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Sustainable land use alternatives in the Tarim Basin, China

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Thesis Declaration

I hereby declare that this Ph.D. thesis entitled **“Sustainable land use alternatives in the Tarim Basin, China”** was carried out by me for the degree of Doctor of Philosophy in English under the guidance and supervision of Prof. Bernd Cyffka as first referee and Prof. Dr. Umut Halik as second referee, Faculty of Mathematics and Geography at the Catholic University of Eichstaett-Ingolstadt, Germany.

I hereby confirm that I independently carried out the research for this thesis and wrote it without any other aids than those referenced. In each individual case, I have clearly identified the source that are taken word for word or paraphrased from other works.

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Catholic University of Eichstätt-Ingolstadt.

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Rouzi Aihemaitijiang /(Ahmatjan)

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Summary

This doctoral thesis 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 deteriorated by excessive land and water use for agriculture, in particular for the growing of cotton. This situation poses a grave threat not only to the natural Tugai vegetation in the area but also to the long-term sustainability of the region.

We explore the hypothesis that the species *Apocynum pictum* may act as a sustainable crop substitute for the region, thereby replacing the water-demanding and widely distributed cash crop, cotton. This idea is motivated by the former having a lower water demand, as well as a number of other traditional and modern uses. To substantiate this hypothesis, a multidisciplinary research scheme has been designed, permitting the analyses of both the ecological and socio-economic potentials of this plant, its potential benefits relative to cotton and a comprehensive analysis of its productivity, water demand and economic potentials. This analysis is divided into three distinct sections.

Biomass and nutrient analysis: Field investigations were conducted to sample biomass and map the spatial distribution of *Apocynum pictum* (abbreviated as *A. pictum*) at five selected sites. At each site, 3-5 plots were randomly selected and the point center quarter method, as outlined by Mueller-Dombois and Ellenberg (1974), was applied for biomass sampling. Concurrently, soil profiles were dug at each site so as to obtain soil samples from the various layers and electrical conductivity was measured as a mean of investigating soil salinity. These steps are essential for determining the physical and production basis for alternative land-use considerations.

The results obtained show that the total above-ground biomass ranges from 0.6 t/ha (Qongaral 1) to 1.25 t/ha (Xayar 1), and that the total below-ground biomass of *A. pictum* is at 11.25 ± 5.41 t/ha. The biomass of *A. pictum*, relatively moderate when compared to other steppe and desert ecosystems, reflects strains of soil and water conditions for plant growth in desert margins.

Evapotranspiration and water budget: Evapotranspiration (ET) is a key component of water balance and is closely linked to ecosystem productivity. Climate parameters were measured with mobile climate stations to calculate reference crop evapotranspiration (ET_0) via the Penman-Monteith equation. Diurnal foliar transpiration and conductance were

measured with a porometer to calculate canopy resistance. Leaf samples were photographed and analyzed for the leaf area index (LAI) in the study area so as to calculate crop evapotranspiration under standard conditions (ET_c) and crop factors (K_c). Finally, the water consumptions of *A. pictum* and cotton were calculated and compared so as to identify which is better suited for dry environments.

The results show that cotton in this study attained a high yield compared to the world average, and at a rather low ET_c. Among the three plants tested, *A. pictum* required the least amount of water during the vegetation season with 217.2 mm a year, while the Chinese red date came close second with 339 mm and cotton was least water-efficient with 524.7 mm, thus demonstrating the viability of *A. pictum* as an alternative with significant water-saving potential.

Economic analysis: Purposive sampling was used, with relevant participants in the study being approached by flow population and snowballing or chain sampling methods. The desired information was then obtained via a structured-questionnaire survey. Three natural resource management types of *Apocynum* were identified and a cost-revenue analysis was carried out for each.

The results show that all three types of institutional arrangements – open access, ranching and farming – are present in our study and at various levels. *Apocynum* costs 1083.35 Yuan/mu, generates 3267.63 Yuan/mu of revenue from raw materials and brings a profit of 2184 Yuan/mu – the highest among of all three cash crops compared.

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, while also serving 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.

Zusammenfassung

Alternativen für eine nachhaltige Bodennutzung im Tarim-Becken, China

Die vorliegende Dissertation untersucht ein Modell für nachhaltige Bodennutzung in den Oasen entlang des Tarim-Flusses im Nordwesten Chinas, in denen ein fragiles, semiarides Ökosystem durch den übermäßigen Land- und Wasserverbrauch für die Landwirtschaft, insbesondere für den Anbau von Baumwolle, zerstört wird. Die jetzige Situation ist nicht nur für die natürliche Tugai-Vegetation dieses Gebietes eine große Gefahr, sondern auch für die langfristige Zukunft der ganzen Region.

Es wird die Hypothese geprüft, dass der Anbau von *Apocynum pictum* eine nachhaltige alternative Lösung für diese Region darstellen könnte. Der Gedanke, anstelle von Baumwolle, welche hier großflächig angebaut wird und einen besonders hohen Wasserverbraucht hat, diese Nutzpflanze anzubauen, begründet sich darauf, dass sie einerseits deutlich weniger Wasser benötigt und andererseits eine Reihe traditioneller und moderner Anwendungsmöglichkeiten bietet. Um diese Hypothese zu untermauern, wurde ein multidisziplinäres Forschungsvorhaben entwickelt, das sowohl die Analyse der ökologischen und sozio-ökonomischen Potenziale dieser Pflanze und ihrer möglichen Vorteile gegenüber der Baumwolle gestattet, als auch eine umfassende Analyse ihrer Produktivität, ihres Wasserbedarfs und ihrer wirtschaftlichen Potenziale. Diese Analyse ist in drei Abschnitte unterteilgliedert.

Biomasse und Nährstoffanalyse: Bei Felduntersuchungen wurden Proben von Biomasse entnommen und an fünf ausgewählten Standorten die räumliche Verteilung von *A. pictum* auf einer Karte eingetragen. An jedem der Standorte wurden nach dem Zufallsprinzip 3-5 Areale ausgewählt und nach dem von Mueller-Dombois und Ellenberg (1974) entwickelten Point-Center-Quarter-Verfahren stichprobenartig Biomasse entnommen. Gleichzeitig wurden an jeder dieser Orte Bodenprofile ausgehoben, um Proben aus den verschiedenen Schichten zu erhalten und die elektrische Leitfähigkeit wurde gemessen, um so den Bodensalzgehalt untersuchen zu können. Diese Schritte waren für die Bestimmung der physikalischen Gegebenheiten ebenso notwendig wie für Überlegungen zu alternativer Landnutzung.

Das Ergebnis zeigt, dass die gesamte oberirdische Biomasse zwischen 0.6 t/ha (Qongaral 1) und 1.25 t/ha (Xayar 1) liegt, während die gesamte unterirdische Biomasse von *A. pictum* 11.25±5.41 t/ha beträgt. Die Biomasse von *A. pictum*, die im Vergleich zu anderen Steppen- und Wüstenökosystemen relativ niedrig ist, weist die Boden- und Wasserbedingungen auf, die für das Pflanzenwachstum in Wüstenrandgebieten typisch sind.

Evapotranspiration und Wasserhaushalt: Die Evapotranspiration (ET) ist eine Schlüsselkomponente der Wasserbilanz und steht in engem Zusammenhang mit der Produktivität eines Ökosystems. Mit mobilen Klimastationen wurden Klimaparameter gemessen, anhand derer mit Hilfe der Penman-Monteith-Gleichung die Evapotranspiration (ET_0) der Referenzpflanze errechnet werden konnte. Für die Berechnung des Canopy-Widerstandes wurden die diurnale Blatttranspiration und die Leitfähigkeit mit einem Porometer gemessen. Blattproben wurden fotografiert und analysiert, um den Blattflächenindex (LAI) im Untersuchungsgebiet und damit die Evapotranspiration der Pflanzen unter Standardbedingungen (ET_c) sowie die Pflanzenfaktoren (K_c) zu berechnen. Schließlich wurde der Wasserverbrauch von *A. pictum* und Baumwolle ermittelt und verglichen, um festzustellen, welche der beiden Pflanzen für Trockengebiete besser geeignet ist.

Das Ergebnis zeigt, dass Baumwolle im Vergleich zum Weltdurchschnitt einen hohen Ertrag und einen relativ niedrigen ET_c erreichte. Von den drei getesteten Pflanzen, benötigte *A. pictum* während der Vegetationsperiode mit 217,2 mm pro Jahr die geringste Wassermenge. An zweiter Stelle kam die chinesische rote Dattel mit 339 mm und Baumwolle an letzter Stelle mit 524,7 mm, was bestätigt, dass *A. pictum* eine Alternative mit hohem Wassersparpotenzial ist.

Ökonomische Analyse: Nach dem Schneeballprinzip oder Kettenstichprobenverfahren wurden Teilnehmer der Studie ausgewählt, die an einer strukturierten Fragebogenerhebung teilnahmen, um die gewünschten Informationen zu erhalten. Drei Ressourcenmanagementarten von *Apocynum* (Tisdell, 2005) wurden ermittelt und unter Verwendung der M.-Hilmi-Methode (2006) für jede von ihnen eine Kosten-Umsatz-Analyse durchgeführt.

Die Ergebnisse zeigen, dass in unserer Studie alle drei Arten der institutionellen Landnutzung – freie Landwirtschaft (Open access), Weidewirtschaft, Agrarwirtschaft – vorhanden sind, und zwar in unterschiedlichem Ausmaß. *Apocynum* kostet 1083.35 Yuan/mu an Rohmaterial und erwirtschaftet 3267.63 Yuan/mu, das bedeutet einen Gewinn von 2184 Yuan/mu – den höchsten der drei miteinander verglichenen Cash-Crop-Pflanzen.

Daraus schließen wir, dass *A. pictum* eine Möglichkeit bietet, die Vegetation in den ariden, versalzenen, flussnahen Ökosystemen des Tarim-Beckens zu verbessern, und gleichzeitig eine realisierbare Alternative zu Baumwolle als Cash Crop darstellt, da es einen gewissen Gewinn in Form von Tee und Fasern einbringt sowie Viehfutter liefert.

摘要

题目：中国塔里木盆地可选择的可持续土地利用

本文以中国西北最大内陆河——塔里木河流域可持续土地利用模式作为主要探讨目标，针对该地区大量开垦，尤其是棉花地面积扩大而引起的大量农业用水造成的脆弱河岸林生态系统破坏问题进行了研究。该区域棉花地面积的扩大不仅对周围吐加依林植被类型带来危害，而且对区域可持续发展造成威胁。

本文提出了罗布麻可作为适合于该地区可持续发展的主要作物类型。由于区域其他作物类型需水量较大，从长远考虑，它可以与该区域需水量最大的经济作物棉花代替。

本研究为了回答罗布麻在该区域推广是否有一定的优势这一科学问题，运用交叉学科的相关理论方法拟定了研究方案，对罗布麻的经济和社会效益进行探讨，基于罗布麻的生产量，需水量和经济潜力等三方面的综合分析，对罗布麻与棉花这两种作物的经济效益进行对比。具体由以下三个部分内容组成。

生物量与营养成分分析：通过野外调查对塔里木河岸林选择五个不同采样点，对采样点内罗布麻进行采样并绘制其空间分布图，本文采取 Mueller-Dombois 和 Ellenberg（1974）提出的 1/4 点中心样地选择方法对 3-5 方块样地进行罗布麻的采集。同时，对不同层次土壤进行取样以及测定其含盐量。这些过程拟定土地利用可持续发展模式中必须考虑的重要环节。

结果表明：罗布麻地上生物量呈从 0.6 t/ha（Qongaral 1）至 1.25 t/ha（沙雅 1），罗布麻的地下生物量是 11.25±5.41 t/ha。罗布麻的总生物量与其他草原和荒漠生态系统相比较为一致，这体现了沙漠边缘土壤和水分条件对植物生长具有很大的限制性。

植物蒸腾量和需水量：蒸腾量是生态系统水热平衡的主要组成部分。气候参数是由移动式气象站获取，本文利用彭曼公式估算作物蒸发量（ET_0)，通过日蒸发量和电导率推算植物冠层阻力。通过植物叶片样品拍照，分析了叶面积指数（LAI)，以及得出了正常情况下的植物蒸腾量（ETc)和作物系数（Kc)。最后，对罗布麻和棉花的耗水量进行定量，通过两种作物的耗水量进行对比，筛选出适合于干旱区作物种类。

