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Water Efficient Alternative Crops for Sustainable Agriculture along the Tarim Basin: A Comparison of the Economic Potentials of *Apocynum pictum*, Chinese Red Date and Cotton in Xinjiang, China

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Abstract: This study explores a paradigm of sustainable land use in the oases along the Tarim River of northwest China, where a fragile, semi-arid riparian ecosystem is being damaged by excessive land and water use for agriculture, especially for the growing of cotton. The reliance of agriculture on water-demanding cash crops in this region poses a grave threat to survival of the natural Tugai vegetation in the area and to the long-term sustainability of the region. We explored the hypothesis that the species *Apocynum pictum* (*A. pictum*), known as Lop-Kendir by locals, and the Chinese red date (*Zyzyphus jujube*) may act as sustainable crop substitutes for the region, thereby replacing the widely distributed cash crop of cotton that has high water demands. Therefore, we investigated current utilization and cost-revenue structure of these two alternative plants and compared the results to cotton. Three natural resource management types of *A. pictum* were both identified in the wild and cultivation, with cost-revenue analysis carried out for each. The results show that all three types of institutional arrangements of natural resources, which are namely open access, ranching and farming, were present in our study and at various levels for *A. pictum. A. pictum* farming costs 16,250.25 yuan/ha, generates 49,014.45 yuan/ha of revenue from raw materials and brings a profit of 32,764.2 yuan/ha, which is the highest of all three cash crops compared. The Chinese government encourages Chinese red date plantations with a "Grain for green" campaign in the Tarim Basin with this plant being more profitable than cotton, which could serve to diversify the region's agriculture. We conclude that *A. pictum* offers opportunities for the restoration of vegetation in riparian ecosystems on salinized sites under the arid conditions of the Tarim Basin. Furthermore, it can serve as a viable land-use alternative to cotton for cash crop agriculture, as it may generate a certain income in the form of tea and fibers as well as fodder for livestock.

Keywords: Tarim River; cotton; *A. pictum*; Chinese red date; cost-revenue analysis

1. Introduction

Water is increasingly becoming the most limited resource for future global agricultural development [1,2]. Arid and semi-arid regions of the world are being subjected to severe water shortages due to climate change and over-exploitation of water resources [3]. Similar to other arid regions, the agricultural activities in the Tarim River basin in northwest China are particularly vulnerable to such human-induced changes [2,4]. In the Tarim Basin, which is one of the most arid areas of the world, the irrigated land area has been steadily increasing since the 1950s [5]. Cotton has become the major cash crop from the end of the 1980s. With irrigation consuming more and more water, this has resulted in a decrease in river runoffs into the Tarim River as well as into the other rivers of the Tarim Basin. As such, the floodplain vegetation at the lower reaches of the Tarim River has been degraded and is nearly at the point of being completely destroyed [6]. Furthermore, irrigation often leads to soil salinization, resulting in reduced cotton yields and potential abandonment of entire fields [7]. The cotton production of the past and present has thus resulted in a loss of ecosystem functions (ESF) and ecosystem services (ESS) provided by the riparian ecosystems along the Tarim River, which is detrimental to the long-term sustainability of the region [8]. Along the river, the ecosystem functions are degraded most severely along the lower and partially along the middle reaches due to the over-utilization of water along the upper reaches [9]. Furthermore, soil salinization reduces the amount of fertile soil available for agriculture and for future natural ecosystems [10].

As documented by scientists [11], the aftermath of the Aral Sea desiccation altered its ecosystems irreversibly and brought significant socio-economic upheavals to Central Asia. Therefore, developing sustainable land use alternatives for the Tarim Basin could help avoid an "Aral Sea" type of disaster, thus making this vital to the overall wellbeing of the region. Studies [12] have tried to simulate future crop choices in Uzbekistan under different climate scenarios, which frequently has water conflicts between neighboring countries and different sectors. In the drought-stricken central valley of California, which is also known as the "fruit basket" of the United States, improved irrigation and alternatives crops are being considered [13]. Many arid regions in the world have been dealing with similar problems in agricultural production and the case of the Tarim River can offer additional new perspectives to other arid regions as well.

During the past five decades, the intensive exploitation of water resources, mainly by agricultural water consumption, has resulted in changes in the temporal and spatial distribution of water resources in the Tarim Basin and has caused periods of water shortage along the downstream sections of the Tarim River [4]. Due to its extremely arid climate with an annual precipitation of less than 100 mm, agriculture and natural vegetation as well as settlements and industry directly or indirectly depend on the river water as their major water source. Agriculture with the major crop being cotton depends completely on irrigation [14,15]. In contrast, natural vegetation relies on groundwater [15,16], which is recharged by the rivers of the Tarim Basin [17]. Most plant species of the natural riparian vegetation along the Tarim River are so-called "phreatophytes" as they exploit the groundwater and can thus survive under the extremely arid climate [16]. Settlements and industry extract water from the surface water bodies and groundwater [18].

In Xinjiang, Gansu and Inner Mongolia, there are attempts to curb or even reduce the area under irrigation and shift the land use to perennial plants, such as fruit trees, fodder plants and medicinal plants, which are adapted to the local environmental conditions. In this context, our study investigates the land use alternatives that are more sustainable in terms of water and pesticide use given the current water situation. At the same time, we need to ensure these alternatives are economically interesting when compared to the traditional cash crop of cotton. *Apocynum pictum* (*A. pictum*) is a promising candidate for alternative land use. As a perennial plant, this grows in salinized areas with leaves that can be harvested for medicinal applications and stems that may be used as raw material for fiber production. Additionally, it serves as a honey plant and can be grazed [19], although this requires irrigation. In recent years, the Chinese government has implemented the "Grain for Green" project in Xinjiang similar to the project started in the Loess Plateau in 1999. This encourages the planting of Chinese red date trees, which are considered to be drought resistant and of great economic potential [20].

