e., state-owned and collective-owned farms, respectively), into smaller farms. As a result of policy reforms, ownership of farmland by private individuals was granted in Kyrgyzstan and Kazakhstan [1], while in Tajikistan and Uzbekistan the state owns the land but the rights to use the land has been transferred to individuals. Conversely, in Turkmenistan, the state recognizes private property but land is virtually owned by the state.

Land reforms resulted in a mismatch with the irrigation systems that were designed for large-scale farms, and current farms with smaller land area do not share responsibilities to maintain the irrigation systems [37]. Agrarian reforms liberalized crop production in Kazakhstan, Kyrgyzstan and Tajikistan, allowing farmers to decide which crops to cultivate. In contrast, Turkmenistan and Uzbekistan continue the Soviet model of agricultural production policies by imposing crop production targets on farmers. According to the state cotton procurement policy of Uzbekistan, farmers must allocate half of their land for cotton, meet target output and sell the entire harvest to the state at prices substantially lower than potential border prices [38]. Uzbek farmers also have to allocate about 20% of their land to wheat production. In Turkmenistan, about 42% and 49% of farmland is allocated to cotton and wheat production, respectively. The land lease contract for farmers may be conditional on fulfillment of the state target crop production [1,36]. Previous investments in institutions, infrastructure, factories and management practices were effective for centrally planned agricultural production.

Table 1. Development characteristics of Central Asian countries as of 2014.

Indicators	Kazakhstan	Kyrgyzstan	Tajikistan	Turkmenistan	Uzbekistan
GDP (percent growth) [28]	5	−0.9	7.5	11.1	8.2
Agriculture in GDP (%) [28]	5	20	27	15	19
Main agricultural activity [28]	Wheat cultivation	Animal husbandry and wheat cultivation	Cotton and wheat cultivation	Cotton cultivation	Cotton and wheat cultivation
Population (in millions) [28]	16.8	5.6	8	5.2	29.8
Rural population (% of total) [28]	46	65	73	51	64
Employment in agriculture (%) [28]	26	35	66	48	29
Population below 1.25 USD a day (% of total) [28]	<2	6.7	14.7	63.5	n.a.
Rating of status of agricultural reforms [39]	6.2	7.2	4.4	1.8	4.8
State target agricultural production [39]	Abolished	Abolished	Abolished	Present	Present

Note: n.a. indicates information is not available; in rating of status of agricultural reforms, 1 = centrally planned economy, and 10 = completed market reforms; rating of status of agricultural reforms and state target agricultural production are as of 2005.

Land use patterns have changed in the CAC during the transition. Rangelands constitute up to 65% (mainly in Kazakhstan, Kyrgyzstan and Tajikistan), irrigated lands up to 2.6% (mainly in Turkmenistan,

Uzbekistan, and southern Kazakhstan), rainfed lands up to 5.4% (mainly in Kazakhstan) and the remaining 27% of the land belongs to non-agricultural activities [28,40,41]. In Kazakhstan, wheat production continues and producers have started to grow food peas and chickpeas. In Kyrgyzstan, the area in wheat production has doubled and cultivation of dry beans is increasing. In Tajikistan and Turkmenistan, the area in wheat cultivation has increased, while, in Uzbekistan, the area in cotton and fodder cultivation has declined as a result of an increase in wheat area [27]. Land use mainly consists of crops and pasture, while forests have a negligible role. For example, Kyrgyzstan and Kazakhstan, which have the highest share of tree cover in the CAC, have a tree cover of only 5% and 2%, respectively [42].

The CAC continue to experience economic difficulties in adjusting to policies, institutions and infrastructure. This may reflect the legacy of previous agro-economic policy that viewed the countries as a single production unit of the larger Soviet economy. For instance, despite a relatively high share of agricultural production in national GDP, Kyrgyzstan does not produce sufficient food to meet demand for nutrient consumption [43], which was achieved during Soviet Union era by receiving commodities from other republics. During the Soviet Union period, distribution of water from the rivers was coordinated for upstream and downstream countries. Food and fodder crops, as well as electricity were distributed by the state. After the collapse of the Soviet Union there was no coordination to distribute commodities and resources. Uncoordinated distribution of resources among the CAC has increased competition for them. For example, the overriding issue concerning water distribution is that the upstream countries (i.e., Kyrgyzstan and Tajikistan) of the two major rivers (i.e., Syr Darya and the Amu Darya) are expanding construction of hydropower dams. This may reduce the amount of water for downstream areas that are dependent on irrigated agricultural production (i.e., Turkmenistan, Uzbekistan, and southern regions of Kazakhstan) [44].

3.2. Ecological Changes

Land degradation: Economic developments throughout the region, especially state imposed procurement targets for cultivated crops, have depended on intensive use of natural resources [1,27]. This resource-dependent approach has impacted natural resources and ecosystems, which is evidenced by land degradation of about 20%–30% of agricultural lands [45]. Biomass carbon from agricultural lands has decreased from 0.48 PgC in 2000 to 0.47 PgC in 2010 [3].

Present agrarian policies do not reflect state strategies towards market system and this disparity may lead to continued inappropriate land use and continued degradation of the land base. Land degradation includes soil erosion in rainfed areas, especially in Kazakhstan as a result of expansion of intensive wheat cultivation. Cultivating crops on steep mountainous areas of Tajikistan and Kyrgyzstan has degraded land through extensive soil erosion [46,47]. Poor irrigation and drainage systems have resulted in excessive soil salinization on 90% of the crop land in Turkmenistan and on 60% of crop land in Uzbekistan [8,48]. Poor pasture management has degraded rangelands throughout the region [2,8,49]. The on-going land degradation is excessive, which is evident by the irrigated area of Uzbekistan where the share of highly saline arable lands increased from 21% in 1990 to 60% in 2012 [48]. The monetary value of land degradation is high, e.g., rangeland degradation has been estimated at about 4.6 billion USD between 2001 and 2009 [2].

Deforestation: About 30% of the rural population of the CAC live near forests and do not have alternative sources of forest products. Since independence, all CAC, except for Turkmenistan that has substantial gas reserves, have experienced an increase in demand for fuelwood [50]. More than 80% of rural households in Tajikistan rely on fuelwood as the main source of cooking energy [50], while, in Kyrgyzstan, households collect 4 to 41 m^3 of fuelwood every year from walnut forests [51]. Insufficient production of fodder in mountainous areas of Kyrgyzstan and Tajikistan resulted in grazing in forests, which leads to degradation of these resources. The value of deforestation between 2001 and 2009 was estimated at about 0.32 billion USD [2]. Deforestation is complicated by the cessation of subsidized timber production, the lack of institutional capacity to protect and regulate forests, and a lack of alternative energy sources for domestic use [52].