该区域棉花生产量已高于世界平均水平，但其蒸腾量（ETc）低于世界平均值。通过罗布麻、中国红枣和棉花等三种植物年需水量对比可知，罗布麻年需水量为 217.2 mm，处于最低。中国红枣年需水量为 339 mm，处于中等。棉花年需水量为 524.7 mm，年需水量为最大。该结果显示罗布麻具备明显的节水潜力。

经济效益分析：通过立意抽样法、以滚雪球式或者链式抽样方法，获取所需要的信息。罗布麻的三种天然资源管理类型进行确定，并使用成本效益分析方法，对成本收益进

行分析。结果表明：该研究区存在开放获取资源型，围栏放牧和农业土地利用方式。罗布麻成本是 1083.35 Yuan/mu ，产生收入 3267.63 Yuan/mu，从原材料中收取的利润是 2184 Yuan/mu，与其他两种作物相比，它的经济效益是最高的。

罗布麻为塔里木河河岸林植被的恢复与更新提供可选择的代替种类。假如罗布麻代替为棉花的土地利用方式可行，它作为茶叶，纤维以及畜牧饲料生产的主要材料，会带来更好的经济效益。

جۇڭگونىڭ تارىم ئويمانلىقىدا يەردىن سىجىل پايدىلىنىشنىڭ باشقىچە يوللىرى

قىسقىچە مەزمۇنى:

بۇ دوكتورلۇق ماقالىسى جۇڭگونىڭ غەربىي شىمالىغا جايلاشقان تارىم دەريا ۋادىسىدىكى بوستانلىقلاردا يەردىن ئۈزلۈكسىز پايدىلىنىشنىڭ بىر پۈتۈن يوللىرى ئۈستىدە ئىزدىنىدۇ . بۇ رايۇننىڭ ئاجىز ، يېرىم قۇرغاق كەلگەن دەريا ۋادىسى ئىكولوگىيىلىك سىستېمىسى يېزا ئىگىلىك ، بولۇپمۇ پاختا ئىشلەپچىقىرىشنى مەخسەت قىلغان ھەددىدىن زىيادە يەر ۋە سۇ ئىشلىتىش سەۋەبىدىن ئېغىر بۇزغۇنچىلىققا ئۇچرىماقتا . بۇ ئەھۋال يالغۇز بۇ رايۇندىكى تەبىئىي توقاي يېپىنچىلىرىغىلا ئەمەس يەنە بۇ رايۇننىڭ ئۇزاق مەزگىللىك سىجىل تەرەققىياتىغىمۇ ئېغىر تەھتىت پەيدا قىلماقتا .

بىز بۇ رايۇندىكى زىرائەتلەرنىڭ ئورنىنى سىجىل ئېلىشى مۇمكىن بولغان لوپنۇر كەندىرى ۋە بۇ تۇرنىڭ ھەددىدىن زىيادە سۇ تەلەپ قىلىدىغان ھەم كەڭ تارقالغان ئىقتىسادىي زىرائەت   پاختىنىڭ ئورنىنى ئېلىش قىياسى ئۈستىدە ئىزدىنىمىز . بۇ ئىدىيىگە بۇرۇنقى ئاز سۇ تەلەپ قىلىدىغان يەر ئىشلىتىش شۇنداقلا يەنە يەردىن پايدىلىنىشقا دائىرىيەنە بىر قانچە خىل ئەنئەنىۋى ئۇسۇللىرىنىڭ ئىلھامى تۈرتكە بولغان . بۇ ئىدىيىنى ئىسپاتلاش ئۈچۈن مەركىز ئۆسۈملۈكنىڭ ئىكىلوگىلىك ۋە ئىجدىمائىي ئىقتىسادىي يوشۇرۇن كۈچى ، پاختىغا سېلىشتۇرغاندىكى يوشۇرۇن ئەۋزەللىكى ، ئۇنىڭ مەھسۇلات مىقتارى توغرىسىدىكى ئومۇميۈزلۈك ئانالىز، سۇغا بولغان تەلىپى   شۇنداقلا ئىقتىسادىي قىممىتى قاتارلىقلار بىر گەۋدىلەشكەن كۆپ قاتلاملىق تەتقىقات سخىمىسى لاھىيىلەندى . بۇ ئانالىز ئوخشىمىغان ئۈچ بۆلەككە بۆلۈنگەن .

بىئوماسسا ۋە ئوزۇقلۇق ئانالىزى : بىئوماسسىدىن ئەۋرىشكە ئېلىش ۋە لوپنۇر كەندىرىنىڭ بەش خىل تاللانغان ئورۇندىكى بوشلۇقتا تارقىلىش خەرىتىسىنى سىزىش ئۈچۈن دالا تەكشۈرۈشى ئېلىپ بېرىلدى . ھەر بىر ئورۇندا 3دىن 5 كىچە نوقتا خالىغانچە تاللىنىپ ، مۆللىر دومبىئوس ۋە ئېلىنبېرىگ 1974 يىلى ئوتتۇرىغا قويغان نوقتا مەركەز كۋادرات ئۇسۇلى ئارقىلىق بىئوماسسا ئەۋرىشكىسى ئېلىندى . نۆۋەتتە ھەربىر ئورۇن كولانغاندىكى تۇپراق كەسمە يۈزىنىڭ ئوخشىمىغان قاتلاملىرىدىن ئەۋرىشكە ئېلىنىپ ، تۇپراقنىڭ شورلۇق دەرىجىسىنى تەكشۈرۈش ئۈچۈن ئەۋرىشكىنىڭ توك ئۆتكۈزۈشچانلىقى ئۆلچەپ چىقىلدى . بۇ جەريانلار يەردىن باشقىچە ئۇسۇلدا پايدىلىنىشنى ئويلىنىشتا ئاساس بولىدىغان ماددىي ۋە ئىشلەپچىقىرىش ئامىلىنى بەلگىلەشتە ناھايىتى زۆرۈردۇر .

ئېرىشىلگەن نەتىجىدە شۇنى كۆرسەتتىكى يەر ئۈستىدىن ئېلىنغان بىئو ماسسانىڭ دائىرىسى ھەر گېكتارغا 0.6 توننىدىن (چوڭ ئارال 1)، ھەر گېكتارىغا 1.25 توننىغىچە (شايار 1) ، لوپنۇر كەندىرىنىڭ يەر ئاستى بىئوماسسىسى بولسا 11.25 ± 5.41 بولدى . لوپنۇر كەندىرىنىڭ بىئوماسسىسى باشقا يايلاقلار ۋە چۆل ئىكولوگىيىلىك سىستېمىلىرىغا سېلىشتۇرغاندا ئانچە پەرىقلەنمەيدىغان بولۇپ ، بۇ ئەھۋال چۆللۈك گىرۋەكلىرىدىكى ئۆسۈملۈك ئۆسۈشكە باپ كېلىدىغان سۇ ۋە تۇپراق شارائىتلىرىنىڭ چەكلىك ئىكەنلىكىنى كۆرسەتتى .

ئۆسۈملۈكنىڭ سۇ ئېھتىياجى ۋە سۇنى پارلاندۇرۇشى : ئۆسۈملۈكنىڭ سۇنى پارلاندۇرۇشى سۇ تەڭپۇڭلۇقىنىڭ ئاچقۇچلۇق تەركىبىي قىسمى بولۇپ ئىكىلوگىيىلىك سىستېمىنىڭ ئىشلەپچىقىرىشچانلىقى بىلەن زىچ مۇناسىۋەتكە ئىگە . كىلىمات پارامېتىرلىرى يۆتكۈلۈشچان كىلىمات پونكىتلىرى ئارقىلىق ئۆلچىنىپ ، پېنمەن مونتىخ تەڭلىمىسى ئارقىلىق پايدىلىنىش زىرائىتىنىڭ سۇنى پارلاندۇرۇشى ھېساپلاپ چىقىلدۇ . كۆندۈزلۈك

سۇ پارلاندۇرۇشى ۋە ئۆسۈملۈك يۇپۇرمىقىنىڭ ئۆتكۈزۈشچانلىقى پىرومېتىر ئارقىلىق ئۆلچىنىپ يۇپۇرماقنىڭ قارشى تۇرۇش كۈچى ھېساپلاپ چىقىلدۇ. تەتقىقات رايوندىكى يۇپۇرماق يۈزى كۆرسەتكۈچىسىنى ئانالىز قىلىش ئۈچۈن، يۇپۇرماق ئەۋرىشكىسى سۈرەتكە ئېلىنىپ زىرائەتنىڭ ئۆلچەملىك شارائىتتىكى سۈنى پارلاندۇرۇشى ۋە زىرائەت فاكتورى ھېساپلاپ چىقىلدۇ . ئاخىردا لوپنۇر كەندىرى بىلەن پاختىنىڭ سۇ ئىستىمالى ھېساپلاپ چىقىلىپ ۋە سېلىشتۇرلۇش ئارقىلىق بۇ ئىككىسىدىن قايسىسىنىڭ قۇرغاق شارائىتقا بەكرەك مۇۋاپىق كېلىدىغانلىقى تېپىپ چىقىلدۇ .

نەتىجە شۇنى كۆرسەتتىكى گەرچە سۈنى پارلاندۇرۇش بىر قەدەر تۆۋەن بولسىمۇ بۇ تەتقىقات رايۇندىكى پاختا مىقتارى دۇنيانىڭ ئوتتۇرىچە سەۋىيىسىدىنمۇ يۇقىرى بولدى . تەجربە قىلىنغان ئۈچ خىل ئۆسۈملۈك ئىچىدە لوپنۇر كەندىرىنىڭ كۆكرىش مەزگىلىدىكى سۇ ئېھتىياجى ئەڭ تۆۋەن بولۇپ يىلىغا 217.2 مىللىمىتىر ، چىلاننىڭ يىلىغا 339 مىللىمىتىر ، پاختىنىڭ سۇ ئۇنۇمى ئەڭ تۆۋەن بولۇپ يىلىغا 524.7 مىللىمىتىر بولۇپ لوپنۇر كەندىرىنىڭ سۇ تېجەشتىكى ئەڭ ياخشى تاللاش ئىكەنلىكىنى كۆرسەتتى .

ئىقتىسادىي ئانالىز : تەتقىقاتقا مۇناسىۋەتلىك قاتناشقۇچىلارنى بارغانسىرى كۆپەيتىش ياكى زەنجىرسىمان ئەۋرىشكە ئېلىش مىتوتى ئارقىلىق نىشانلىق ئەۋرىشكە ئۇسۇلى ئىشلىتىلدى . ئېھتىياجلىق ئۇچۇرلار قۇرۇلما خارەكتىرلىق سوئال سوراش ئۇسۇلى ئارقىلىق توپلاندى . تىستىلىنىڭ نەزىرىيىسى بويۇنچە لوپنۇر كەندىرىنىڭ ئۈچ خىل تەبىئىي بايلىقنى باشقۇرۇش شەكلى ئېنىقلاپ چىقىلدى شۇنداقلا م. خىلمىنىڭ مىتوتى ئارقىلىق ھەربىرى ئۇستىدە ئايرىم ئايرىم ھالدا كىرىم چىقىم ئانالىزى ئېلىپ بېرىلدى.

نەتىجە شۇنى كۆرسەتتىكى ئۈچ خىل ئۇسۇلىنىڭ تۈزۈلمىۋى ئورۇنلاشتۇرىلىشى بولغان خالىغانچە پايدىلىنىش ، قاشالاش ۋە فېرما قىلىش تەتقىقاتىمىزدا ئوخشىمىغان سەۋىيەدە كۆرۈلدى.لوپ كەندىرىنىڭ يىللىق چىقىمى مو بېشىغا يىلىغا 1083.35 يۈئەن بولۇپ، يىغىۋىلىنغاندىن كىيىن خام ئەيشا ماتىريال قىلىنسا يىلىغا بىر مو يەردىن 3267.63 يۈئەنگە سېتىلىدىغان بولۇپ، ساپ كىرىم موسىغا 2184 يۈئەن بولۇپ ، پايدىسى بۇ يەردىكى ئۈچ خىل ئىقتىسادىي زىرائەت ئىچىدە ئەڭ يۇقۇرى تۇرغان.