In this paper, we investigate the current utilization of *A. pictum* and the structure of *A. pictum* (Lop-Kendir) farming as well as its production and sales chain. After this, we carried out a cost-benefit analysis of *A. pictum* farming to assess its competitiveness and the plausibility of its implementation as an alternative. We proposed to study water-efficient alternative crops for sustainable agriculture along the Tarim Basin and suggest that these are viable land-use alternatives to cotton for cash crop agriculture in the context of current and projected climate change scenarios. We specifically address the following research questions:

1. What is the institutional framework for the application of different crop types in this region?
2. What is the cost-revenue structure of *A. pictum*, Chinese red date and cotton and which one is the most cost effective?
3. What is the viability of the three aforementioned crop (*A. pictum*, cotton and Chinese red date) types under consideration of the institutional framework and the results of the economic analysis under global climate change?

2. Materials and Methods

2.1. Study Area

At 1321 km, the Tarim River is the longest inland river in China, which is fed by water from melted glaciers and acts as the main water source for the Tarim Basin in the Xinjiang Uyghur Autonomous Region of China (XUAR) [15,21] (Figure 1). The basin is surrounded by the Tianshan Mountains in the North, the Kunlun Mountains in the South and the Pamir Mountains in the west. This basin comprises the entire southern part of XUAR, covering an area of 1.02 million km^2 and is inhabited by 8.26 million people [15,21]. Tarim River Basin is one of the driest inland basins in the world with an annual precipitation of less than 50 mm and potential evaporation of more than 2000 mm [22].

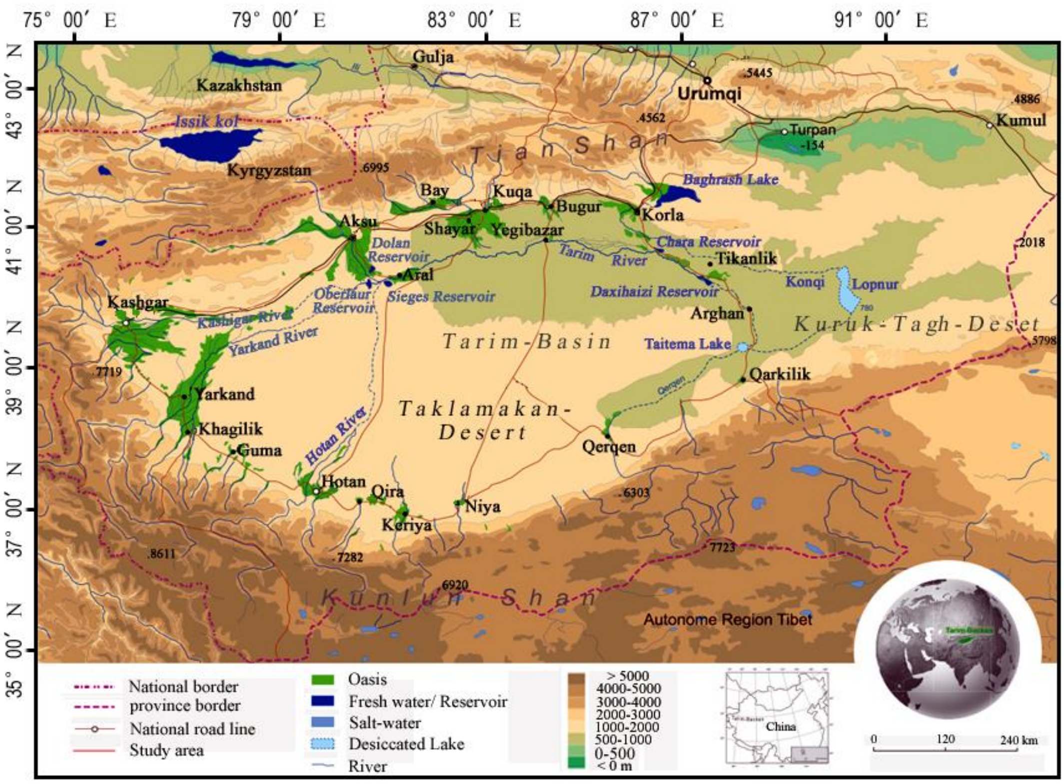

Figure 1. Map of the major oases along the Tarim River.

The headwaters of the rivers within the Tarim Basin are supplied by snowmelt, glacier melt and summer rainfall in the Kunlun, Pamir and Tianshan mountains [15]. Due to global climate change, the glacier areas surrounding the Tarim Basin have decreased, with the changes being especially pronounced in the Western Tianshan and Pamir mountains where the Kaidu and Yarkand rivers originate [23]. Rapid population growth and growth in agricultural production has increased the need for water in the rivers upstream of the Tarim, which has far outpaced the relatively small increases in river runoffs in the headwaters. Thus, this has led to less water in the middle and lower streams of the river [24]. As such, the gains to the headwaters due to increased precipitation and glacier melt have been largely offset by anthropogenic factors, with human influence being the dominant factor with regard to river runoff in this area [25].

The Tarim Basin is also a major base for the production of grain and cotton in China, in addition to being home to large oil and mineral deposits that are now being exploited at an unprecedented pace [26]. However, it is becoming increasingly evident that future development in this area will be limited by the environmental problems induced by the water crises [26]. Feike [27] has split the main drivers behind the agricultural development along the Tarim River into four main categories: demographic, socio-economic, natural and technological.

2.1.1. Cotton Production in Xinjiang and Tarim Basin

Despite its reduced share in the textile fiber market, cotton still remains the major natural fiber used in textiles [28]. Cotton is grown in many drylands of the world with irrigation needed, such as in Central Asia (Uzbekistan, Turkmenistan, and northwest China), Turkey, Texas (USA) and Australia [29]. China is both the major global producer and consumer of cotton. In 2012–2013, China was responsible for 28% of the global cotton production, 35% of the consumption and 50% of global stocked cotton [30].