Biodiversity loss: Deforestation also leads to biodiversity loss [53]. An assessment of the conservation status of trees in the CAC found that 44 out of 96 taxa evaluated were either critically endangered, endangered, or threatened, with a further five taxa near threatened [52]. An estimated 90% of fruit and nut forest habitats have been lost across the region in the last 50 years [54]. Walnut and fruit-tree forests have disappeared from about 10 Mha during the last century, and dense pistachio and almond forests are almost completely deforested. The forests growing on the foothills of the Tien Shan, Pamir-Altai and Kopetdag mountains, especially those near rural settlements, are among the most threatened [54]. This includes the slow-growing juniper forests of Tajikistan and Kyrgyzstan, which have been heavily impacted by fuelwood collection and over-grazing [52]. Kyrgyzstan, for example, lost 35% of its mountain juniper in just a few decades [55], and the juniper forests in Uzbekistan which accounts for 52% of the remaining forest cover is threatened [52].

Poor water use management and coordination: Intensive uses of water resources for furrow irrigation and poor conditions of irrigation canals have reduced water flow to the Aral Sea. Most of the region's water used for irrigation is for production of the state target crop (i.e., cotton) in Uzbekistan and Turkmenistan. In addition, poor coordination of water use for agricultural production in downstream countries and water use for hydropower generation in upstream countries have reduced downstream river discharges [56]. These are vividly illustrated by the shrinkage of Aral Sea to 10% of its original size and a decrease in surface area of the deltaic zone of the sea from 550,000 ha to less than 30,000 ha [57].

Climate change: Land degradation, biodiversity loss, and lack of water availability may be further exacerbated by the climate change [58,59]. Land degradation also may contribute to climate change by reducing carbon sequestration in the soil and emitting greenhouse gases. Zomer et al. [59] estimated that by the year 2050, mean annual temperatures for the CAC will increase by 2.0 °C to 3.6 °C. Kazakhstan is projected to show the largest increase in temperature in the region which may reduce yields of rainfed spring wheat in the north and irrigated winter wheat in the south [60]. Although the melting of glaciers may increase water volume in the short and mid-term [61], the reserves are limited and water scarcity may continue [62]. With a 1 °C increase in temperature, demand for irrigation in the arid and semi-arid regions of the CAC, due to increased evapotranspiration, is estimated to grow by at least 10% [61]. Climate change effects on water availability can be confirmed by the increase in frequency of droughts, which have been particularly acute in the downstream regions [41].

3.3. Socio-Ecological Feedbacks

Development policies in the CAC and the legacy of past policies have repercussions on the region's ecosystems and natural resources (see Table 2). Current interactions between the ecological and social systems appear not as adaptive measures to changes from the Soviet Union, but as inherited from that era. Developments in agricultural production affected the structure of land and water use and other natural resources, and the impacts were evaluated mainly in economic contributions to state budgets. The high priority on annual crop production and under-development of other sectors lead to land degradation, deforestation and biodiversity loss. The costs of land degradation due only to land use and land cover change were estimated to be 6 billion USD between 2001 and 2009 [2].

In this case study, adaptive measures to changing ecological system are absent or lagging behind. For example, the drying of the Aral Sea, which is mainly caused by water withdrawn for irrigation, impacts health, incomes and diets, decreases employment opportunities and increases dust storms from the Aralkum [61]. Severe droughts in 2000–2001 reduced the incomes of rural population, with a recovery period of five years for household to previous average economic levels [41]. Moreover, climate change exacerbates and leads to decreases in carbon storage in soil, increases in carbon emissions from forest harvest, disappearance of species adapted to agro-ecological zones, and increases in evaporation and melting of glaciers.

Table 2. Major socio-ecological characteristics during the centralized economy and transition to market economy in Central Asian countries.

Stages	Social Changes	Ecological Changes
Soviet Union (1922–1991)	*Centralized economy*	
	Central Asian Countries are viewed as agricultural producers and production oriented for the needs of economy of the Soviet Union [31];	Transformation from steppe to cropland and expansion of irrigated areas and canals for increasing agricultural production [4,32];
	Each country specialized in certain agricultural products [24];	Land degradation caused by agricultural input intensification and overgrazing [8];
	Development of institutions, irrigation networks and other infrastructure to meet the state target production [31,36];	
	Increase in agricultural output by target production, intensification, increasing arable land and irrigation supply [33];	Decrease in Aral Sea by more than 60% from 1960 to 1990 due to increased use of water for irrigation in downstream countries [56].
	Coordination of resource and commodity distribution among countries [31].	
Independent states (since 1991–present)	*Transition to market-based economy*	
	Agriculture plays important role, in Turkmenistan and Uzbekistan production of cotton and wheat is under state procurement targets [33];	Increase in land degradation as a result of continued intensified agricultural production and overgrazing;
	Provision of subsidies, functioning of institutions and infrastructure to meet state target crop production [33];	Substantial deforestation and biodiversity loss [52,54];
	Land reforms that dismantled large-scale *sovkhozes* and *kolkhozes* into smaller farms [1,36];	Increase in frequency of water shortages in downstream countries due to disputes between upstream and downstream countries [41];
	Private ownership of land in Kyrgyzstan and Kazakhstan, while in Tajikistan, Turkmenistan and Uzbekistan land is owned by the state [1,39];	Drying of Aral Sea up to 10% of original size, because of poor coordination of water [56];
	Disputes among countries in resource distribution (e.g., between upstream and downstream countries) [41].	Water scarcity and crop yield reduction due to climate change [60,61].

4. Sustainable Land Use Practice

4.1. Agroforestry to Address Socio-Ecological Issues

Agroforestry offers a variety of approaches that can provide beneficial effects for conservation and for livelihoods. The CAC are home to wild relatives of fruit species such as apple (*Malus* spp.), pear (*Pyrus* spp.), plum (*Prunus* spp.), pomegranate (*Punica granatum* spp.), almond (*Amygdalus* spp.), and grape (*Vitis* spp.) [7]. The region has an estimated 500–600 arborescent species, of which 100–150 are trees [52]. During the Soviet Union, agroforestry was mainly considered for timber and fruit production and land amelioration [63–65]. Early agroforestry research focused on identifying the suitability of tree species [66–68] and management practices [15,69,70], and analyzing yield of fruits and wood under different agro-ecological conditions [71]. In the 1930s, Russian scientific expeditions sent to assess forest resources of Kyrgyzstan proposed the domestication of wild fruit tree species to increase fruit productivity through forest gardening [14,72].