لوپنۇر كەندىرىنىڭ تارىم دەرياسىنىڭ قۇرغاق شارائىتىدا شورلاشقان يەرلەردىكى دەريا بويى ئىكولوگىيىلىك سېستىمىسىنىڭ ئەسلىگە كىلىشى شۇنداقلا ئىقتىسادىي زىرائەت يېزائىگىلىكىدىكى پاختا ئىشلەپ چىقىرىشقا قارىتا باشقىچە ئۇنۇملۈك يەر ئىشلىتىش يوللىرى ، مەسىلەن بەلگىلىك ئىقتىسادىي قىممەت يارىتىشى مۇمكىن بولغان چاي ئۆستۈرۈش ، توقۇمىچىلىق ياكى چارۋا مالLAR ئۈچۈن يەم خەشەك ئىشلەپ چىقىرىشقا ئوخشاش ئىشلارئۈچۈن پۇرسەت بىلەن تەمىنلەيدىغانلىقىنى خۇلاسىلەپ چىقتۇق .

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1. Introduction

1.1 Statement of the problem

Due to the over-utilization of water resources and the advent of global climate change, current land use in Xinjiang, China is facing great challenges with regard to sustainable land use and landscape development. In the Tarim Basin in particular, which is one of the most arid areas of the world, the irrigated land area has seen a steady increase since the 1950s, with cotton has become the major cash crop from the end of the 1980s. With irrigation consuming more and more water, there has resulted 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 up to the point of being almost completely destroyed (Cyffka, et al., 2013). Furthermore, the irrigation often leads to soil salinization; so that cotton yields shrink and entire fields are sometimes abandoned (Thevs, et al., 2008b). The cotton production of the past and present has thus resulted in a loss of ecosystem functions (ESF) and ecosystem services (ESS) as provided by the riparian ecosystems along the Tarim River, which has become detrimental to long-term sustainability of the region (Thevs, 2008). Along the river, the ecosystem functions are degraded most severely along the lower and partially, the middle reaches due to over-utilization of water along the upper reaches. Furthermore, soil salinization today reduces the amount of fertile soil available for agriculture or for future natural ecosystems.

As scientists have well documented, 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" style disaster, and is thus vital to the overall wellbeing of the region.

1.2 Research Question and Objectives

This thesis is part of the “Sustainable Management of River Oases along the Tarim River” (SuMaRiO) project, which is funded by the BMBF under the “Sustainable Land Management” program aiming to offer land management solutions for problems arising from global environmental change. This thesis covers Work Packages 4.2.2 and 5.1.3 of this project.

The following issues will be addressed:

Investigating the productivity of the above-ground (harvested) biomass of *Apocynum pictum* and of the below-ground biomass and soil carbon stock under *Apocynum* in order to calculate the carbon storage capacity; Measuring the water consumption and water use efficiency of *Apocynum pictum* on the stand level; Researching the current utilization of *Apocynum* and delivering a cost-benefit analysis of *Apocynum* farming and products; Modeling the economic impact of a land use shift towards *Apocynum*.

The key questions that will be explored in this thesis are:

What are the above- and below-ground biomasses of *Apocynum pictum* and how are they related to their environmental parameters, such as the ground water table, soil carbon and soil salinity? What is the total carbon storage capacity of *Apocynum*? How do the nutrients reflect the different sites' conditions? What is the overall water consumption of *Apocynum pictum*? How does it fare against cotton *(Gossypium hirsutum)* and the Chinese date (*Zizyphus jujuba*)? What are the main economic uses and products of *Apocynum*? How would the cost-benefit scenario develop, if land use shifted from cotton to *Apocynum*?

All the data and results will be supplied to the Decision Support System (DSS) of the SuMaRio project so as to integrate them into the local stakeholder’s decision making (Fig. 1.1).

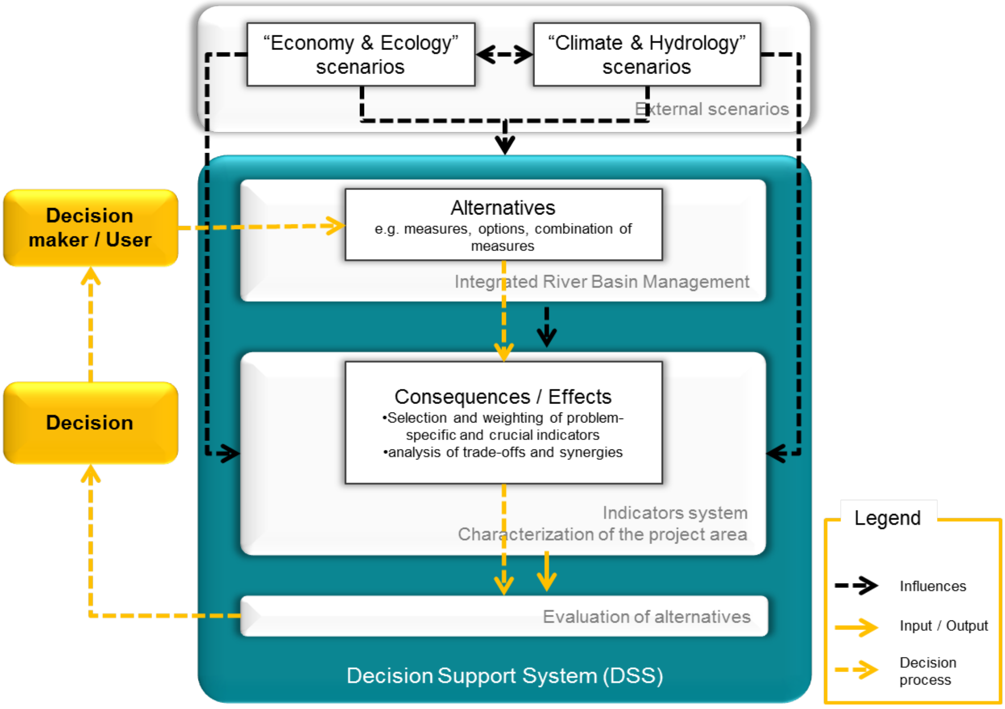

Figure 1.1: Decision Support System for the "Sustainable Management of River Oases along the Tarim River" project (Source: Cyffka, et al., 2013, page 83).

1.3 State of the Art

Dong first recognized *Apocynum* as a plant species that could be used against desertification in 1958. Zhang, et al. (2000) has done a plant division study on *Apocynum* distribution in China, and Zhang (2003) following with an investigation of *Apocynum* resources in the Aksu prefecture of Xinjiang and in Shangdong. Zhang (2006) has offered some classification and utilization strategies. Hu, et al. (1998) in the article "Artificial plantation of *Apocynum*", offered concise guidelines to grow and manage the *Apocynum* at the farm scale. Zhang, et al. (2005) have conducted studies on the generative reproduction of *Apocynum*, in particular focusing on how it pollinates. At the same time, He also have researched its vegetative reproduction by its roots.

Zhang (2008) studied the community composition of *Apocynum* in the North China plains. Su (1997) has studied the morphologies of *A. pictum* and *A. venetum* in eight different communities. Wang (2011) discovered that *A. pictum* and *A. venetum* have bifacial leaves. Zhang (2007) has studied the photosynthesis of *Apocynum* for different light conditions and found that *Apocynum* has a certain adaptability to low light levels, in addition to exploring how low light levels could reduce photosynthesis and impact the plant's growth. Ning, (2010) studied the impact of salt stress on the growth of *Apocynum* and found that it would reduce the growth rate and that the K^+/Na^+, Ca^{2+}/Na^+ and Mg^{2+}/Na^+ values would also diminish.

Lu, et al. (2009), studied the relationship between stem diameter and diurnal stem flow of *Apocynum* in the lower reaches of the Tarim River under extreme aridity and found that stems of *Apocynum* shrink during the day and expand at night, with stem flow being influenced by sun radiation, soil and wind conditions, and showing two daily peaks.

Yang (2011) carried out a DNA analysis of wild *Apocynum* in Inner Mongolia, which may offer a genetic source as a basis for further exploitation of this plant.

Many studies have been carried out on the medicinal role and components of *Apocynum* (Li & Chen, 2012). According to Xie (2012), 142 journal articles had been published on the topic by 2011, of which 112 are in Chinese and 30 in English (Xie, et al., 2012). My own literature review on *Apocynum* will be given in Chapter 4.1.

2. Study Area

2.1 Geomorphology and geology

At 1320 km, the Tarim River is the longest inland river in China, being fed by glacier-melt water and acting as the main water source for the Tarim Basin in the Xinjiang Uyghur Autonomous Region of China (XUAR) (Song, et al., 2000; Thevs, 2011). The basin – surrounded by the Tianshan Mountains in the North, the Kunlun Mountains in the South and the Pamir Mountains in the west – comprises the entire southern part of XUAR, covering an area of 1.02 million km^2 while being inhabited by 8.26 million people, the latter figure not including the population of the state military farms under the Xinjiang Production and Construction Corps (Song, et al., 2000; Thevs, 2011).

The research sites of this study are situated in the part of the Tarim Basin that used to harbor the ancient Tethys Sea, later to be replaced by the Kunlun and Tianshan mountain ranges that were created by the collision of the Eurasian and Indian plates, the collision leading to the formation of the Tarim basin as we know it today (Thevs, 2007). This historical Tarim Basin has been continuously filled with sediments in the Tertiary and Quaternary up until today (Zhou & Chen, 1992).

2.2 Hydrology

The Tarim River (Fig. 2.1) starts its course in Xiaojiake at the confluence of the Aksu, Hotan, Kashgar, and Yarkand rivers, and acts as the main water source for the Tarim Basin (Halik, 2003).

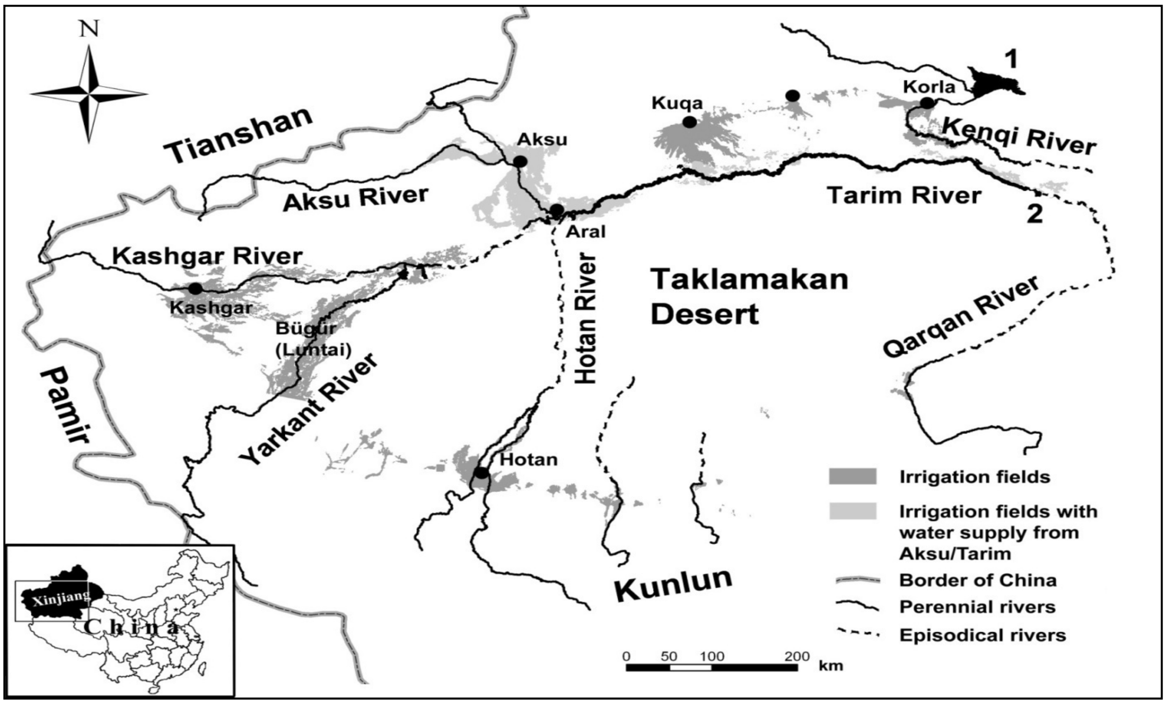

Figure 2.1: Map of the major rivers in the Tarim Basin, Xinjiang.