National cotton production in China during 1990–2012 has fluctuated with a slight increase from 4.5 million tons in 1990 to 6.83 million in 2012 [31]. However, Xinjiang has displayed a steady increase during this period, with the fraction of national cotton produced in Xinjiang jumping from one tenth in 1990 to a half in 2012 with 3.53 million tons produced [31]. Xinjiang's cotton regions are characterized by "drought in the spring, flood in the summer, water shortage in the fall and low water in the winter" [28,32]. At the same time, the total planted cotton area for all of China shrunk from 5.58 million hectares in 1992 to 4.68 million hectares in 2012, while the total planted cotton area for Xinjiang quadrupled in the same period (Figure 2) before stabilizing after 2009. As this region has little rainfall in most years, its cotton production depends completely on irrigation [28,33]. Due to irrigation works and their utilization of both surface water and groundwater, Xinjiang's cotton regions expanded from 435 thousand ha in 1990 to over 1720 thousand ha in 2012. The construction of irrigation channels and the adoption of water-saving irrigation technology have made Xinjiang an important cotton-producing region [28,33], with a per mu yield of cotton that is consistently higher than the national average. In turn, this has made Xinjiang the most attractive region for the expansion of cotton production, even though the water availability still poses a significant constraint [33].

Our study area in the Aksu-Tarim River region, which is considered a major cotton production base in Xinjiang, has experienced a dramatic acceleration in the planted cotton area and production due to central government's western development policy, which made cotton the main cash crop and has led to an increased population. In the Aksu-Tarim River region, the area for cotton production expanded from 99,107 ha in 1989 to 639,880 ha in 2011 (a 6-fold increase). In particular, dramatic acceleration was noted after 2003. Meanwhile, the cotton output also saw a corresponding rise from 78,666 tons in 1989 to 1,283,980 tons in 2011 (Figure 2). The population for the same time periods has also increased steadily from 2,837,371 in 1989 to 4,243,542 in 2012.

China is currently planning to enact direct subsidization in lieu of the national cotton reserve policy in 2014, with Xinjiang becoming the pilot region. The target price is expected to be at around 18,300 RMB per ton [34].

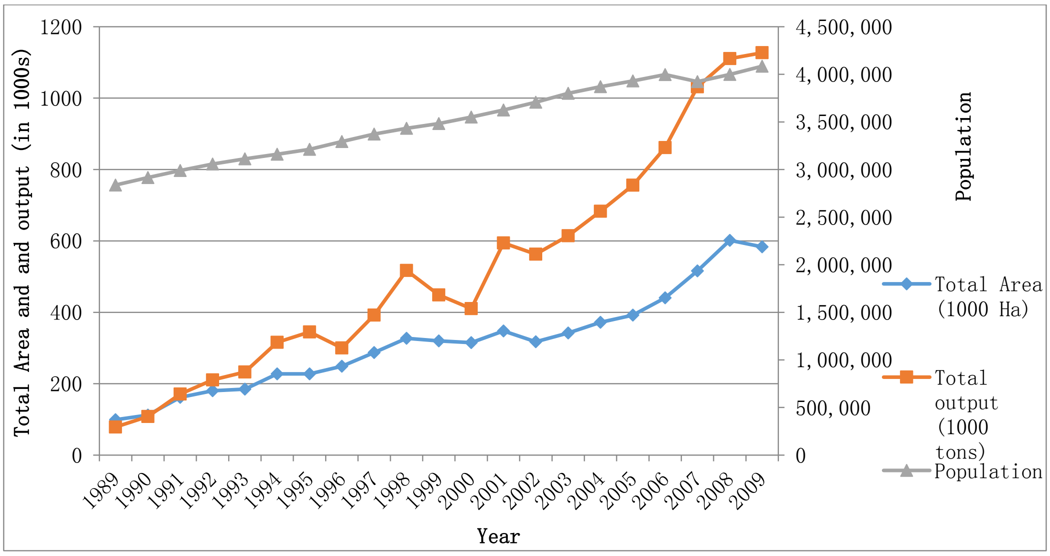

Figure 2. Cotton area and production for the Tarim region during 1980–2011 [31].

2.1.2. Chinese Red Date Cultivation in Tarim Basin

Along the southern rim of the Tarim Basin, the fruit tree of the Chinese red date (*Zyzyphus jujube*) or sometimes called Hongzao in Chinese, has been promoted since the previous decade [35]. Chinese red date is one of the world's major fruit crops, which is cultivated in India, Russia, Middle East, southern Europe and especially China [36]. It has versatile uses as it can also be used as timber wood for furniture, fodder for cattle, while honey and all other parts can be used in medicine [36]. Since 2002, there has been a rapid increase in the Chinese red date plantation area in Xinjiang (Figure 3).

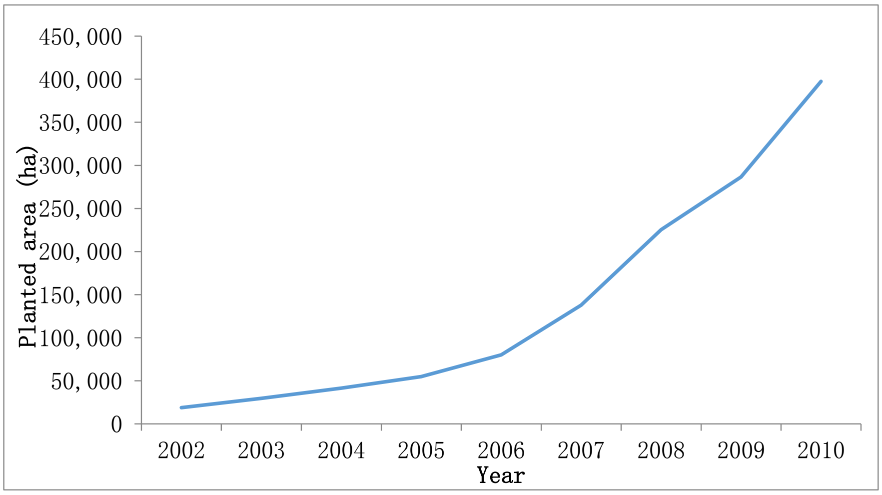

Figure 3. Chinese red date plantation in Xinjiang, 2002 and onwards (Xinjiang statistical year books).