Currently, agroforestry practices such as alley cropping, silvopasture, windbreaks, live fences, fruit-based kitchen gardens, managed woodlands for timber and non-timber forest products and riparian buffers are practiced in the CAC to different degrees of intensity (Table 3). These agroforestry practices have many purposes including commercial and subsistence production, and protection of natural resources. The extent of these practices ranges from 0.05 ha at the household level to regions along riparian zones. No data are available on the area devoted to different agroforestry practices. Almost every rural household has a kitchen garden, while windbreaks, live fences and woodlands managed for non-timber forest products are rarely practiced.

Table 3. Agroforestry practices in Central Asian countries.

Agroforestry Practices	Description	Market-Orientation and Main Purpose	Spread of the Practice	Sources
Alley cropping	Crops are grown between widely spaced rows of woody plants. For example, on mountain slopes of Tajikistan and Kyrgyzstan, rainfed wheat production is combined with apple trees. Other trees include *Ailanthus altissima*, *Fraxinus pennsivanica*, walnut, mulberry, acacia, apricot, and almond. Some alley crops can serve as green manure (e.g., peas, lentil, and flax). First records of such practice in Central Asia can be already found in the 19th century.	Commercial.	Moderately practiced. Mainly in Tajikistan and Kyrgyzstan. The scale is 0.1–40 ha.	[5,73,74]
Silvopasture	Combines trees and livestock, involves planting of fodder trees (e.g., *Robinia pseudoacacia* L., and *Gleditsia triacanthos* L.), tree-based understory fodder production-hay-making and grazing and cover-crops for orchard floor management. This practice is commonly observed in Kyrgyzstan and Tajikistan.	Commercial and subsistence.	Rarely practiced. The scale is 0.1–100 ha.	[5,7,51,75]
Windbreaks	Includes wide spaced, single and multiple rows of trees in agricultural fields that mitigate the impact of excessive wind, and ameliorate soil erosion. Windbreaks with poplar trees increase crop yields by 10%–20% in Uzbekistan. Using windbreaks along crop fields can increase yields of winter wheat by 14%–28%, maize by 17%–40%, and sugar beet by 7%–17%.	Commercial and state owned for protection from wind.	Rarely practiced.	[5,17,76]
Live fences	Consists of single or multiple rowed lines of trees which are mainly used to keep animals off arable land. For example, in Tajikistan live fences consist of rose hip and *Elaeagnus angustifolia* L. (Russian Olive).	Commercial.	Rarely practiced.	[5,76]
Fruit-based agroforestry	Includes growing fruit trees on farms Fruit-based agroforestry is established for income generation and for household consumption. Intercropping of wheat or other understory crops in orchards is often found throughout the region, e.g., in Khorezm province of Uzbekistan almost all farmers intercropped fruit trees with annual crops.	Commercial.	Moderately practiced but increasing. The scale is 0.1–100 ha.	[7,62]
Kitchen gardens	Almost all rural households of Central Asia have kitchen gardens which are attached to their home. In kitchen gardens households grow fruits, berries, vegetables and fodder to sustain household nutrition and food security, and obtain fuelwood for domestic energy use during the winter.	Subsistence.	Extensively practiced. The scale is 0.05–0.4 ha.	[5,12,77]
Managed woodland for non-timber forest products	Managed woodland for timber and non-timber forest products includes producing timber, fuelwood, fruits, nuts, berries, mushrooms and medicinal herbs. For example, in southern Kyrgyzstan, farmers have tradition to harvest walnuts and hay from such plantations.	Commercial.	Rarely practiced. The scale is >0.1 ha.	[76,78]
Riparian buffers	Planted along streams and rivers to protect the banks from erosion and to slow the movement of nutrients from farm fields into the water system, as well as providing wildlife habitat and biodiversity conservation.	Farm or state owned for protection of farmlands and nature.	Moderately practiced.	[5,50]

Agroforestry can help to provide products and services that were supplied during Soviet Union through coordinated regional distribution. Benefits of agroforestry include diversification of income, food and energy security, provision of fodder, and other ecosystem services. For example, managing agroforest for non-timber products can yield honey, mushrooms and nuts for household consumption, and protect natural resources and help to sequester carbon to mitigate climate change. Experiments in Tajikistan showed that an agroforestry system with 12% trees, 30% alfalfa and 58% in traditional agriculture can improve drainage while decreasing salt accumulation at the root zone [79]. Agroforestry on marginal croplands with *Elaeagnus angustifolia* L., *Ulmus pumila* L. and *Populus euphratica* Oliv. in irrigated area of Uzbekistan helped to rehabilitate such lands [6] and to generate higher financial benefits than major crops [18]. Households can save 50 USD annually by producing fuelwood for domestic energy through agroforestry instead of purchasing fossil fuels [18]. Agroforestry with *Robinia pseudoacacia* L., and *Gleditsia triacanthos* L. can provide nutritious tree-based fodder [65] that can help to reduce grazing pressure on forests.

Agroforestry can be practiced at the household level and extended to a larger area [73]. Accordingly, as most of Tajikistan is mountainous, the slopes could be planted with contour rows of trees such as *Ailanthus altissima* and *Fraxinus pennsivanica* while the alleys between these trees could be planted with barley or lucerne, which improves soil fertility and protects against erosion [5,7]. The trees' wide root system protect from water erosion and decreases runoff [16,80]. Agroforestry

can mitigate non-point source pollution by creating multipurpose vegetative buffer strips that result in improved infiltration, sediment deposition and nutrient uptake [81]. Windbreaks, buffer strips and other tree-based practices ameliorate the spread and impact of dust from the Aralkum desert, particularly for farmers that are located in northwest Uzbekistan and south Kazakhstan. Vegetative buffers filter air borne particulates harmful to human health and agricultural production.

Agroforestry also has potential for supporting biodiversity conservation, particularly agricultural biodiversity through in-situ conservation of important genetic resources, such as fruits and nut bearing trees. Encouraging the economic cultivation of local and endemic cultivars provides viable in-situ conservation options for conserving genetic diversity.

Furthermore, fast growing poplar trees on farms may mitigate negative effects of droughts by absorbing groundwater with their deep roots. Estimated carbon sequestration potential of agroforestry ranges from under 100 Mt CO_2 per year by 2030 [82] to over 2000 Mt CO_2 per year over a 30-year period [83]. Afforestation using *Echinacea angustifolia* L. and *Populus euphratica* Oliv. can store 17 and 23 tCO_2 ha^{-1}, respectively, over a five-year period [6]. In addition, Djanibekov et al. [18] showed that in northwest Uzbekistan, fuelwood from agroforestry can substitute for domestic energy sources and reduce the CO_2 emissions of rural households.