The river can be identified in both "broad" and "narrow" terms. According to Chen 2014, The "broad" Tarim River drainage system includes the Hotan, Yarkand, Aksu, Kaidu-Konqi, Kashgar, Cherchen, Dina, Weigan, Kuche, and Keriya rivers, thereby includes nine major river systems comprising a total of 144 rivers in the area (Chen, 2014). According to his definition, the Tarim River system includes most of the rivers in the Tarim Basin, even though many of these would not merge with the main course to form a single river. He also estimates the total length of the Tarim River to be 2437 km, as measured from the Yarkand Laskaimu River to Taitema Lake (Chen, 2014). However, the "narrow" definitions proposed by Tang & Deng, (2010) only include the Aksu, Yarkand, Hotan, and Kaidu-Konqi rivers. Although the Tarim River drainage system includes the aforementioned 144 river streams such as the Kaidu-Konqi, Yarkand, Hotan and Kashgar rivers, the Aksu River is the only major tributary that supplies water all year round, the other four rivers occasionally discharging the Tarim River main course during times of high flooding (Tang & Deng, 2010).

Tang & Deng, 2010 defined the “four source rivers and one mainstream”, with the Tarim River being the main stream and the four contributing tributaries of Aksu, Yarkand, Kashgar and Hotan being the source rivers (Fig. 2.2). Together, these cover a drainage area of about 260000 km^2, as shown in Table 2.1. The total annual accumulated runoff of the four source rivers is estimated at 25.67 km^3, thereby accounting for 64.4 % of the entire Tarim Basin.

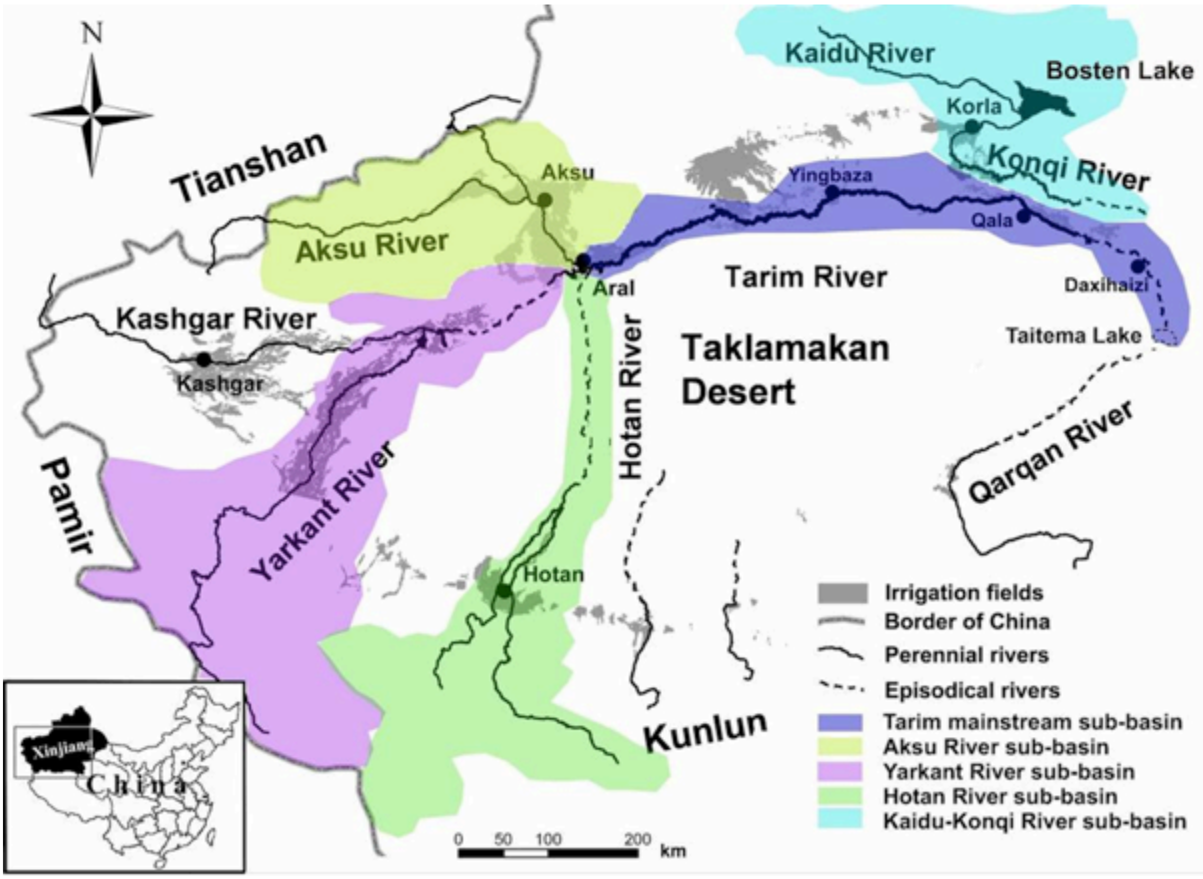

Figure 2.2: The four source rivers and one mainstream (Source: Peng, 2014, Page 545).

In former times, Lopnur Lake used to act as the terminal lake for the Tarim River, but following its gradual desiccation in the 1950s, Taitema Lake took over this role (Chen, 2014). However, this role was further shifted to the Daxihaizi Reservoir when the latter was constructed in 1972 (Chen, 2014).

Table 2.1: Size and drainage statitics for the "four source rivers and one main stream" (Source: Tang & Deng, 2010).

		Drainage Area (10^4 km^2)		
River name	River lengh (km)	Total drainage area	Mountain	Plain
Tarim River (main ourse)	1321	1.76		1.76
Kaidu-Konqi River	560	4.96	3.3	1.66
Aksu River	588	6.23 (1.95)	4.32 (1.95)	1.91
Yarkand River	1165	7.98 (0.28)	5.69 (0.28)	2.29
Hotan River	1127	4.93	3.8	1.13
Total	4761	25.86 (2.23)	17.11 (2.23)	8.75

*Numbers given in parentheses indicate additional area outside of China.

According to Chen 2014, two tributaries, the Kumalake (Kunmalik) and Tuoshigan (Toshkan) rivers, have their source in the southern Tianshan Mountains at the Chinese-Kyrgyzstan border, with the former originating in the Kyrgyzstan Tianshan glaciers. The two meet in Wensu (“Onsu” in Uyghur) and form the Aksu River for 130 km up to Xiaojiake, where it becomes the Tarim River and is a trans-boundary river (Zhang, et al., 2012). The Aksu River’s runoff is generated from glacier and snow melt and from rainfall in the two headwater catchments of the Aksu – the Sari-Djaz (area: 13000 km^2, 21 % glacier) and Kokshaal (area: 18400 km^2, 4 % glacier) catchments (Rumbaur, et al., 2014).

During the summer flooding season, the Hotan and Yarkand rivers also flow into the Tarim (Chen, 2014; Thevs, 2011). The Hotan River originates in the northern slope of the Kunlun Mountains and runs through the southwestern Tarim Basin (Chen, 2014). It is formed by the convergence of two tributaries – the Yurungkax River that comes from the northern Kunlun Mountains and the Karakax River, which descends from the Karakoram Mountains (Chen, 2014). The main stream of the Yarkand River originates from the Karakoram Pass in the Northern slope of the Karakoram Mountains and is the largest river in the Kashgar prefecture (Xu, et al., 2013)

The Kaidu River is situated at the northern fringe of the Yanqi Basin on the south slope of the Tianshan Mountains. It starts in the Hargat and Jacsta valleys amidst the Tianshan and terminates in the Bosten Lake (Li, et al., 2011), having a total length of 560 km, with the Konqi River (i.e., the lower part of the Kaidu-Konqi River) then draining out of the Bosten

Lake and flowing parallel to the Tarim lower reaches. The Konqi was hydrologically connected with the Tarim through natural wetlands and river branches until the 1970s. Today, it supplies water through artificial channels into the Tarim's downstream section (Peng, et al., 2014).

As shown in Fig 2.3, the Aksu River has the highest water volumes for both surface and non-surface water-charged ground water at 95×10^8 m^3 and 11.36×10^8 m^3, respectively, supplying water to natural vegetation and the people in the middle and lower reaches of the Tarim. This is due to its larger glacier sources and relatively higher precipitation, which also charges the ground water (Tang & Deng, 2010). Although the Yarkand and Hotan rivers also have very high surface water volumes, they do not merge into the mainstream during the non-flood season, and instead support the vegetation and livelihoods in the surrounding oases. The Kaidu-Konqi River exhibits the lowest surface water volumes, which may be attributed to its shorter length as compared to the other rivers.

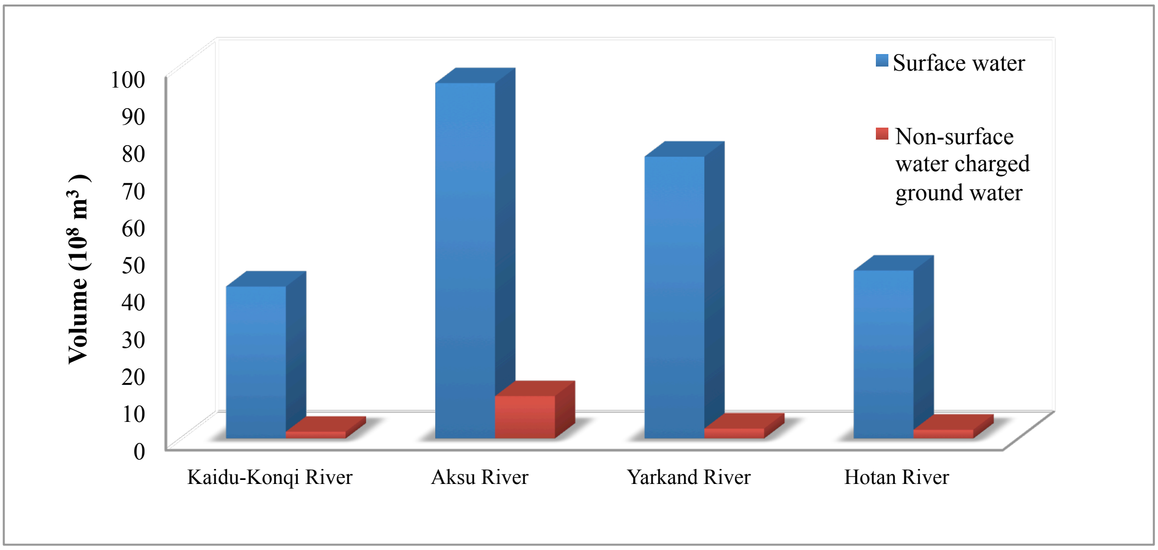

Figure 2.3: Annual water resources in the four branches of the Tarim River (Tang & Deng, 2010).

The headwaters of the rivers within the Tarim Basin are supplied by snow melt, glacier melt, and summer rainfall in the Kunlun, Pamir and Tianshan mountains (Thevs, 2011). According to Chen 2006, snow- and glacier-melt water comprises 48.3 % of the total river runoff in the Tarim River, which results in the runoff being highly susceptible to the changes in glacier area. Due to global climate change, 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 (Shangguan, et al., 2009). This has led to a modest increase in total annual runoff in the Aksu and Yarkand rivers, although no significant changes have appeared in the Hotan and Kaidu-Konqi rivers (see Fig 2.4). In terms of runoff quantity, the Aksu River is the most reliable and largest source to the Tarim River, with an annual runoff of 93.13 × 10^8 m^3 (as of 2005), with the Kaidu-Konqi River having the smallest annual runoff of 35.82 × 10^8 m^3 (2005). The Yarkand and Hotan rivers have annual runoffs of 80.94 × 10^8 m^3 and 53.42 × 10^8 m^3, respectively, although they seldom supply water to the Tarim.