The Chinese red date is usually served as a dry fruit, used in traditional medicine and acts as a nourishing food. Its plantations require dry and hot summers, although this plant can also endure cold winters. As such, date trees are well-adapted to the desert conditions of the Tarim Basin [37]. The fruit yield in the first two or three years is usually very low. Afterwards, the yield increases steadily and reaches its peak when the tree is about 20 years old, after which the yield decreases until the tree dies. Nowadays, the Chinese red date serves as the major cash crop and source of income for the locals in the oases of Qarqan and Qarklik.

2.1.3. *A. pictum* and Artificial Cultivation

Recently, *A. pictum* has attracted attention as a medicinal and fiber crop. *A. pictum* is a perennial herb, which is part of the natural riparian vegetation along the rivers of the Tarim Basin [10]. Due to limited knowledge on the economic use of *A. pictum*, we will focus our research on *A. pictum*.

Within the genus Apocynum, the two species *Apocynum venetum* L. and *Apocynum pictum* Schrenk, are distributed over Central Asia and Northwestern China [38]. Both species are part of the natural riparian vegetation along the rivers flowing through the dry lands of these regions, such as the Amu Darya, Syr Darya, Ili River and Tarim River. *A. venetum* and *A. pictum* are used as medicinal plants and to some extent as fiber plants [39]. In China, the leaves are harvested as raw material to produce anti-hypertonic tea and drugs. The stems contain the best fibers, which are used on a small scale to produce textiles [10]. Therefore, *A. venetum* and *A. pictum* as species of the natural riparian vegetation offer a wide range of opportunities for utilization [39–42].

A. venetum is distributed in semi-arid, semi-humid and humid areas receiving annual precipitation of more than 250 mm. In contrast, *A. pictum* is restricted to areas characterized by arid climates with annual precipitation of less than 250 mm [43]. Within Xinjiang, *A. pictum* is mainly distributed in the Tarim Basin and the southern rim of the Zhungarian Basin, while *A. venetum* is distributed in the less arid northern part of the Zhungarian Basin and the foothills of the Altay Mountains [41,43].

As *A. pictum* adapts better to extremely arid conditions, such as water shortage and soil salinization, compared to *A. venetum* [10], it may be more suitable for revegetating areas along the lower Tarim River with water shortages due to upstream irrigation practices. In addition, *A. pictum* has a wider distribution than *A. venetum* in Tarim Basin and artificial plantations can be created.

2.2. *Analytical Framework*

In this section, we will employ Schlager & Ostrom's theory [44] of "Property Rights and Natural Resources" and Tisdell's [45] concept on institutions for Natural Resource Management types in order to identify property-rights schemes and management institutions, which offers a foundation for analyzing the impact of the different institutional arrangements on the economic potentials of *A. pictum*.

2.2.1. Property Rights of Natural Resources

Hardin [46] proclaimed that natural resources are susceptible to overexploitation due to the "tragedy of the commons", which could potentially lead to the collapse of the whole ecosystem. At the time, he used the grazing commons in England as an example. According to Schlager & Ostrom [47], "most natural resources can be classified as common pool resources", which are natural or man-made facilities or stocks that generate flows of usable units over time. As they pointed out, many common pool resources are faction fact open access. Schlager & Ostrom, [47] have also stated that "property rights is the authority to undertake particular actions related to a specific domain", which are comprised of the owner, proprietor, claimant and authorized user. The rights associated with natural resources include access and withdrawal, management, exclusion and alienation. Only the owner has all of the associated rights to use the resources, including alienation and exclusion.

During our investigation, the existing property rights schemes and actors for the *A. pictum* plant were studied and identified. According to Berkes [48], exclusion and regulation are fundamental to the management of natural resources. He then categorized three types of exclusion, which are namely open-access, private property and communal and state property. Berkes [48] also noted that the state property rights regime has the most issues with being enforced. In this study, all of the different property-rights domains and their associated rights will be investigated with regard to the *A. pictum*.

2.2.2. Resources Use Types

Institutional arrangements for the ownership and management of natural resources offer potential users with an institutional and logistical basis for exploitation [45]. Tisdell has categorized natural resource management into three institutions: open access, ranching and farming. We review them below.

In the case of open access, everyone is free to use the resources. Individuals or groups of individuals gain no property rights from conserving the resource or undertaking investments to increase its economic value or productivity. In the open-access scenario, the quantity of exploited resources employed in the open-access industry will be such that the value of its average product is equal to its price, which results in Kaldor-Hicks social deadweight loss. Essentially, this is lost economic efficiency and reduction in social benefits, due to negative externalities [49]. As a consequence, common resources are prone to being misallocated across the regions, as seen for the *A. pictum* in our study, or completely depleted in the nature, as in case of overfishing in oceans.

"Ranching involves the practice of capturing the young or collecting the eggs of a species and rearing these in captivity". This is a technique that intends to maximize survival, growth rate and biomass for the species targeted to an extent greater than what is normally attained under natural conditions. Excess capturing of the species for ranching may lead to reductions in their population in the wild, such as the shrimp in Ecuador [45].

In farming, farmers use closed inbreeding, seed selection and growth control mechanisms to maximize production subject to land use rights. Farming not only involves closed indoor breeding to propagate and produce, but also gives the farmers private property rights.