4.2. Constraints of Agroforestry

In spite of the many advantages of agroforestry, it has not been widely adopted. Although countries in the region differ in policies and agro-ecological conditions, they have similar issues impeding adoption of agroforestry (Table 4). For example, research on agroforestry in the CAC is rarely found in international literature because of the Soviet iron curtain [5], and it is not well disseminated within CAC. The break-up of the Soviet Union led to the collapse of the agricultural extension services, and a decline in communication between research institutions left rural communities lacking information and support of agricultural production. In Tajikistan farmers do not practice windbreaks in pastures or orchards due to a common belief that they will shade crops and waste valuable space [5]. In addition, farmers lack knowledge about the diversity of crops they can grow, how to properly irrigate, when to seed and harvest, and the specialized skills for fruit growing and tree grafting [7,84]. In addition, farmers are not familiar with the range of ecosystem services provided by agroforestry and thus have a low perceived value of this land use [85]. Messerli [11] identified a major challenge impeding agroforestry adoption in Kyrgyzstan as the perception by farmers that it would lead to the loss of valuable arable land and deprive the farmers of other subsistence agricultural opportunities.

Table 4. Constraints of agroforestry in Central Asian countries.

Constraints	Kazakhstan	Kyrgyzstan	Tajikistan	Turkmenistan	Uzbekistan
Perception and knowledge					
Lack of knowledge in local scientific institutions and among farmers on various ecosystem services and management practices [5,7,85]	X	X	X	X	X
Farmers fear losing the land if not fulfilling the target level of the state procurement crops [36,85]				X	X
Policy					
Weak legal definition of agroforestry [7,17]	X	X	X	X	X
Preferential support for the strategically important crops [7,12]	X	X	X	X	X
Policy restrictions to cultivate state procurement crops [1,33]				X	X
Land tenure insecurity [1,86]				X	X
Institutions and infrastructure					
Markets and processing industry is developed for annual crops [87,88]	X	X	X	X	X
Agrarian institutions and infrastructure are shaped for achieving the target output for the state procurement crops [1,31,36]				X	X

National legislations of the CAC do not clearly define agroforestry. Agroforestry was not included in the CAC government agenda during the Soviet Union [17], and since government policies have developed without consideration for agroforestry. Although definitions and efforts are mentioned for adopting agroforestry in the Forest Code of each CAC (e.g., see Article 65 of Forest Code of Tajikistan (e.g., see [89,90])), agroforestry is not viewed as important as monoculture crops. In Kazakhstan in 2009, financial support was introduced for fruit plantations, but only for varieties recognized in the National Register of Breeding Achievements. Under the program, farmers had to plant a minimum of 5 ha, use drip irrigation, install fruit frames, and assess technical sustainable production [7]. Such support excludes small-scale farms that use ancestral varieties with low-input and traditional practices, as well as orchards and vineyards inherited from *kolkhozes* and *sovkhozes* [7].

The lack of importance of agroforestry in the CAC can be explained by the fact that agricultural policies were shaped by Soviet Union strategies. Command-and-control institutional structure and absence of land tenure locked farmers into cotton and wheat production. Farmers in Turkmenistan and Uzbekistan are reluctant to invest in sustainable practices [91] as the state may withdraw land from farmers that fail to deliver the state target crop production. The lack of adoption of agroforestry in Kyrgyzstan where farmers own land [1], illustrates that land tenure alone does not lead to the adoption of this practice. Current infrastructure (e.g., irrigation networks, agricultural machinery, processing plants) was designed to sustain certain agricultural production and may be unsuitable for agroforestry. Providing farmers agriculture subsidies, production inputs, and low interest credit for strategically important crops biases agricultural production to these crops. For example, Rowe [12] reported that the lack of inputs for fruit plantations in Tajikistan was a major reason for little area devoted to this land use. The deficit of water is the main reason for poor diversification of fruit tree production in Turkmenistan [7]. In Kazakhstan, subsidies are provided to large-scale wheat producers and not to smallholders for agroforestry [7].

Processing adds value to strategically important agricultural crops along the market chain [87]. Markets for tree products are less efficient and less developed than for annual crop products, and thus demand for tree products is less [88]. Abandoning previous policies, processing and infrastructure and investing in new agroforestry oriented policies, processing and infrastructure may lead to substantial changes in the economic sector. Such changes could result in high costs for the state, which may not be desirable under the current transition of economic developments.

Limited provision of machinery to manage agroforestry, and the lack of processing equipment and access to credit complicates adoption of agroforestry [7]. Resource conservation technologies, which were partly implemented by the state during the Soviet Union are obsolete, require higher costs and are beyond farmers' capabilities [92]. At the same time, agroforestry practices usually require higher investments during initial years and may take years before farmers break-even from such investments. Most farmers are inclined to invest their time and resources for short-term returns because of insecure land tenure and the inherited perception of the lack of benefits of agroforestry. The transitional nature of policies with frequent changes creates uncertainty for farmers. As a result, they refrain from long-term investments and continue known practices of growing annual crops.

4.3. Recommendations to Enhance Agroforestry Adoption

The adoption of agroforestry will be slow or nonexistent without government support and progressive policy reforms [8]. There is a need to influence peoples' understanding of agroforestry and its advantages through national legislation. Such policies need to be accompanied by more secure land tenure that would allow farmers to make more flexible decisions and more investments into a new and long-term land uses [77]. Flexibility in allowing farmers to decide what type of crop and where to cultivate can improve the potential for adoption of agroforestry. Because of the importance of cotton and wheat production in the CAC, it may be more effective to retain current crop production practices and instead identify suitable areas for diversification with agroforestry. For example, although the CAC differ in agro-ecological conditions, pasture degradation is common

across the region. Silvopasture in sloping areas of Kyrgyzstan and Tajikistan may be more suitable than annual crop production. In Turkmenistan and Uzbekistan agroforestry may be a viable option for degraded croplands where diversified crop production would be better. Djanibekov et al. [18] showed that giving farmers flexibility in land use can lead to afforestation on degraded croplands and a shift of cotton cultivation to more productive lands. Furthermore, state subsidies can support and encourage agroforestry adoption. For example, subsidies by Kazakhstan's government for no-till practices have accelerated its adoption [93], and similar approaches could be used to encourage agroforestry adoption.

Along with development of favorable policies, establishment of institutional and physical infrastructure and increasing the flow of production inputs for agroforestry could provide incentives to adopt agroforestry [4]. Storage and processing facilities and better markets for agroforestry products would boost the economic value of this land use practice. In addition, internalizing the value of ecosystem services (e.g., carbon sequestration, biodiversity increase, and land rehabilitation) of agroforestry and providing farmers the markets to sell such services can reduce the time until farmers can break-even from investments needed to adopt agroforestry (e.g., see [94]).