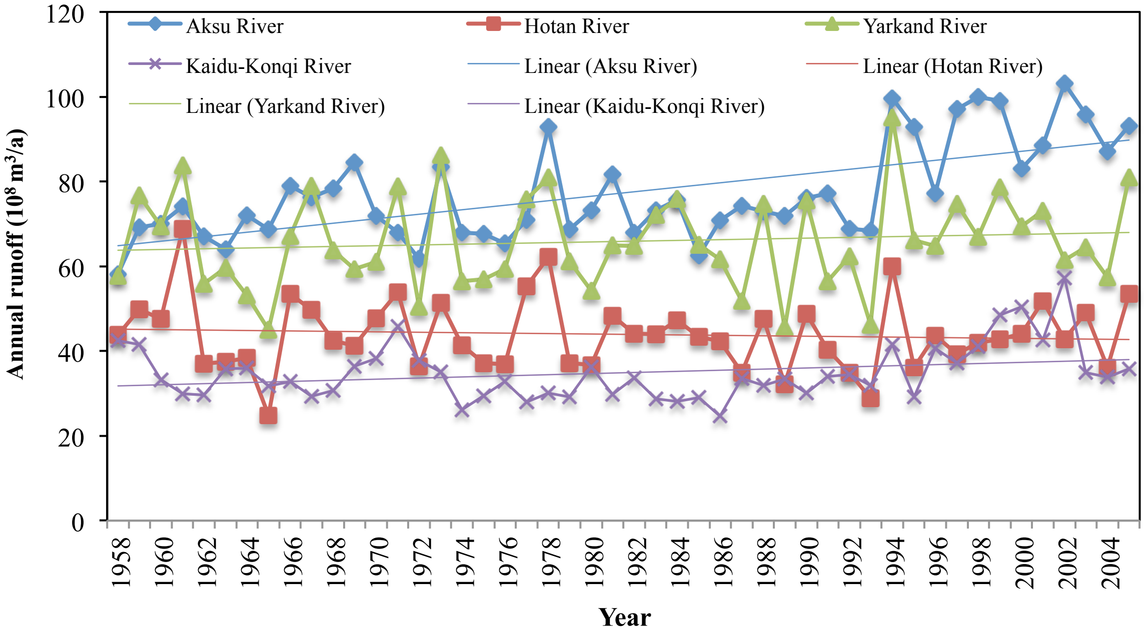

Figure 2.4: Annual river runoff in the four source rivers of the Tarim River, from 1958 to 2005 (Source: Tang & Deng).

However, rapid population growth and growth in agricultural production has increased the need for water in the upper-stream rivers of the Tarim, which has far outpaced the relatively small increases in river runoffs in the headwaters and has led to less water in the mid and lower streams of the river (Hao, et al., 2007). The river runoff measured at four water stations located in different sections of the river between 1957 and 2000 shows (Fig 2.5) that they all exhibit declines in runoff, with the Qiala Station of Yuli county, located at the lower end of the river, experiencing the most dramatic decline, which has exacerbated the existing water scarcity and has had devastating impacts on natural vegetation as well as on the local residents' livelihoods. The Xinqiman and Yingbaza (located in Luntai, or Bugur, county) stations also showed a decline in water supply, while Alar, which is located in the upper reaches of river, has experienced the lowest decline among all four stations.

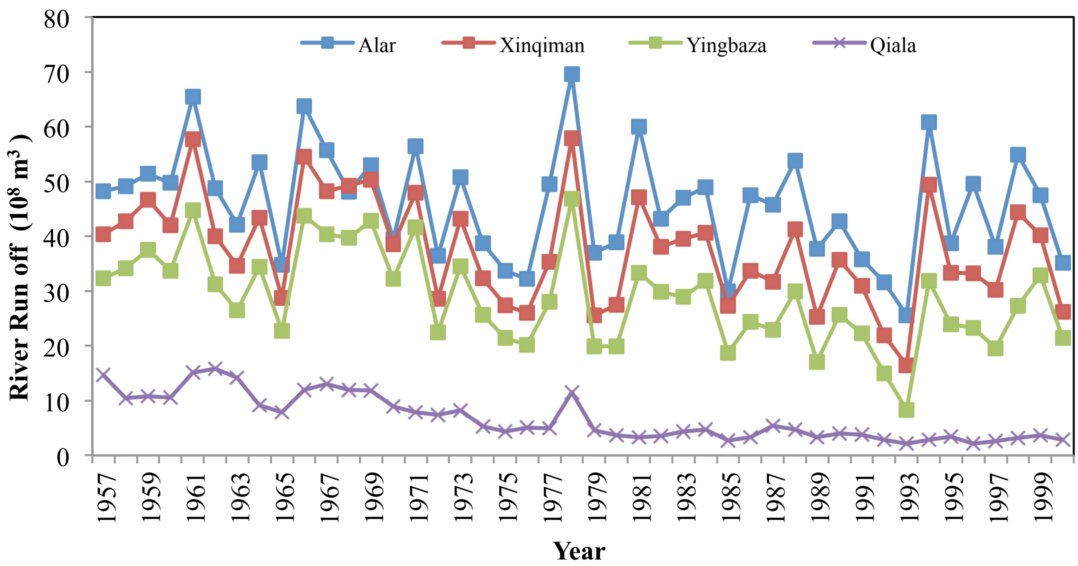

Figure 2.5: Annual river runoff at the four different water stations along the Tarim, from 1957 to 2000 (Source: Hu, et al., 2005).

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 (Tao, et al., 2011).

Like many inland rivers in Central Asia, the Tarim is impacted by climate change and the anthropogenic disturbances in the region, which will be discussed in detail in Chapter 2.6. The ambitious government-initiated agriculture campaign in the 1960s led to vast areas of the land being cultivated and developed in the lower reaches of the river, which has led to massive migration to the area from the coastal provinces of eastern China, to the construction of numerous reservoirs and to the irrational use of water resources. As a result, the water flow in the Tarim River decreased rapidly and approximately 320 km of the river course desiccated, with the groundwater level dropping by 4-8 m in the lower reaches (Chen, et al., 2006; Li, et al., 2009) and surface water salinity rising from 1.3 g/L in 1960 to 4.0 g/L in 1982, and then further to 7.8 g/L in 1998 as a result of the return flow from irrigation (Li, et al., 2009).

To reverse the situation and restore the degraded ecosystems along the Tarim, China's government decided to invest 10.9 billion Chinese Yuan (about 1.3 billion USD) and initiated a water-diversion project in the year 2000 (Li, et al., 2009). This project diverted water from Lake Bosten to the main channel of the Tarim through the Konqi River and the Daxihaizi Reservoir to the river's lower reaches. From 2000 to 2006, an average of about 320 MCM of water was transferred annually, with water transfers carried out twice a year, once in late spring and once in the early fall (Li, et al., 2009). This has increased ring increment (Yu, et al., 2011) and root suckering (Aishan, et al., 2013) of the *Populous euphratica*, which is a keystone species of the Tugai vegetation along the Tarim. The ground water from the river banks in the middle reaches has risen 2-4 m after the water conveyance, which has made positive contributions to the rehabilitation and to restoring vegetation along the river (Chen, et al., 2010).

2.3 Climate

Because the Tarim Basin is surrounded by mountain ranges, it receives very little precipitation and suffers from very strong evaporation (Zhou, et al., 2012), as may be seen in Fig. 2.6. Its continental climate is characterized by hot summers and cold winters, with strong winds and dust storms occurring in the spring. The mean annual precipitation is less than 50 mm, while the mean annual evaporation is around 2,300-3,000 mm. The annual accumulated temperature (10 °C) ranges from 4,000 to 4,350 °C, with an average annual temperature ranging from 10 to 11 °C (Zhao, et al., 2012). This has led to the region being classified as winter cold steppes and deserts by Walter & Breckle (1999) and Thevs (2007). The mean January temperature ranges from -7 °C in Korla to -6 °C in Bachu, while the mean July temperature ranges from 26 °C in Korla to 34 °C in Bachu (www.weatherbase.com).

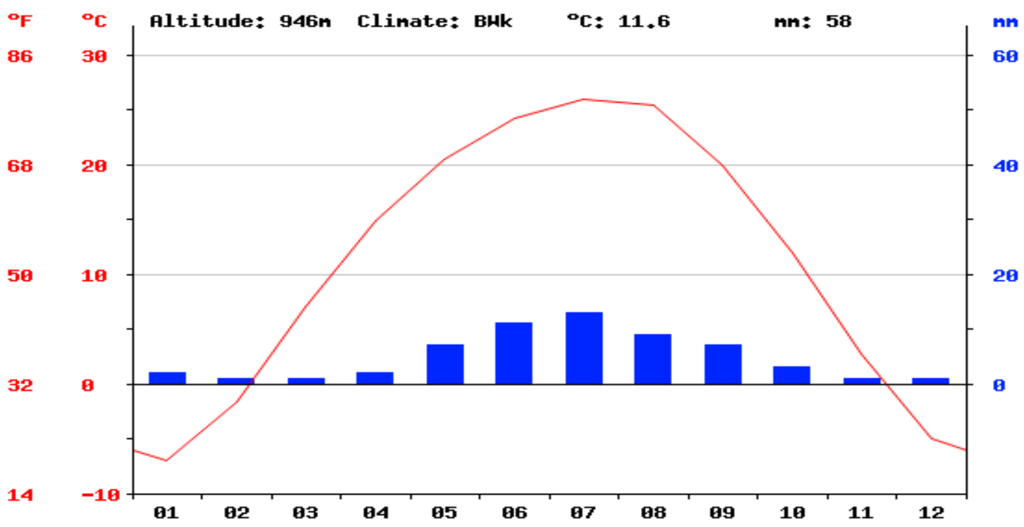

Figure 2.6: Climate diagram of study location (downloaded from http://en.climate-data.org/location/2426).

Using the Mann-Whitney and Mann-Kendall non-parametric methods from climate data from 19 different stations between the years of 1958 and 2002, Xu, et al. (2006) have observed sharp changes in the long-term temperature and precipitation trends in the basin .Their results showed increases in both temperature and precipitation (Chen, et al., 2013). The sharp increasing trend started from the mid-1980s and has continued ever since, with the 1990s being the warmest and most humid decade (Chen, et al., 2013) in the past half-century, a development which parallels the climate change of the entire Xinjiang region (Chen, et al., 2013). According to the analysis of Shang, et al. (2009), which is based on data from 25 weather stations in the Tarim Basin, a warming of 0.77 ± 0.16 °C (0.019 °C yr^{-1}) and a precipitation increase of 22.8 ± 7.9 % between 1960 and 2000 were observed in the region (Rumbaur, et al., 2015), something that has brought unprecedented changes to both the climate and natural vegetation (Chen, et al., 2006).

2.4 Soil

The parent materials for soils in the study area are either fluvial or eolian sediments (Thevs, 2007). According to the FAO soil classifications, the relevant soil types in the study area are: Fluvisols, Solonchak, Arenosols, and Anthrosols (Thevs, 2007).

Fluvisols have parent material that consists of fluvial sediments and organic matter accumulated from litter and is mainly found in the floodplains and alluvial fans along the Tarim and Konqi rivers and their branches. Solonchak is formed by salt accumulation. It can be found in depressions in the flood plains. Arenosols are soil formations that are weak because of aridity, and are distributed in piedmont gravel areas in the Kuruktag foothills.

Finally, Anthrosols are formations of a horizon with gleyic properties, arising from irrigation and is distributed in the areas influenced by irrigation (Thevs, 2007).

2.5 Vegetation

The Tarim Basin is home to the so-called "Tugai" vegetation, which is the riparian vegetation along the rivers in the continental, winter cold deserts of Central Asia – i.e., it is found along the Tarim River in the Tarim Basin, as well as along the Amu and Syr rivers in the Aral Sea Basin (Thevs, et al., 2008b). It mainly consists of *Populus euphratica* Oliv., *Populus pruinosa* Schrenk. and *Elaeagnus angustifolia*, but is also associated with shrub communities (mainly the *Tamarix* species) and with grassland vegetation, i.e., *Phragmites australis* Trin. ex Steud (Thevs, et al., 2008a). Along the middle and lower reaches of the Tarim, the Tugai forests almost exclusively consist of the tree species *P. euphratica* (Thevs, et al., 2008a). Consequently, *P. euphratica* is a keystone species (Bond, 1994; Thevs, et al., 2008a) of these riparian forests.

Most common species found in this region are listed in Table 2.2. Hao, et al. (2005) has divided the different plant communities in the basin into the following four groups by their environmental and site conditions:

Table 2.2: The common plant species in the lower reaches of the Tarim River (Hao, et al., 2009; Halik, et al., 2009 modified)

No	Type	Plant species
1	Tree	*Populus euphratica*
2		*Populus pruinosa*
3		*Elaeagnus angustifolia*
4	Shrubs	*Tamarix ramosissima*
5		*Tamarix leptostachys*
6		*Tamarix hispida*
7		*Lycium ruthenicum*
8		*Nitraria sibirica*
9		*Halimodendron halodendron*
10		*Halostachys caspica*
11	Herbs	*Aeluropus pungens*
12		*Alhagi sparsifolia*
13		*Apocynum venetum*
14		*Apocynum pictum*
15		*Sophora alopecuroides*
16		*Glycyrrhiza inflata*
17		*Cirsium japokicum DC*
18		*Karelinia caspica*
19		*Cynanchum sibiricum*
20		*Echinops gmelinii*
21		*Inula salsoloides*
22		*Salsola* sp.
23		*Salsola ruthenica*
24		*Hexinia polydichotoma*
25		*Scorzonera* sp.
26		*Taraxacum* sp.
27		*Kochia scoparia*
28		*Kochia prostrata*
29		*Phragmites australis*
30		*Calamagrostis pseudophragmites*

Group I contains *Salsola ruthenica, Halostachys caspica* and *Taraxacum mongolicum*, and is found in the shallow groundwater zone with high soil moisture content.