2.3. Survey and Calculation Methods

Both primary data and secondary data were obtained, with the latter compiled from statistical yearbooks and the former retrieved through semi-structured interviews taken in 2012 and 2013. Stakeholders involved in growing, selling, producing and retailing *A. pictum* and its related byproducts were interviewed in Urumqi, Korla, Lopnor, Xayar and Altay via a semi-structured questionnaire and workshops. As there is only a small number of *A. pictum* users, interviewees were approached in an explorative manner in 2012 [50]. In 2013, additional interviewees were approached by snowballing and chain-sampling methods [50]. A total of 17 household and expert interviews have been included here, who are from the counties of Lopnor, Bügür, Xayar, and Korla. Although this was not located in the Tarim Basin, one interview was also conducted in the Altai Region with the largest *A. pictum* textile producer in Xinjiang. Furthermore, expert interviews with relevant scientists and members of the Xinjiang Forestry Administration and the Xinjiang Pasture Land Administration were conducted in Urumqi, the capital of Xinjiang. The following information was obtained through a set of structured questions: (i) basic information about the interviewees; (ii) resource types relevant to *A. pictum* utilization; (iii) all types of inputs, such as site establishment inputs, labor inputs, machines, lease and other fees for different resource types; (iv) prices of the different *A. pictum* raw materials and processed products; and (v) practices and techniques in *A. pictum* planting. Harvested yields from *A. pictum*, selling prices of its raw materials and related costs associated with growing and harvesting *A. pictum* for use in different resources were presented and used in cost-revenue calculation.

The revenue of *A. pictum* utilization is calculated as follows [51]:

$$\text{Revenue} = \text{Value of production} - \text{Fixed costs} - \text{Variable costs}. \quad (1)$$

All revenues and costs were adjusted for inflation, with 2012 as the reference year [52]:

$$V_{2012} = V_t \frac{\text{CPI}_{2012}}{\text{CPI}_t} \quad (2)$$

where V_t is the original value in the year t; CPI_{2012} is the CPI (consumer price index) in 2012 and CPI_t is the CPI of the year t.

The secondary data in this study were retrieved from the official statistical yearbook of the Bazhou prefecture and from other official agency reports.

3. Results

3.1. Property Rights in China

According to Barbier [53], "given that open access conditions and ill-defined property rights are thought to be important factors driving agricultural land expansion and forest conversion in developing countries, there needs to be developed an adequate economic model of forest land conversion under open access that can be empirically tested". Outlining the legal bases for the ownership of grasslands and wastelands where most of the wild *A. pictum* grows is critical to understanding the property rights of these plants.

The Chinese constitution mandates ownership of land by the state and collectives, which has basically resulted in the land in the cities being owned by the state and the land in the rural and suburban areas being owned by collectives [54]. In addition, the Land Administration Law of 1986 and the Rural Land Contracting Law of 2002, together with the Property Law of 2007, provide a basic legal framework for land property ownership and use [54]. In 2007, the National People's Congress of China adopted the Property Law of the People's Republic of China, in which it offers protection for state, collective and private property [54], although the land still remains state or collective property. The lack of private ownership of the land and the government's selective implementation of land-related laws is still a major issue surfacing in land disputes all over China [54].

As Kung 2002 [55] explained, both agricultural and forest lands in China are subject to "quasi-private" property rights [56]. Liu et al. [57] state that there are "four aspects of land rights that can vary among Chinese villages: residual income rights, unencumbered use rights, rights to secure possession and transfer rights". The unclear property rights structure, along with the low economic value of grasslands (the semi-arid and arid areas in particular), has generally led to overgrazing, desertification and soil degradation due to the exploitation of medicinal herbs, such as *A. pictum* [58].

According to the definitions of the Chinese Ministry of Agriculture, this undeveloped land can be divided into wastelands, waste mountains, sandy wastes and waste gullies ("huangdi", "huangshan", "huangtan" and "huanggou" in Mandarin, respectively) [58]. However, the term of "wasteland" is misleading, as a great portion of this land is used by peasants for animal grazing, small-scale forestry and the exploitation of forest byproducts, such as Matsutake mushrooms, medicinal herbs and animals. The direct use of wastelands generally yields low economic returns and its ecology is often fragile [58]. Grasslands located further away from the collectives are often considered state property, yet are still used by the different villages or neighboring areas [58]. Many of the wild *A. pictum* areas in our study area are very remote and therefore, are regarded as state property. Due to its remote location, *A. pictum* can be grown in marginalized lands, which are inhospitable for traditional crop growing. Most natural *A. pictum*-distributed areas along the Tarim River are regarded as grasslands or wastelands. Therefore, the property rights and legal framework of these areas have a direct impact on how they are being utilized and exploited. An ambiguous legal framework for property rights for grasslands and wastelands has allowed for many people to access *A. pictum*-distributed areas so as to harvest and sell it without legal consequences.

3.2. Resource Use Types of *A. pictum*

All three types of institutional arrangements [45] are present in our study at various levels. *A. pictum* is used in the three management types of open access, ranching and farming [45].

For open access, the *A. pictum* in this study have extensive natural or wild distributions in the remote areas of riverbanks, oases and towns along the Tarim River. In these areas, people freely or illegally access *A. pictum* for harvesting and trading (Figure 4) without paying for harvesting rights, resulting in a "tragedy of the commons" scenario due to wild *A. pictum* stands being harvested in an open-access manner. This type of biomass harvest is not completely legal. Although all of the public lands owned by the government in China as well as natural grasslands and forests are entitled to protection under the grassland law (and other relevant laws), insufficient implementation of these rules by the local administrations and the remote location of these lands results in a vacuum where people access the wild *A. pictum* areas with and without consent of the local officials, harvesting and exploiting the *A. pictum* during the vegetation season.

Figure 4. Wild unclaimed *A. pictum* in Xayar (photo by A. Rouzi).

In this case, people may only need to spend money on the labor and transportation costs associated with harvesting. After harvesting, the *A. pictum* biomass is transported and sold to either intermediate traders or directly to *A. pictum* companies. According to Ostrom's theory, those people who harvest *A. pictum* display access and withdrawal rights, although in some cases they are not authorized to enter and use these resources and are never entitled to those rights. As such, these individuals can only be classified as "authorized entrants" and not as "authorized users".