Sharing knowledge from research institutions with farmers about agroforestry practices, ecosystem services and management strategies is essential for wide-spread adoption [7]. Knowledge can be disseminated through capacity building activities of NGOs, farmers' associations, village centers and local state administrations [95]. For example, the Kyrgyz Association of Forest and Land Users works directly with farmers who use forest resources and work on arable lands. Other potential institutions include horticultural associations formed by farmers in Kazakhstan and Tajikistan, and the Republican Farmers' Association in Uzbekistan. These institutions could bridge gaps between farmers and national governments, advocate for agroforestry policies, develop and disseminate technical materials, and help to market products [7,95].

5. Conclusions

In this study, we analyzed constraints and options to adopt agroforestry practice in CAC. For this analysis, we used the coevolutionary socio-ecological systems framework. By using this framework, we show how the previous Soviet Union policies affect the socio-ecological systems during the transition process and result in socio-ecological challenges. Agroforestry is being practiced in the CAC and there are opportunities to address socio-ecological issues, however, legacies of the Soviet Union constrain the extent of adoption of such land use. Current agricultural policies have not completely transitioned to market economies as the countries inherited preferential support for the state strategic crops. Existing agricultural production systems are locked-in and hinder adoption of alternative land uses. Moving towards agroforestry may be expensive during the transition to a market economy, as state priority crops contribute substantially to the national economies. Several incentives and systematic changes are essential in fully realizing the potential of agroforestry in the CAC. Recognition of agroforestry in the legislation is an initial action to increase its adoption. Promotion of agroforestry must be geographically differentiated as some areas are less suitable. Selecting areas less suitable for monoculture crop cultivation and integrating with trees (i.e., agroforestry) might mitigate competition between the state strategic crops and diversified land use systems, and avoid high economic costs of changing agricultural production. Internalizing potential benefits, creating markets, processing industries, infrastructure and institutions are needed to drive adoption of agroforestry.

Author Contributions: Utkur Djanibekov, Grace B. Villamor, Klara Dzhakypbekova, James Chamberlain and Jianchu Xu conceived and designed the study; Utkur Djanibekov and Grace B. Villamor developed the conceptual framework; Utkur Djanibekov and Klara Dzhakypbekova collected literature; Utkur Djanibekov analyzed collected literature and integrated into the conceptual framework; and all authors wrote the paper.

References

1.　Lerman, Z. Land reform, farm structure, and agricultural performance in CIS countries. *China Econ. Rev.* **2009**, *20*, 316–326. [CrossRef]

2.　Mirzabaev, A.; Goedecke, J.; Dubovyk, O.; Djanibekov, U.; Le, Q.B.; Aw-Hassan, A. Economics of land degradation in Central Asia. In *Economics of Land Degradation and Improvement—A Global Assessment for Sustainable Development*; Nkonya, E., Mirzabaev, A., von Braun, J., Eds.; Springer: Cham, Switzerland, 2016; pp. 261–290.

3.　Zomer, R.J.; Neufeldt, H.; Xu, J.; Ahrends, A.; Bossio, D.; Trabucco, A.; van Noordwijk, M.; Wang, M. Global tree cover and biomass carbon on agricultural land: The contribution of agroforestry to global and national carbon budgets. *Sci. Rep.* **2016**, *6*, 1–12. [CrossRef] [PubMed]

4.　Saiko, T.A.; Zonn, I.S. Irrigation expansion and dynamics of desertification in the Circum-Aral region of Central Asia. *Appl. Geogr.* **2000**, *20*, 349–367. [CrossRef]

5.　Romer, B. *Agroforestry in Tajikistan: Overview of Current Situation, the Potential, and the Influencing Factors of Agroforestry Systems*; CAMP—Central Asian Montain Partnership: Dushanbe, Tajikistan, 2005; pp. 1–37.

6.　Khamzina, A.; Lamers, J.P.A.; Vlek, P.L.G. Conversion of degraded cropland to tree plantations for ecosystem and livelihood benefits. In *Cotton, Water, Salts and Soums—Economic and Ecological Restructuring in Khorezm, Uzbekistan*; Martius, C., Rudenko, I., Lamers, J.P.A., Vlek, P.L.G., Eds.; Springer: New York, NY, USA, 2012; pp. 235–248.

7.　Lapeña, I.; Turdieva, M.; López Noriega, I.; Ayad, W.G. *Conservation of Fruit Tree Diversity in Central Asia: Policy Options and Challenges*; Bioversity International: Rome, Italy, 2014; pp. 1–240.

8.　Gupta, R.; Kienzler, K.; Mirzabaev, A.; Martius, C.; de Pauw, E.; Shideed, K.; Oweis, T.; Thomas, R.; Qadir, M.; Sayre, K.; et al. *Research Prospectus: A Vision for Sustainable Land Management Research in Central Asia*; Sustainable Agriculture in Central Asia and the Caucasus Series No. 1; CGIAR-PFU: Tashkent, Uzbekistan, 2009; pp. 1–84.

9.　Kienzler, K.; Lamers, J.P.A.; McDonald, A.; Mirzabaev, A.; Ibragimov, N.; Egamberdiev, O.; Ruzibaev, E.; Akramkhanov, A. Conservation agriculture in Central Asia—What do we know and where do we go from here? *Field Crop. Res.* **2012**, *132*, 95–105. [CrossRef]

10.　Bekchanov, M.; Lamers, J.P.A.; Martius, C. Pros and cons of adopting water-wise approaches in the lower reaches of the Amu Darya: A socio-economic view. *Water* **2010**, *2*, 200–216. [CrossRef]

11.　Messerli, S. Agroforestry—A way forward to the sustainable management of the Walnut Fruit Forests in Kyrgyzstan. *Schweiz. Z. Forstwes.* **2002**, *153*, 392–396. [CrossRef]

12.　Rowe, W.C. "Kitchen Gardens" in Tajikistan: The economic and cultural importance of small-scale private property in a Post-Soviet society. *Hum. Ecol.* **2009**, *37*, 691–703. [CrossRef]

13.　Dzhakypbekova, K. Potential of Agroforestry Systems in Kyrgyzstan. Master's Thesis, Kyrgyz National Agrarian University, Bishkek, Kyrgyzstan, 2014.

14.　Popov, M.G.; Klabukov, A.G.; Malkovsky, M.P. *Wild Fruit Brushwoods in Alma-Ata Vicinity of Zailiy Alatau (Tien-Shan)*; Kazakhstan Academy of Science: Alma-Ata, Kazakhstan, 1935. (In Russian)

15.　Prutensky, D.I. *Practice of Cultivating Wild Fruit Trees in Walnut-Fruit Forests in Kyrgyzstan*; Kyrgyz Forest Research Station: Frunze, Kyrgyzstan, 1962. (In Russian)

16.　Muhamedshin, K.D. *Juniper Forests of Tien-Shan and Their Role in the Forestry*; Kyrgyz Forest Research Station: Frunze, Kyrgyzstan, 1977. (In Russian)

17.　Juldashev, U.; Messerli, S. *Trees and Agriculture in the Walnut Fruit Forests of Southern Kyrgyzstan: Current Situation and the Potential for Agroforestry*; Programme Document of Intercooperation; LES-IC: Bishkek, Kyrgyzstan, 2000; pp. 1–77.