Group II comprises *Hexinia polydichotoma, Glycyrrhiza inflata* and *Salsola pellucid*, and is also generally associated with the shallow groundwater zone where mineralization and pH values are relatively high.

Group III is made up of *Alhagi sparsifolia, Phragmites australis, Apocynum venetum, Nitraia sibirica,* and *Karelinia caspica*. These are mostly herbaceous species and occur as a group in the middle groundwater zone (referred to as Zone II). This zone is also characterized by high soil moisture content and high soil alkalinity.

Group IV includes *Populus euphratica, Tamarix ramosissima, Tamarix hispida, Tamarix leptostachys* and *Lycium ruthenicum*, all of which are shrub/tree species and occur as a group in the deep groundwater zone. This group contains all the species of *Tamarix*, which are deep-rooted phreatophytes that depend on groundwater for their water supply (Zhang, et al., 2005). Groundwater levels played a dominant role in determining the ecosystem structures and functions in the lower reaches of the Tarim River (Chen, et al., 2006) and are also the constraining factor for riparian ecosystem restoration (Hou, et al., 2007; Zhang, et al., 2013)

The Tugai vegetation is a unique and threatened flood plain ecosystem that offers an important habitat for plant and animal life and contains the highest biodiversity in the region (Thevs, 2007). Additionally, it provides numerous ecosystem services such as

- Biomass production (supporting services),
- Providing wood, fodder, fiber and fuel (provisioning services) to local populations,
- Flood and climate regulation, soil and riverbank stabilization, sand fixation and wind protection (regulating services),
- Offering tourism, educational and recreational opportunities (cultural services).

The total area of the Tugai forests in the Tarim Basin declined from approximately 500,000 ha in 1958 to approximately 200,000 ha in 1978 (Thevs, 2008a). Some Tugai forests and vegetation were destroyed directly in order to gain new farmland and indirectly as a consequence of the excessive use of water resources for irrigation. Land degradation and declining groundwater tables have also caused a decline in species diversity, with the disappearance of herbaceous plants and serious degeneration of semi-shrubs and shrubs becoming frequent (Liu, et al., 2005; Hao, et al., 2009). As the region comprises the world's largest contiguous Tugai forests, the conservation and restoration of this riparian vegetation should be of worldwide concern. The natural riparian vegetation is a mosaic that consists of *Populus euphratica* forests (Westermann, et al., 2008), reed beds of *Phragmites australis* (Thevs, et al., 2007), *A. pictum* meadows*, Tamarix* shrub lands and halophyte communities (Thevs, et al., 2008b). The natural riparian vegetation is grazed nearly everywhere, with reed beds close to the river courses grazed from spring until the summer flooding. When the floodwaters rise, the herders move away from the reed beds to places of higher elevation.

The construction of the Daxihaizi Reservoir in 1972 disrupted much of the streamflow in the Tarim, resulting in the absence of surface water for a stretch of approximately 320 km, with groundwater levels dropping in the lower reaches. The two lakes previously serving as the terminals of the Tarim River, Lakes Lopnur and Taitema, dried up in 1970 and 1972, respectively. The groundwater level has also dropped from 3-5 m to 8-12 m below the ground surface over the past three decades (Chen, et al., 2006). The dropping groundwater levels have resulted in marked changes to the community structures of plants and and to the species composition.

2.6 Human Geography, Water and Land Use

Xinjiang is one of the most ethnically diverse regions in China, with ethnic Uyghurs making up the largest proportion of the population with 10.05 million (XJSYB, 2011) people, thereby accounting for 47 % of the regional population. They are followed by the Han Chinese (39 %) and other minority groups such as the Kazahk, the Hui, the Kirgiz, the Mongol, and the Xibe making up the rest. Since 1949 there has been a substantial increase of in-migration to Xinjiang from other parts of China, with Xinjiang's population increasing dramatically from just 4.3 million in 1949 to 21.8 million in 2010 (XJSYB, 2011). In particular, the migration of Han Chinese has drastically altered the traditional population balance of the region – in 1949, the ethnicity accounted for around 7 % of the total population, with the number going up to approximately 40 % in 2006. The Tarim Basin as shown in Fig 2.7 is inhabited by a total of 8.26 million people, which does not include the populations of the state military farms under the Xinjiang Production and Construction Corps (Song, et al., 2000; Zhang, et al., 2006; Thevs, 2011).

There are two administrative systems in Xinjiang. The first is the local government system, the same as in rest of China, while the second is the Bingtuan system (i.e., the Production and Construction Corps of the Chinese military), which is known to be present in the border areas of the country such as Xinjiang and Inner Mongolia, and which currently has a total of 14 divisions (numbered from 1 to 14), in addition to several departments. The Bingtuan system has provincial government authority, and its economy and social development are carried out both separately and exclusively under the state plan (Shen, 2009). According to the administrative divisions, it covers (a) the city of Aksu, Shaya County, Xinhe County and Kuche County in the Aksu Prefecture, (b) Luntai County, Korla City, Yuli County, Ruoqiang County in the Bayinguoleng Mongolian Autonomous Prefecture and (c) 15 farms under Agricultural Division No. 1 (State farm 7, 8, 9, 10, 11, 12, 13, 14, 15 and 16) and Agricultural Division No. 2 (State farm 31, 32, 33, 34 and 35) of the Xinjiang Production & Construction Corps (Huang, et al., 2010).

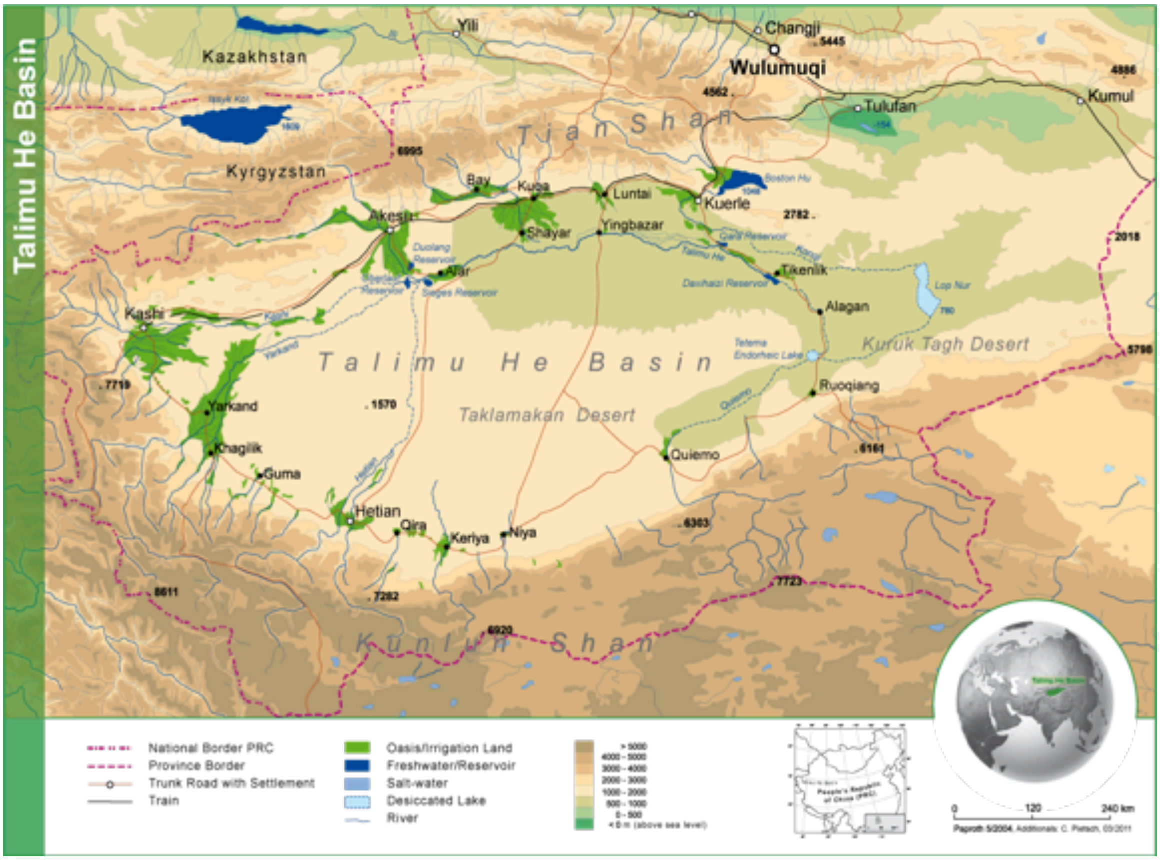

Figure 2.7: Map of the major oases along the Tarim River (Source: Cyffka, et al., 2013, Page 78).

As explained in the previous section, the extreme aridity of the Tarim Basin makes all agriculture there dependant on irrigation (Hoppe, 1992; Thevs, 2011). Settlements and industry extract water from the surface water bodies as well as from the groundwater (Tang & Deng, 2010). The natural vegetation relies on groundwater (Gries, et al., 2003; Thevs, 2011), which is recharged by the local rivers (Hou, et al., 2007; Thevs, 2011). In the basin, the natural vegetation and agriculture, as well as settlements and industry, directly or indirectly depend on the river water as their major water source, thus leading agriculture, settlements, industry, and natural ecosystems to compete for limited river water. From the 1950s to the 1970s, the area under irrigation was steadily enlarged, resulting in an increasing demand for irrigation water (Hoppe, 1992; Giese, et al., 1998; Halik, 2003; Thevs, 2011). This led to the 320 Km long lower reaches of the Tarim River being desiccated and to the disappearance of the terminal Lakes Lopnor and Taitema in the 1970s, which then further resulted in severe degradation of the natural riparian vegetation (Song, et al., 2000; Giese, et al., 2005; Thevs, 2011). After 2002, within the framework of the Tarim River Regulation Scheme, flood pulses were diverted into the lower reaches of the Tarim River (Zhu, et al., 2006; Thevs, 2011). However, in the ten years from 2001 to 2010, five of those years saw a cessation of water during the spring and early summer seasons (the planting and irrigation seasons) throughout the entire middle reaches and the lower section of the upper reaches. Consequently, water consumers, the farmers especially, faced water severe shortages (Thevs, 2011).

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 (Zhao, et al., 2012). It is, however, becoming increasingly evident that future development in this area will be curtailed by the environmental problems induced by the water crises (Zhao, et al., 2012). When water flow in the Tarim's mainstream was tremendously reduced, thus leading to around 320 km of the river course in its lower reaches being desiccated in the early 1970s, up to 46 % of the riparian wetlands in the middle and lower reaches of the river disappeared within the 20 years from 1980 to 2000 (Zhao, et al., 2012). The world's largest habitat for *Populus euphratica* shrank from 454,000 ha in the 1950s to 247,300 ha in 2000 (Zhao, et al., 2012).

Water allocation and water rights of the Tarim River

Within the framework of the 1988 Water Law of China, the Xinjiang government issued the Interim Provisions for Water Administration and Water Resource Management of the Tarim River Basin in 1994, which led to the adoption of the Tarim Regulations in 1997 (Thomas, et al., 2006; Zhu, et al., 2006; Thevs, 2011) and to the establishment of the Tarim River Basin Water Resource Commission (Thevs, 2011), which guides and supervises the water management of the whole Tarim Basin and Tarim River catchment (Peng, et al., 2014). Two World Bank projects – the "Tarim Basin Project" (1991-1997) and the "Tarim Basin II Project" (1998-2005) – have been carried out to build water infrastructure and institutions for sustainable water resource management (World Bank, 2007; Thevs, 2011).