From our interviews and investigations, we found out that harvesters also harvest other medicinal plants, such as *Cistanche deserticola* and *Glycyrrhiza inflate*, along with *A. pictum*. Since this is done sporadically or in some cases illegally, it may harm the intactness of grasslands and may pose a serious threat to the existing plant species in the area, which may result in depletion of grassland resources. Additionally, this structure makes it harder to investigate supply chains in the market. As Tisdell has pointed out, open access resources, such as *A. pictum*, are not likely to be conserved and sustained and invested in in a way that maximizes the value of production.

In the case of ranching, the company or farmer makes an agreement with the local pasture administration to harvest certain wild *A. pictum* areas (Figure 5). These *A. pictum* areas are fenced and monitored in order to exclude grazing. Occasionally, the water flow is also controlled to avoid drought or inundation. Those companies and individuals have access, withdrawal, management and exclusion rights, but lack the alienation rights to sell and lease *A. pictum* land. They can thus be classified as "proprietors".

Breeding or growth control are not applied, such as fertilizer and pesticide. This tends to result in faster growth rate and higher biomass for *A. pictum* under natural conditions. As such, proprietors are not involved in the day-to-day operations of farming. Ultimately, they harvest the yield and either use it for their companies or sell it to other buyers. In this case, the company only needs to invest in fencing and harvesting. If there is enough water during the flood season, the proprietors will also ensure that the local water administration releases water into their fields or plots. Therefore, this style does not require intensive investment, as they cannot control the yield and quality. Due to the remoteness of the land, it is hard to be present to guard the plot at all times, with livestock potentially intruding in the absence of guards. The means by which they gain the approval of the local administration are not transparent. Often, those people with good connections or a convincing case for *A. pictum* use will have the rights to use the land. In some cases, bribery is also involved. Although the profitability of growing wild *A. pictum* in fenced-off areas should theoretically increase the demand for other wild *A. pictum* areas, there has not been much competition to access such areas so far. This is likely due to a lack of awareness and the areas' innate inaccessibility.

Figure 5. Fenced-off *A. pictum* plot in Yuli county, owned by a company in Korla (photo by A. Rouzi, 2011).

For farming, companies and farmers have their own lands for growing and harvesting Kendir artificially by the methods of seed selection and root propagation. With these two methods, they manage the farm by carrying out regular irrigation, fertilization, weeding and other relevant activities during the vegetation season as well as hiring labor for harvesting in order to maximize production. The companies and individual farmers operating these farms often use *A. pictum* for tea or fiber production, with their yields either used directly or sold the contracted companies (e.g., tea, textile or pharmaceutical companies), as shown in Figure 6.

Figure 6. Cultivated *A. pictum* farm in Altai, owned by the Gebao company (photo by A. Rouzi, 2012).

This is a full-scale and well-established scheme in need of greater investment and better-allocated labor and management practices compared to open access and ranching. The farmers and companies can also affect and control the yield and quality via different sub-management schemes. One issue present here is that due to a lack of sufficient *A. pictum* farming experience and skills, farmers could fail to grow *A. pictum* and may not meet expected yields in the initial years. Since the market for *A. pictum* may also be unstable and immature, producers have to take certain risks on their returns. Farmers have access, withdrawal, management, exclusion and quasi-alienation rights where they can lease or sell the land use rights. Therefore, they can be classified as "owners". Since there is no private ownership of land in China, people cannot sell the land as property.

Farming could potentially alleviate the pressures from harvesting and prevent extinction of *A. pictum*, although it could still become extinct in the wild. However, farming could also alter the genetic stocks of *A. pictum*, while the continuing success of farming depends on the genetic diversity sustained in the wild [45]. In some cases, it was found that farming and business were well integrated, with the parent companies of *A. pictum* farms also engaged in production and sale of processed *A. pictum* products.

3.3. Cost-Revenue Analysis

A. pictum is chiefly used as a medicinal and fiber plant. The leaves harvested in June/July serve as raw material for tea and medicines, while the stems harvested in summer or autumn serve as raw material for fiber extraction. Medical studies show that compared to cotton, *A. pictum* fibers have anti-microbial properties and high hygiene, which is attributed to the stem cells containing tanning agents [10]. Furthermore, *A. pictum* is part of the natural riparian vegetation [59]. However, in our study, all of 17 people interviewed have said that stems should be harvested in the winter when dry stems can easily be collected without destroying other plants, while leaves and flowers should be harvested in June and July [59]. The flowers are also used for tea.

The prices and revenues generated from *A. pictum* are given in Table 1. Although the flowers are the raw material that can be sold for the highest price of approximately 36.18 yuan/kg to make tea or honey, they are rarely harvested and used. Stems and leaves are sold at similar prices of 7.79 yuan/kg and 7.81 yuan/kg, respectively. The overall revenue generated from the raw material is potentially 49,014.45 yuan/ha, but this reduces to 31,264.2 yuan/ha when the flowers are not harvested.

Table 1. Revenues and profits of *A. pictum* products (Inflation adjusted to 2012 in accordance with consumer price index published by OECD *).

Raw Material or Products	Yields (kg/ha)	Single Price yuan/kg	Potential Total Revenue = Production × Single Price (yuan/ha)
Stem	3075	7.79	23,954.25
Leaf	1680	7.81	13,120.8
Flower	330	36.18	11,939.4
Raw Material Total	5085		49,014.45
Tea	1125	146.52	164,835
Fiber	330	97.59	32,204.7

* OECD stands for The Organization for Economic Co-operation and Development.

However, processed tea and fibers have much higher revenues with added values. In particular, *A. pictum* tea can be sold at 164,835 yuan/ha, which is much higher than the price of the other raw parts of the plant.