18.　Djanibekov, U.; Djanibekov, N.; Khamzina, A.; Bhaduri, A.; Lamers, J.P.A.; Berg, E. Impacts of innovative forestry land use on rural livelihood in a bimodal agricultural system in irrigated drylands. *Land Use Policy* **2013**, *35*, 95–106. [CrossRef]

19.　Norgaard, R.B. Sustainable development: A co-evolutionary view. *Futures* **1988**, *20*, 606–620. [CrossRef]

20.　Norgaard, R.B. Bubbles in a back eddy: A commentary on "the origin, diagnostic attributes and practical application of coevolutionary theory". *Ecol. Econ.* **2005**, *54*, 362–365. [CrossRef]

21.　Kallis, G.; Norgaard, R.B. Coevolutionary ecological economics. *Ecol. Econ.* **2010**, *69*, 690–699. [CrossRef]

22. McGlade, J.; Murray, R.; Baldwin, J.; Ridgway, K.; Winder, B. Industrial resilience and decline: A co-evolutionary framework. In *Complexity and Co-Evolution: Continuity and Change in Socio-Economic Systems*; Garnsey, E., McGlade, J., Eds.; Edward Elgar Publishing Ltd.: Cheltenham, UK, 2006; pp. 147–176.

23. Van Assche, K.; Beunen, R.; Duineveld, M. *Evolutionary Governance Theory: An Introduction*; Springer: Cham, Switzerland, 2014; p. 95.

24. Nelson, R.R.; Sampat, B.N. Making sense of institutions as a factor shaping economic performance. *J. Econ. Behav. Organ.* **2001**, *44*, 31–54. [CrossRef]

25. Van den Bergh, J.C.; Faber, A.; Idenburg, A.M.; Oosterhuis, F.H. Survival of the greenest: Evolutionary economics and policies for energy innovation. *Environ. Sci.* **2006**, *3*, 57–71. [CrossRef]

26. Arthur, W.B. Competing technologies, increasing returns, and lock-in by historical events. *Econ. J.* **1989**, *99*, 116–131. [CrossRef]

27. Suleimenov, M. Trends in the agriculture of Central Asia and implications for rangelands and croplands. In *Novel Measurements and Assessment Tools for Monitoring and Management of Land and Water Resources in Agricultural Landscapes of Central Asia*; Mueller, L., Saparov, A., Lischeid, G., Eds.; Springer Science & Business Media: Berlin, Germany, 2014; pp. 91–105.

28. The World Bank. *World Development Indicators 2014*; The World Bank: Washington, DC, USA, 2014. Available online: http://data.worldbank.org/data-catalog/world-development-indicators (accessed on 30 April 2015).

29. Rammel, C.; Stagl, S.; Wilfing, H. Managing complex adaptive systems—A co-evolutionary perspective on natural resource management. *Ecol. Econ.* **2007**, *63*, 9–21. [CrossRef]

30. Gual, M.A.; Norgaard, R.B. Bridging ecological and social systems coevolution: A review and proposal. *Ecol. Econ.* **2010**, *69*, 707–717. [CrossRef]

31. Spoor, M. Transition to market economies in former Soviet Central Asia: Dependency, cotton, and water. *Eur. J. Dev. Res.* **1993**, *5*, 142–158. [CrossRef]

32. Glantz, M. *Creeping Environmental Problems and Sustainable Development in the Aral Sea Basin*; Cambridge University Press: Cambridge, UK, 1999; pp. 1–308.

33. Pomfret, R. Constructing market-based economies in central Asia: A natural experiment? *Eur. J. Comp. Econ.* **2010**, *7*, 449–467.

34. Lioubimtseva, E.; Henebry, G.M. Climate and environmental change in arid Central Asia: Impacts, vulnerability, and adaptations. *J. Arid Environ.* **2009**, *73*, 963–977. [CrossRef]

35. Field, N. The Amu Darya: A study in resource geography. *Geogr. Rev.* **1954**, *44*, 528–542. [CrossRef]

36. Djanibekov, N.; Rudenko, I.; Lamers, J.P.A.; Bobojonov, I. Pros and cons of cotton production in Uzbekistan. In *Food Policy for Developing Countries: Food Production and Supply Policies*; Pinstrup-Andersen, P., Cheng, F., Eds.; Cornell University Press: Ithaca, NY, USA, 2010; pp. 1–13.

37. Kazbekov, J.; Abdullaev, I.; Anarbekov, O.; Jumaboev, K. *Improved Water Management through Effective Water Users Associations in Central Asia: Case of Kyrgyzstan*; International Water Management Institute: Pelawatte, Sri Lanka, 2007; pp. 1–26.

38. MacDonald, S. *Economic Policy and Cotton in Uzbekistan*; Economic Research Service of USDA: Washington, DC, USA, 2012; pp. 1–26.

39. Csaki, C.; Kray, H.; Zorya, S. *The Agrarian Economies of Central-Eastern Europe and the Commonwealth of Independent States an Update on Status and Progress in 2005*; ECSSD Environmentally and Socially Sustainable Development Working Paper No. 46; The World Bank: Washington, DC, USA, 2006; pp. 1–148.

40. State Agency of Environment Protection and Forestry. *The National Report on the State of the Environment of the Kyrgyz Republic for 2006–2011*; UNDP: Bishkek, Kyrgyzstan, 2012; pp. 1–119. Available online: http://www.kg.undp.org/content/kyrgyzstan/en/home/library/environment_energy/the-national-report-on-the-state-of-the-environment-of-the-kyrgy.html (accessed on 15 December 2014).

41. Dukhovny, V.A.; Ziganshina, D. Ways to improve water governance. *Irrig. Drain.* **2011**, *60*, 569–578. [CrossRef]

42. Hansen, M.C.; Potapov, P.V.; Moore, R.; Hancher, M.; Turubanova, S.A.; Tyukavina, A.; Thau, D.; Stehman, S.V.; Goetz, S.J.; Loveland, T.R.; et al. High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science* **2013**, *342*, 850–853. [CrossRef] [PubMed]

43. Nurgaziev, R.Z.; Ajibekov, A.S.; Mansurova, A.M. Sustainable food system—A tool for food security. In Proceedings of the World Food Day Conference in Kyrgyz National Agrarian University, Bishkek, Kyrgyzstan, 17 October 2013.