Prior to 2005, Tarim Regulations had set the annual water use quota for each sub-river basin with the agreement of all stakeholders in order to ensure the required annual flow of the Tarim mainstream and water use for ecosystems (Peng, et al., 2014). After carrying out the study and analysis on the water needs of natural vegeration (sanctioned by the Xinjiang Hydrological Administration), the Xinjiang government announced the "Xinjiang Water Resource Management Regulations", which set water quota for different types of natural vegetation as shown in below Table 2.3 (Tang & Deng, 2010) and takes consideration of inter-annual variations of the runoff within the quota system (Thevs, 2011) to allocate water usage between economic development (mainly irrigation agriculture) and the environmental flow all along the Tarim (Song, et al., 2000; Thomas, et al., 2006; Tang & Deng, 2010; Thevs, et al., 2013). By means of this water quota system, it will be guaranteed that an average of 0.35 Km^3 of water reaches the Tarim lower reaches annually (i.e., the river stretch around Arghan), despite the water discharge from the Tarim upper reaches (i.e., upstream of Yingbaza) into the middle and lower reaches being unreliable (Peng, 2014; Thevs, 2011; Thevs, et al., 2013). The natural vegetation is able to remain productive during periods of water shortage –i.e., if the river courses do not carry water for several months – provided that the groundwater layer is recharged during flood events (Thevs, et al., 2013). Therefore, the different species of the natural vegetation might offer land use opportunities under such unfavorable water supply conditions as those found along the Tarim lower reaches or downstream, or in the delta regions of other rivers in Central Asia (Thevs, et al., 2013).

As we can see from Table 2.3, many of the *A. pictum* in this study belong to the "medium density grassland" category and should receive 3525 m^3/ha of water per year. However, there exists no proper mechanism for monitoring whether the natural vegetation is receiving the amount of water set by the quota and often times it suffers from severe water shortages during the reproduction season, when water is needed most.

Table 2.2: Ecological water quota for the "four source rivers and one main stream" for different land types, provided in m^3/ha per year) (Tang & Deng, 2010 modified).

Land Type / Rivers		Hotan River	Yarkand River	Aksu River	Kaidu-Konqi River	Tarim river main course
Forest	Forestland	5775	5775	5565	5250	5775
	Shrub land	3975	3975	3735	3300	3975
	Woodland	1650	1650	1500	1200	1650
	Other forestland	8250	8250	7500	6000	8250
Grassland	High density grassland	8250	8250	7635	6000	8250
	Medium density grassland	3525	3525	3330	2700	3525
	Low density grassland	1050	1050	855	900	1050
Water	River	19890	18150	17310	16200	19425
	Lake	23400	21360	20370	17730	22860
	Reservoir, ponds	23400	21360	20370	19065	22860
Wetland	Shoaly land	16650	16650	16650	12600	16650
	Swampland	23400	21360	20370	19065	25140

A quota system has been adopted by the Tarim River Basin Water Resource Commission so as to allocate water to the Aksu and Bazhou prefectures, as well as to the Xinjiang Production and Construction Corps, along the Aksu and Tarim rivers (Thevs, 2011). Furthermore, within each river stretch, quotas are fixed for the allocation of water into irrigation, oil exploitation, and that left for the natural vegetation – that is, environmental flow (Tang & Deng, 2010; Thevs, et al., 2014) – as is illustrated in Fig 2.8. The headwaters of the Aksu River produce 8.06 Km^3/a of water volume, of which 3.42 Km^3/a are released into the Tarim River via the Alar station, in addition to 0.33 Km^3/a and 0.9 Km^3/a from the Yarkand and Hotan Rivers, respectively (Tang & Deng, 2010). The proposed quota for the Aral station stands at 4.65 Km^3/a, with an additional quota of 0.45 Km^3/a from the Kaidu-Konqi River to be released to the Tarim allocated throughout the middle and lower reaches by different water demands and sections. The upper reaches in the Aksu prefecture and Division 1 of XPCC would consume 0.41 Km^3 and 1.61 Km^3 of water for irrigation and ecological purposes, respectively, whereas the middle reaches in the Bazhou prefecture would use 0.35 Km^3, 0.12 Km^3 and 1.67 Km^3 of water for irrigation, oil exploration and ecological purposes, respectively. Finally, the lower reaches would also receive 0.46 Km^3 and 0.15 Km^3 of water for irrigation and ecological purposes, respectively. Additional strong emphasis is given to the terminal lake Taitema, which should receive 0.35 Km^3/a of water in the end section. Although oil exploitation at the middle reaches could potentially receive 0.12 Km^3/a of water in this quota system currently, future developments in shale gas by hydraulic fracturing, which requires a lot more water than traditional drilling, could accelerate the water demand and exacerbate the situation in the Tarim (Reig, et al., 2014), possibly causing groundwater contamination and thereby bringing about adverse effects on humans and vegetation alike.

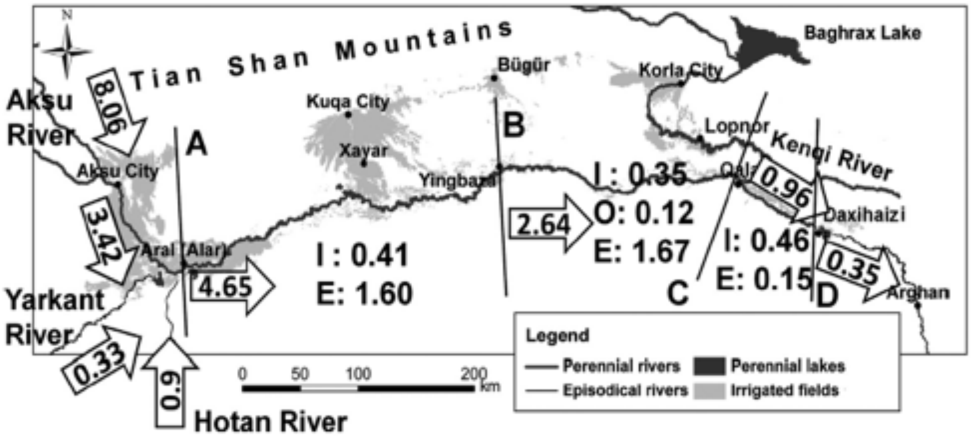

Figure 2.8: Water inflow from the Aksu, Yarkant and Hotan tributaries into the Tarim main stream, with water quotas along the Tarim main stream under average conditions provided [Km^3/a], I: irrigation and industry, E: environmental flow, O: oil exploitation. A–B: upper reaches, B–C: middle reaches, C–D: upper section of lower reaches, D and below: lower reaches (Thevs, et al., 2014, page 4).

According to Tang & Deng (2010), the amount of water released into the Tarim River at Aral has not met the proposed quota or water rights since 1989, as may be seen in Fig 2.9. Rather, it has been persistently lower than the proposed quota, which has exacerbated the water scarcity situation in the middle and lower reaches. Population growth, as well as both industrial and agriculturalexpansion, are the main drivers behind this lag in supply.

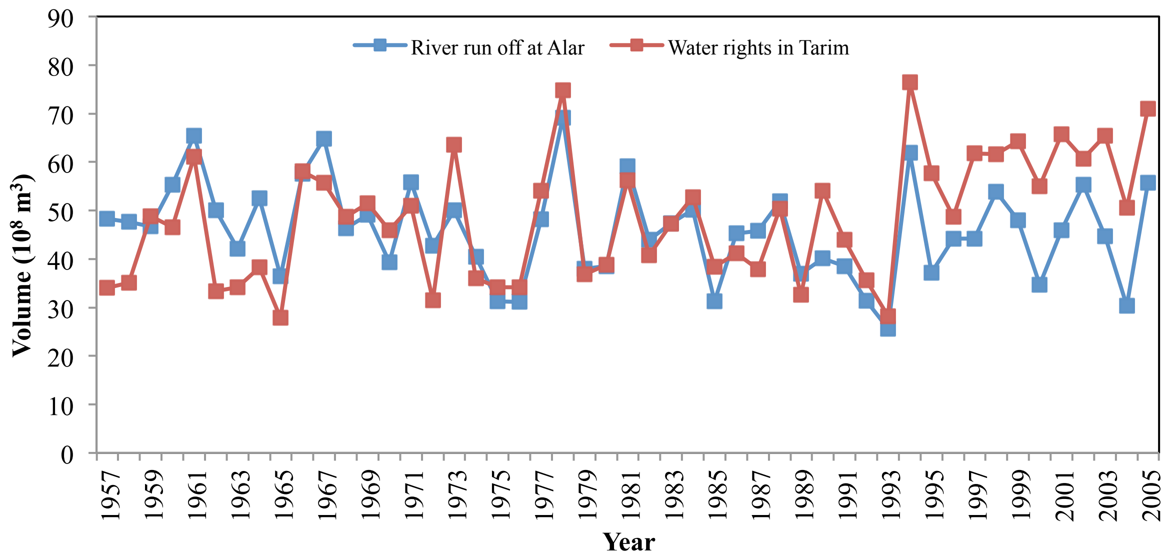

Figure 2.9: River runoff at the Alar water station and the water rights volume along the Tarim River (Tang & Deng, 2010 modified).

Uncontrolled development and unplanned management of water resources, inequitable water distribution, and wastewater dumping along the river have led to conflicts between water users (Qi, et al., 2005). Strict implementation of water pricing policies based on volumetric water pricing systems could increase the water use efficiency (Shen, 2009), thereby potentially minimizing water stress and water related conflicts. Qi, et al. (2005) also claimed that total water consumption in the upstream by agriculture should not exceed 2.0×10^{12} m^3 to ensure sustainability of ecosystem of the Tarim Basin.

Agricultural Development in the Tarim River Basin

Xinjiang's land bureau estimates that between 1991 and 1997 more than 3.3 million mu of land was reclaimed, including the 2 million reclaimed by the Corps. An additional 7 million mu was forecast to be reclaimed between 1996 and 2000, of which 5 million mu would be used to grow cotton (Becquelin, 2000). Mu the most common Chinese unit for area, 1 mu= 666.5 m^2 = 1/15 hectare (Ho, 2005) and this thesis Mu will be used as main area unit for economic analysis of cash crops.

According to reports from China's Department of Environmental Protection, "desertification has progressed in 53 of the 87 districts of Xinjiang. Many lakes are drying up, especially around the Tarim River". Another study has noted that while some 40,000 km^2 of desert was converted into cultivable land, during the same period the desert area increased by 50,000 km^2 (Becquelin, 2000).

A comparison is to be found in Soviet Central Asia. Soviet central planners decided to turn Uzbekistan and Kazakhstan into the Soviet Union's cotton production base, and new lands were extensively opened up, with the two main rivers (Amur Darya and Syr Darya) diverted to irrigate cotton cultivation. The result was an unprecedented ecological disaster, bringing about the desiccation of the Aral Sea, land salinization and damage to vast areas of arable land. It is not surprising, then, that a similar policy was met with opposition from some inside the Xinjiang administration. The plan to turn Xinjiang into a national cotton base seems to make little sense unless the rationale is to encourage the in-migration of Han through massive land reclamation and to facilitate an expansion of the Corps, whose function is to reclaim land and whose state farm structure is favorable to extensive cotton production (Becquelin, 2000).

Starting from 1949, there have been huge campaigns centered on converting desert into farmland, designed to increase agricultural production in Xinjiang. Opening up the so-called "wasteland" is strongly encouraged by both central and local governments and increasing the amount of cultivated land is a key goal of agricultural development at all levels of government (Shen, 2009).

Large areas of wasteland ("huangdi", meaning "unused land", which includes wetlands, forests, grasslands, and deserts) have been "opened up" and have become cultivated land. Statistics on the areas that have been "opened up" have become one of the most important measures of agricultural development at all levels of government. Less attention has been given to the consequences of the loss of grasslands and forests. In general, crop farming has become stressed and animal husbandry is perceived as being inferior in importance and value to some extent. In 1949, the cultivated area was approximately 1.2 million ha. By 2006, it had increased to approximately 3.6 million (XJSYB, 2007; Shen, 2009).

However, much of this "opened up" land had to be abandoned due to problems relating to lack of water and soil salinization (Shen & Lein, 2005; Shen, 2009). The latter is a prevalent problem in all branches of the Tarim River. Around 40 % of the cropland has been impacted by salinization, as may be seen in Fig. 2.10.