There are two reproduction methods for the cultivation of *A. pictum*, which are namely seed propagation and vegetative propagation from root or plant parts [10]. Generally, it could be planted from mid-April to May in order to avoid spring frosts [10]. The best way to achieve higher germination is to sow *A. pictum* in a nursery and transplant the saplings in the second year to farms [10]. The roots can be taken from wild *A. pictum*, although over-exploitation must be avoided. Root pieces with lengths of 10–15 cm are planted 10 cm deep into the soil [10]. The workload is high, because 60,000–70,000 root pieces (1–2 tons) are needed per hectare. It can be started earlier than seed propagation. *A. pictum's* root system is perennial, while the stem is annual and requires one cut each year in the case of farming. *A. pictum* stems are harvested mutually by sickles, leaves will be separated from stems after drying and flowers are also harvested manually [10].

The costs associated with obtaining *A. pictum* biomass are listed separately for open access, ranching, and farming in Table 2. In this study, there has been total of 9 open access, 9 ranching and 7 farming cases were found. In the case of open access, there are only variable costs for labor (i.e., the people who harvest the *A. pictum*) and for the transportation of the harvested biomass. Ranching involves these variable costs and the additional fixed costs of fencing (Table 2). Farming involves more inputs and more variable costs, including the additional costs of water, fertilizer, and weeding. As can be seen from the Table 3, open access is the most profitable way (with a cost of only 3472.05 yuan/ha) of using *A. pictum* resources where there are no fixed costs and only harvest labor and transportation costs exist. However, the reliability and legality of exploitation could bring about problems of inefficient utilization. Ranching requires fixed infrastructure costs (fencing), bringing total costs to a total of 5467.05 yuan/ha.

Table 2. Cost table for different *A. pictum* resource type.

Farming *N* = 7		**Ranching *N* = 9**		**Open Access *N* = 9**	
Fixed Costs		**Fixed Costs**		**Fixed Costs**	
Land Lease	0	Land Lease	0		
Tractor	0	Fencing (yuan/ha)	1995		
Variable Costs		**Variable Costs**		**Variable Costs**	
Planting and site establishment yuan/ha (Includes labor)	1224	Harvesting Labor yuan/Person/a day/ha	2362.2	Harvest Labor (yuan)	2362.2
Harvest labor yuan/Person/a day/ha	2362.2	Transportation yuan/Mu of yield	1109.85	Transportation (yuan)	1109.85
Water fee yuan/ha/Irrigation	2998.5				
Transport yuan/ha of yield	1109.85				
Fertilizer (yuan/ha)	4055.7				
Irrigation and weeding labor (yuan)	4500				
Per ha total costs	16,250.25	**Per ha total costs**	5467.05	**Per ha total costs**	3472.05

A. pictum farming has both fixed and variable costs, but due to the ambiguous implementation of grassland rules in marginal areas, farmers or *A. pictum* companies are not always obliged to pay for leasing the land. They usually hire a contractor with a tractor and labor to manage the field. The various costs include planting and site establishment, harvesting labor, water fees, transport, fertilizer, irrigation and weeding labor, which all amount to a total of 16,250.25 yuan/ha.

4. Discussion

As presented in Table 2, open access has minimum costs of 3472.05 yuan/ha, ranching comes second with costs of 5467.05 yuan/ha and farming comes last with costs of 16,250 yuan/ha. However, open access and ranching has to deal with property rights issues and increasing demands for *A. pictum* raw materials in its limited natural distribution.

The open-access resource model would not be beneficial to the conservation and sustainability of *A. pictum* as a resource. In particular, open access would become problematic as the demand for *A. pictum* grows and would become a significant economic and ecological concern for the Tarim

Basin. Therefore, the efficient utilization of *A. pictum* would depend significantly on the existence of well-defined property rights. However, the implementation and regulation of such rights would also increase the cost of the resources and must also be taken into consideration. Currently, the demand for *A. pictum* is low and thus, the economic benefit from regulating open access is unlikely to exceed the cost of regulation. Locally-devised property regulations would allow for savings on the monitoring and enforcement costs [44] associated with *A. pictum*.

Although ranching is certainly economically more efficient than open access with regard to profitability, it would not be able to match an increase in demand due to limitedness of naturally distributed *A. pictum* areas. *A. pictum* farming can effectively deal with issues inherent to open access and may prevent the exhaustion of the resource in the wild. However, farming would lead to a loss of genetic diversity in the long run, which in turn would decrease *A. pictum* yields in the future.

As discussed in a previous study, cotton has been a dominant cash crop in the Tarim Basin. However, its high investment and labor intensity, together with strong irrigation water demands, make it less attractive in the wake of the global cotton market fluctuations. A situation of non-secure water supplies also poses huge risks to the cotton-dominated irrigated agriculture [4] in the lower reaches of the Tarim River. In 2011, the Chinese government initiated a cotton price floor policy to aid cotton growers, but this policy backfired as textile industries were more willing to import cheap cotton from overseas [60]. The policy was implemented nationally until 2013 and was nationally abolished in 2014, with special provisions being introduced to subsidize cotton growers in Xinjiang only [60].

As seen from Table 3, cotton in Xinjiang costs 28,898.7 yuan/ha to produce while generating 37,114.95 yuan/ha of revenue. With the resulting gross profit of 8216.25 yuan/ha, it is the least profitable of all major cash crops and fruit compared in this study. Although the nationwide cost of producing cotton (29,095.95 yuan/ha) is very similar to that of Xinjiang, the revenues generated from cotton nationwide are much smaller (29,474.85 yuan/ha), and result in a significantly lower overall profit (378.9 yuan/ha). This is largely due to the fact that most of China does not enjoy the cotton subsidies that Xinjiang does and Xinjiang has relatively higher productivity. This apparent profitability of cotton production in Xinjiang, which is heavily dependent on government support, is now wavering in light of cheaper imported cotton.

The Chinese red date has the highest revenue and ranks in the middle for profit, which is reflected by its growing popularity among the farmers in the region. *A. pictum* costs 16,250.25 yuan/ha, generates 49,014.45 yuan/ha of revenue from raw materials and brings a profit of 32,764.2 yuan/ha, making it the most profitable of the three cash crops compared.

Table 3. Cost-revenue comparison of the major cash crops in Xinjiang China in 2012.