44. Eshchanov, B.R.; Stultjes, M.G.P.; Salaev, S.K.; Eshchanov, R.A. Rogun Dam—Path to energy independence or security threat? *Sustainability* **2011**, *3*, 1573–1592. [CrossRef]

45. El Beltagy, A. ICARDA'S experience in rehabilitation of degraded drylands in Central and Western Asia and Northern Africa. In *Rehabilitation of Degraded Drylands and Biosphere Reserves: Proceedings of International Workshop on Combating Desertification*; Lee, K., Schaaf, T., Eds.; UNESCO-MAB: Paris, France, 2002; pp. 1–4.

46. Wolfgramm, B.; Shigaeva, J.; Nekushoeva, G.; Bonfoh, B.; Breu, T.; Liniger, H.; Maselli, D. Kyrgyz and Tajik land use in transition: Challenges, responses and opportunities. In *Global Change and Sustainable Development—Synthesis of Regional Experiences from Research Partnerships, Volume 5, Perspectives of the Swiss National Centre of Competence in Research (NCCR) North-South*; Hurni, H., Wiesmann, U., Eds.; University of Bern/Geographica Bernensia: Bern, Switzerland, 2010; pp. 24–254.

47. Mamytov, A.M. *Soils in mountains of Central Asia and Southern Kazakhstan*; Ilim: Bishkek, Kyrgyzstan, 1987. (In Russian)

48. Akramkhanov, A.; Kuziev, R.; Sommer, R.; Martius, C.; Forkutsa, O.; Massucati, L. Soils and soil ecology in Khorezm. In *Cotton, Water, Salts and Soums: Economic and Ecological Restructuring in Khorezm, Uzbekistan*; Martius, C., Rudenko, I., Lamers, J.P.A., Vlek, P.L.G., Eds.; Springer: New York, NY, USA, 2012; pp. 37–58.

49. Dubovyk, O.; Menz, G.; Conrad, C.; Lamers, J.P.A.; Lee, A.; Khamzina, A. Spatial targeting of land rehabilitation: A relational analysis of cropland productivity decline in arid Uzbekistan. *Erdkunde* **2013**, *67*, 167–181. [CrossRef]

50. Food and Agriculture Organization of the United Nations. *People, Forests and Trees of West and Central Asia: Outlook for 2020*; FAO Forestry Paper No. 152; FAO: Rome, Italy, 2007. Available online: http://www.fao.org/docrep/009/a0981e/a0981e00.htm (accessed on 1 September 2014).

51. Surappaeva, V.; Isakov, A. Country report of Kyrgyzstan on forestry. In Proceedings of the Central Asia Workshop on Agroforestry: Trees, Landscapes and Livelihoods, Kunming, China, 19–21 January 2015.

52. Eastwood, A.; Lazkov, G.; Newton, A.C. *The Red List of Trees of Central Asia*; Fauna & Flora International: Cambridge, UK, 2009; pp. 1–27.

53. Kleine, M.; Colak, A.; Kirca, S.; Sagheb-Talebi, K.; Orozumbekov, A.; Lee, D. *Rehabilitating Degraded Forest Landscapes in West and Central Asia*; IUFR: Vienna, Austria, 2009; Volume 20, pp. 5–26.

54. Conservation International. Biodiversity Hotspots: Mountains of Central Asia. Available online: http://www.biodiversity.hotspots.org/xp/hotspots/central_asia/ (accessed on 3 September 2014).

55. Ministry of Environmental Protection of Kyrgyzstan. *Kyrgyz Republic Biodiversity Strategy and Action Plan*; Ministry of Environmental Protection of Kyrgyzstan: Bishkek, Kyrgyzstan, 1998.

56. Micklin, P. The Aral sea disaster. *Annu. Rev. Earth Planet Sci.* **2007**, *35*, 47–72. [CrossRef]

57. The Economics of Ecosystems and Biodiversity. *The Economics of Ecosystems and Biodiversity (TEEB) in Business and Enterprise*; Bishop, J., Ed.; Earthscan: New York, NY, USA, 2012; pp. 1–217.

58. Aleksandrova, M.; Lamers, J.P.A.; Martius, C.; Tischbein, B. Rural vulnerability to environmental change in the irrigated lowlands of Central Asia and options for policy-makers: A review. *Environ. Sci. Policy* **2014**, *41*, 77–88. [CrossRef]

59. Zomer, R.J.; Wang, M.; Xu, J. *Projected Climate Change and Impact on Bioclimatic Conditions in Central and South-Central Asia*; ICRAF Working Paper 197; World Agroforestry Centre East and Central Asia: Kunming, China, 2015; pp. 1–50.

60. Sommer, R.; Glazirina, M.; Yuldashev, T.; Otarov, A.; Ibraeva, M.; Martynova, L.; Bekenov, M.; Kholov, B.; Ibragimov, N.; Kobilov, R.; et al. Impact of climate change on wheat productivity in Central Asia. *Agric. Ecosyst. Environ.* **2013**, *178*, 78–99. [CrossRef]

61. Fischer, G.; Tubiello, F.N.; van Velthuizen, H.; Wiberg, D.A. Climate change impacts on irrigation water requirements: Effects of mitigation, 1990–2080. *Technol. Forecast. Soc.* **2007**, *74*, 1083–1107. [CrossRef]

62. Hagg, W.; Hoelzle, M.; Wagner, S.; Mayr, E.; Klose, Z. Glacier and runoff changes in the Rukhk catchment, upper Amu-Darya basin until 2050. *Glob. Planet. Chang.* **2013**, *110*, 62–73. [CrossRef]

63. Fimkin, V.P.; Makhno, G.F.; Lysenina, A.D. *Growing Coniferous, Hardwood and Fruit Species on Salinized Lands*; Central Asian Forestry Research Institute: Tashkent, Uzbekistan, 1963; pp. 1–46. (In Russian)

64. State Committee of Forestry Council of Ministries of USSR. *Norms for Silvicultural, Ameliorative and Life Fences Conducted by Hand in Forests of Uzbekistan*; USSR: Moscow, Russia, 1971; pp. 1–320. (In Russian)

65. Mattis, G.Y.; Pavlovsky, E.S.; Kalashnikov, A.F. *Handbook of Agroforester*; Forestry Production: Moscow, Russia, 1984. (In Russian)

66. Kocherga, F.K. *Types of Forest Plantations for Uzbekistan*; State Publishing of Uzbek SSR: Tashkent, Uzbekistan, 1954; pp. 1–185. (In Russian)

67. Jeltikova, T.A. *Forest Nurseries in Central Asia*; State Publishing House of Uzbek SSR: Tashkent, Uzbekistan, 1964. (In Russian)

68. Rovsky, V.M. *Forest species in Uzbekistan*; State publishing house of Uzbek SSR: Tashkent, Uzbekistan, 1963. (In Russian)

69. Anuchin, N.P. *Theory and Practice of Organizing Forestry*; Forestry Production: Moscow, Russia, 1977. (In Russian)

70. Anuchin, N.P. *Problems of Forestry*; Forestry Production: Moscow, Russia, 1986. (In Russian)

71. State Committee of Forestry Council of Ministries of USSR. *Cost-Benefit and Technological Recommendations for Establishing Forest and Commercial Plantations in Karakalpak ASSR*; State Committee of Forestry Council of Ministries of USSR: Tashkent, Uzbekistan, 1988; pp. 1–62. (In Russian)

72. Gusev, P.P. *Forest-Gardens (Issues of Cultivating Wild Fruit Trees)*; State Publishing House of Kolkhoz and Sovkhoz Literature "Selhozgiz": Moscow, Russia, 1938. (In Russian)

73. Mubalieva, S.M.; Aknazarov, O.A. *Technology of Planting Mulberry Gardens on Mountain Slopes of Western Pamir (Recommendation)*; Bioversity International/UNEP-GEF: Khorog, Tajikistan, 2010.

74. Bulichev, A.S. *Experience of Alley Cropping under Different Row Spaces*; Ilim: Frunze, Russia, 1977; pp. 5–31. (In Russian)

75. Djumaeva, D.M.; Djanibekov, N.; Vlek, P.L.G.; Martius, C.; Lamers, J.P.A. Options for optimizing dairy feed rations with foliage of trees grown in the irrigated drylands of Central Asia. *Res. J. Agric. Biol. Sci.* **2009**, *5*, 698–708.

76. Tupitsa, A.; Lamers, J.; Worbes, M.; Martius, C. The functional assessment of tree windbreaks in Khorezm, Uzbekistan, Aral Sea Basin. In Proceedings of the Tropentag Conference, Bonn, Germany, 11–13 October 2006.

77. Kan, E.; Lamers, J.P.A.; Eshchanov, R.; Khamzina, A. Small-scale farmers' perceptions and knowledge of tree intercropping systems in the Khorezm region of Uzbekistan. *For. Trees Livelihood* **2008**, *18*, 355–372. [CrossRef]

78. Rehnus, M.; Mamadzhanov, D.; Venglovsky, B.I.; Sorg, J.-P. The importance of agroforestry hay and walnut production in the walnut-fruit forests of southern Kyrgyzstan. *Agrofor. Syst.* **2013**, *87*, 1–12. [CrossRef]

79. Consultative Group for International Agricultural Research. *CGIAR Program for Sustainable Agriculture in Central Asia and the Caucasus*; Annual Report: 2008–2009; CGIAR: Tashkent, Uzbekistan, 2009; pp. 1–41.

80. Dragavtsev, A.P. *Planting of Fruit Trees in Mountainous Conditions of Zailiy Ala-Tau*; Library of Kyrgyz National Academy of Science: Bishkek, Kyrgyzstan, 1947. (In Russian)

81. Cassman, K.G. Ecological intensification of cereal production systems: Yield potential, soil quality, and precision agriculture. *Proc. Natl. Acad. Sci. USA* **1999**, *96*, 5952–5959. [CrossRef] [PubMed]

82. Smith, P.; Martino, D.; Cai, Z.; Gwary, D.; Janzen, H.; Kumar, P.; McCarl, B.; Ogle, S.; O'Mara, F.; Rice, C.; et al. Agriculture. In *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*; Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., Meyer, L.A., Eds.; Cambridge University Press: Cambridge, UK, 2007; pp. 497–540.

83. Verchot, L.V. *Opportunities for Climate Change Mitigation in Agriculture and Investment Requirements to Take Advantage of These Opportunities. A Report to the UNFCCC Secretariat Financial and Technical Support Programme*; World Agroforestry Centre: Laguna, Philippines, 2007; pp. 1–69.

84. Gulmahmadov, D. *Breaking Down Barriers to Land Reform*; OSCE Magazine: Vienna, Austria, 2004; pp. 8–10.

85. Djanibekov, U. A coevolutionary perspective on the adoption of sustainable land use practices: The case of the Amu Darya River lowlands, Uzbekistan. In *Applying Evolutionary Governance Theory*; Beunen, R., van Assche, K., Duineveld, M., Eds.; Springer: Berlin/Heidelberg, Germany, 2015; pp. 233–245.

86. Djanibekov, N.; van Assche, K.; Bobojonov, I.; Lamers, J.P.A. Farm restructuring and land consolidation in Uzbekistan: New farms with old Barriers. *Eur. Asia Stud.* **2012**, *64*, 1101–1126. [CrossRef]

87. Rudenko, I.; Bekchanov, M.; Djanibekov, U.; Lamers, J.P.A. The added value of a water footprint approach: Micro-and macroeconomic analysis of cotton production, processing and export in water bound Uzbekistan. *Glob. Planet. Chang.* **2013**, *110*, 143–151. [CrossRef]

88. Buttoud, G.; Place, F.; Gauthier, M. *Advancing Agroforestry on the Policy Agenda: A Guide for Decision-Makers*; FAO: Rome, Italy, 2013; pp. 1–37.

89. The Forest Code of the Republic of Tajikstain. Available online: http://www.wildlife-tajikistan.org/downloads/viewcategory/6 (accessed on 12 October 2016).

90. Mislimshoeva, B.; Herbst, P.; Koellner, T. Current pathways towards good forest governance for ecosystem services in the former Soviet republic Tajikistan. *For. Policy Econ.* **2016**, *63*, 11–19. [CrossRef]

91. Sommer, R.; De Pauw, E. Organic carbon in soils of Central Asia—Status quo and potentials for sequestration. *Plant Soil* **2010**, *338*, 273–288. [CrossRef]

92. Asanaliev, A.; Sydykbekov, T. *Water and Soil Conservation Technologies*; CAMP: Bishkek, Kyrgyzstan, 2004.

93. Kazakhstan Farmers Union. Stop the Tractor! I Till No More! Astana, Kazakhstan. 2011. Available online: http://sfk.kz/ru/homepage/?id=9&kid=10 (accessed on 10 December 2012). (In Russian)

94. Engel, S.; Pagiola, S.; Wunder, S. Designing payments for environmental services in theory and practice: An overview of the issues. *Ecol. Econ.* **2008**, *65*, 663–674. [CrossRef]

95. Undeland, A. *The Development Potential of Forests in the Kyrgyz Republic*; Program on Forests (PROFOR): Washington, DC, USA, 2012; pp. 319–364.