Name	Cotton in Xinjiang	Cotton in China	Chinese Red Date in Xinjiang	*A. pictum*
Cost (yuan/ha)	28,898.7	29,095.95	43,396.95	16,250.25
Revenue (yuan/ha)	37,114.95	29,474.85	56,210.4	49,014.45
Profit (yuan/ha)	8216.25	378.9	12,813.45	32,764.2
Output (Kg/ha)	1719.75	2491.5	2128.05	5085
Source	Xinjiang Agricultural cost-revenue material 2013 [61]	Chinese Statistical Yearbook 2013 [62]	Xinjiang Agricultural cost-revenue material 2013 [61]	This study

Cotton has the highest costs and the lowest returns, which is due to its labor and investment intensity. Various government policies and a mature global market have made cotton a reliable cash crop in this region for many years, but rising costs and changes in government policy as well as competition from cheap imported cotton has made it less attractive. As shown in Figure 7, although the material and land costs of cotton have increased steadily from 2003 to 2012, the labor costs per ha area have risen dramatically from 4758.75 yuan/ha in 2003 to 17,560.65 yuan/ha in 2012, thus driving up the production costs. The cotton price has fluctuated during this period, with profits shrinking to mere 378.9 yuan/ha in 2012. Cotton has the highest share of labor costs among the six major crops in China, with 60% of the production costs associated with labor [60]. Due to rising labor prices, cotton is expected to be the least profitable crop in the years to come. The government subsidies in Xinjiang to help farmers grow cotton are not sustainable in terms of market demand and cannot be a long-term strategy.

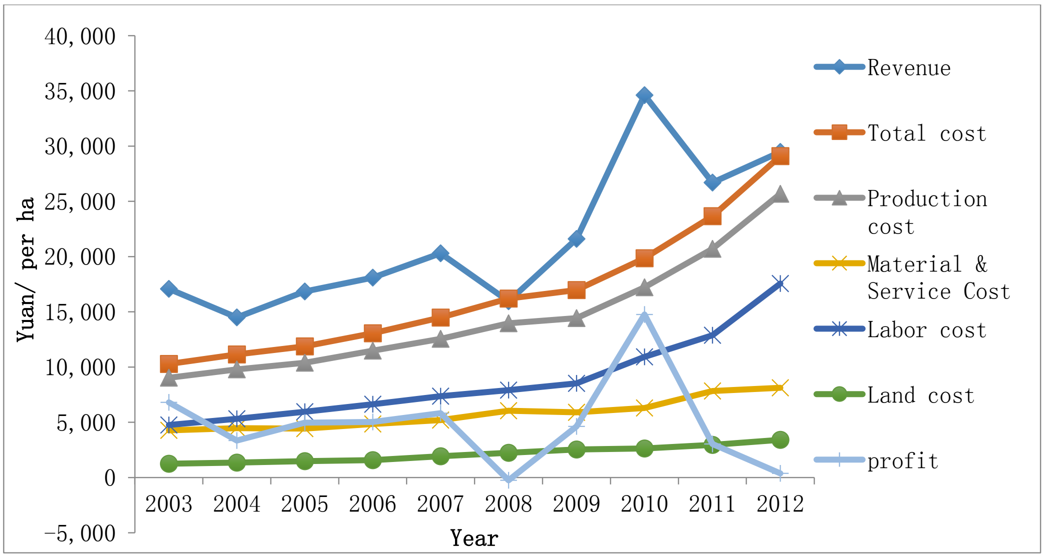

Figure 7. Cost-revenue trends for cotton in China during 2003–2012 [62].

The number of fruit tree plantations has increased tremendously in recent years, which is largely due to a high demand, market demand from eastern China and the government policy providing subsidies to farmers for converting their croplands to fruit orchards. The Chinese red date is one of the most popular and has been replacing croplands in the Tarim Basin in recent years. Chinese red date trees are regarded as forests and as such, are entitled to government subsidies as part of the policy, with each farmer getting a 3000 yuan/ha subsidy for the first five years after the newly planted trees produce fruit.

Although fruit trees, such as the Chinese red date, are leading alternatives to cotton for the moment, *A. pictum* could also be a strong alternative with its low cost and high profitability when sufficient government support is put in place. High quality fibers extracted from *A. pictum* could also become valuable textile material for its hygienic features. Chinese red date prices are also in decline because of oversupply, costs are rising as labor prices increasing and diversifying the region's agricultural sector is the key to long-term sustainable development. These new crops could also reduce agricultural water use to some degree and alleviate water stress.

5. Conclusions

The results show that all three types of institutional arrangements (open access, ranching, and farming) are present in our study and appear at various levels. *A. pictum* costs 16,250.25 yuan/ha, generates 49,014.45 yuan/ha of revenue from raw materials and brings a profit of 32,764.2 yuan/ha, with the latter being the highest among all of the three cash crops compared. Thus, this demonstrates that the growth of this crop is economically viable. Given cotton's declining profitability and its heavy reliance on subsidies, *A. pictum* and the Chinese red date may be seen as promising candidates for substitution. The Chinese government's encouragement for Chinese red date plantation with the "Grain for green" policy in Tarim Basin would provide necessary incentives for farmers to switch and would diversify the region's agriculture. It should be noted that *A. pictum* might also generate income via tea production and its uses as fibers and fodder for livestock. Finally, we conclude that *A. pictum* offers restoration opportunities, because artificially planting *A. pictum* into some of those barren or salinized lands in marginal areas would enrich biodiversity and create suitable habitats, which grassland ecosystem depends on. Furthermore, *A. pictum* requires less water than other traditional crops grown in this area, which would reduce water consumption [10]. Initiating stricter protection of already existing *A. pictum* in the wild could improve nutrient dynamics in the riparian areas of Tarim River, which could also restore already degraded floodplain ecosystems under the arid conditions in the Tarim Basin with increased biodiversity [63,64]. Future research could focus on the reaction of plants to different levels of nutrients under different farming management practices.

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