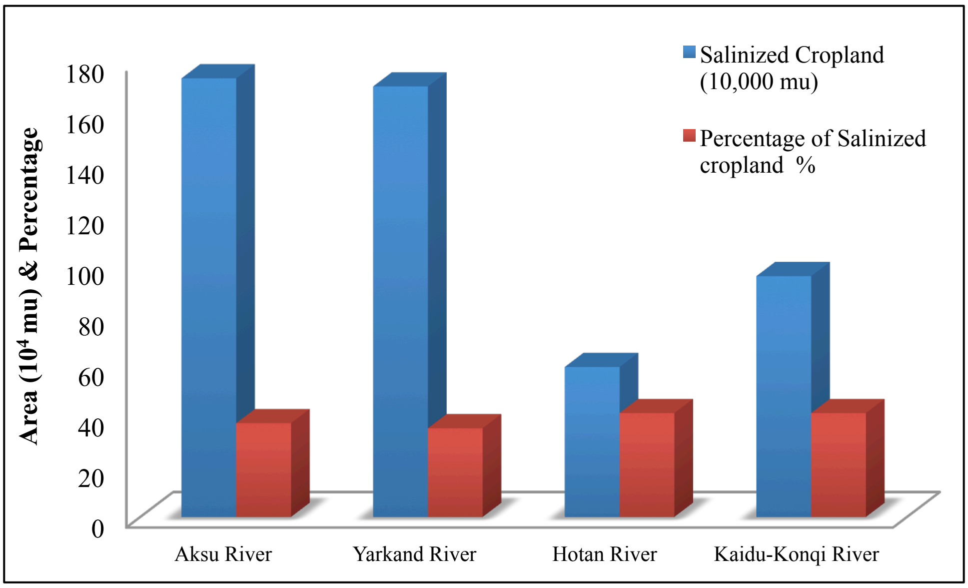

Figure 2.10: Salinized croplands at four branches of the Tarim River (Tang & Deng, 2010 modified).

Today, the local government still actively encourages farmers to save money to open up the so-called “five wastelands”: wastelands (desert), waste beaches, waste sloping lands, waste wetlands, and waste hillside lands. The policy is that “whoever invests in opening up wasteland receives the benefit from it”, and anyone can open up as much wasteland as they can afford (Shen, 2009). The settlement of large numbers of migrants from outside the region has resulted in rapid development of agricultural projects and the diversion of freshwater to newly reclaimed land for crop production. However, poor management practices soon led to severe environmental degradation at the early stages of the land reclamation in the Tarim Basin and its adjacent areas (Deng, et al., 2001; Chen, et al., 2006). The problems were further exacerbated by deforestation and irrigation-induced salinity, resulting in considerable economic losses (Chen, et al., 2006).

The Tarim region is abundant in resources, but has a fragile ecological environment which creates an intensive conflict between economic development and the ecological environment (Huang, et al., 2010). For the restoration of the ecosystems, the Chinese local governments have carried out high-priority projects designed to make the Tarim River regain its original flow rate, to restore the ecosystems and to restrain the extent of desertification (Liu, et al., 2013).

Since the late 1990s, the protection of the ecological environment of the lower reaches of the Tarim River Basin has become focal point, largely as a consequence of the central government’s Great Western Development Strategy (Hou, et al., 2005, 2006; Jiang, et al., 2005; Xu, et al., 2008; Yang, et al., 2006; Zhu & Lei, 2003; Shen, 2009). Zhu & Lei, (2003) claim that the 'Tuigenghuanlin' ("returning croplands to forests") project will definitely improve the ecological systems of the oases in Xinjiang, although to date the benefits have not been fully understood.

Water use efficiency in the Tarim Basin runs between 35 % and 40 %, which means that most of the water is lost by evaporation, cycling, or through water conveyance (Qi, et al., 2005). Feike has split the main drivers behind the agricultural development along the Tarim River into four main categories: demographic, socio-economic, natural and technological (Feike, et al., 2014).

Cotton production in Xinjiang and the Tarim Basin

Despite its reduced share in the textile fiber market, cotton still remains the major natural fiber used in textiles (Zhao & Tisdel, 2009). Cotton is grown in many drylands of the world – e.g., in Central Asia (Uzbekistan, Turkmenistan, and northwest China), Turkey, Texas (USA), and Australia (Chapagain, et al., 2006) – where it needs to be irrigated. In addition to being the major global producer of cotton, China is its major consumer as well. In 2012-2013, China was responsible for 28 % of the global cotton production, for 35 % of the consumption and for 50 % of global stocked cotton (ICTSD, 2013).

Since 1980, the location of China's cotton production has tended to shift towards its western regions, particularly Xinjiang (Zhao & Tisdel, 2009), which is the only cotton region with large-area plantations and with a high-level of mechanization (Zhao & Tisdel, 2009). In 2012, Xinjiang alone produced half of China's cotton (3.53 million tons out of a total of 6.83 million, as seen in Fig 2.11). The figure also shows that national cotton production from 1990 to 2012 has fluctuated with a slight increase from 4.5 million tons in 1990 to 6.83 million in 2012. 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. 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" (Ouyang, 2008; Zhao & Tisdel, 2009).

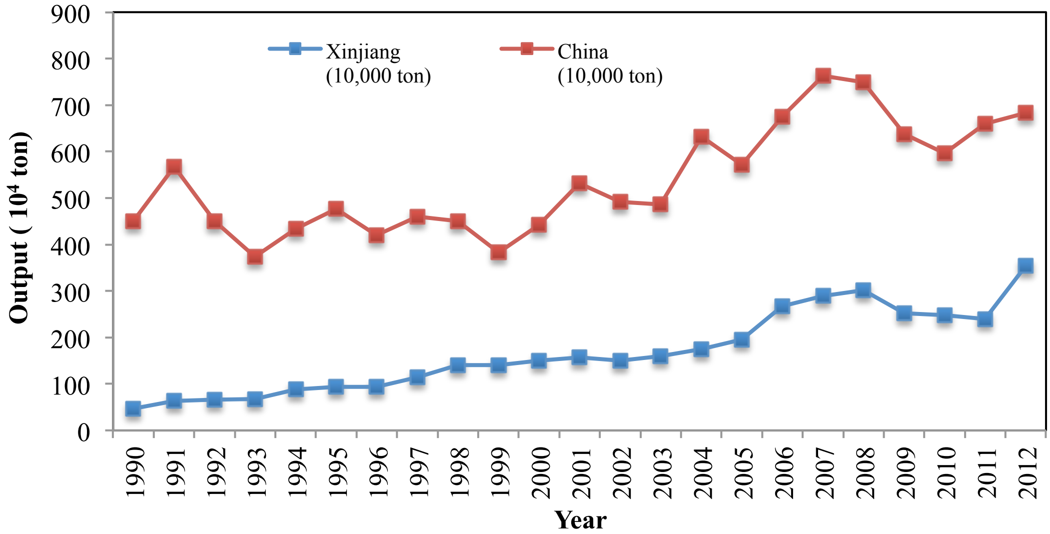

Figure 2.11: Cotton output for all of China and Xinjiang (NBSC & XJSYB, 2013).

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 went on to quadruple in the same period (Fig 2.12) before stabilizing after 2009. Because this region has little rainfall in normal years, its cotton production depends completely on irrigation (Zhang, 2001; Zhao & Tisdel, 2009). 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.

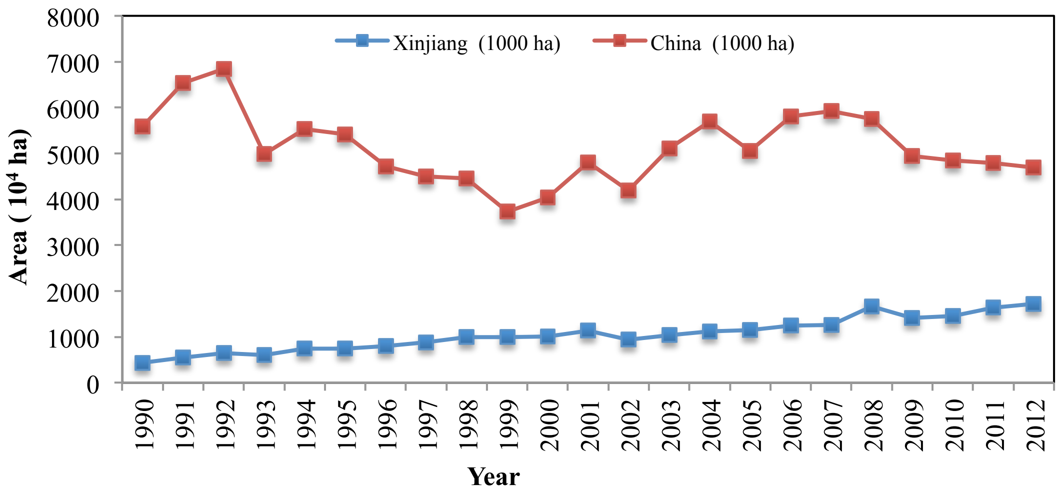

Figure 2.12: Cotton area for all of China and Xinjiang (NBSC & XJSYB, 2013).

The construction of irrigation works and the adoption of water-saving irrigation technology have made Xinjiang an important cotton producing region (Zhang, 2001; Zhao & Tisdel, 2009), with a per mu yield of cotton that is consistently higher than the national average (Fig

2.13). This, in turn, has made Xinjiang the most attractive region for the expansion of cotton production, even though the water availability still poses a significant constraint (Zhang, 2001; Zhao & Tisdel, 2009).

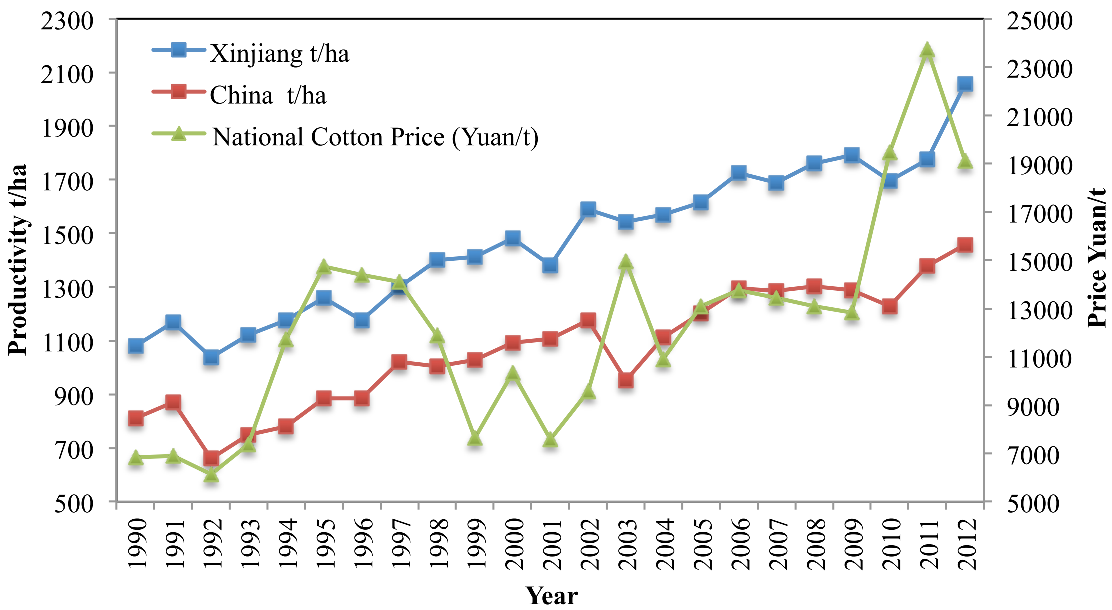

Figure 2.13: Cotton productivity for Xinjiang and All of China, together with cotton price (NBSC & XJBSY, 2013).

Returns from growing cotton are presently very unstable in China, with economic returns tending to be low and fluctuating because of the constant fluctuations in the cotton price (see Fig 2.13). Furthermore, international market competition is fierce, and the increase in production and labor costs cut into the profit margins. Accordingly, the gains from cotton production have declined sharply in recent years, thereby lowering incentives for farmers to plant cotton (Zhao & Tisdel, 2009).

Our study area in the Aksu-Tarim River region, 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 population increase. 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). Dramatic acceleration has been noted after 2003 in particular. Meanwhile, the cotton output also saw a corresponding rise from 78,666 tons in 1989 to 1,283,980 tons in 2011 (Fig 2.14). The population for the same time periods has also increased steadily, from 2,837,371 in 1989 to 4,243,542 in 2012.

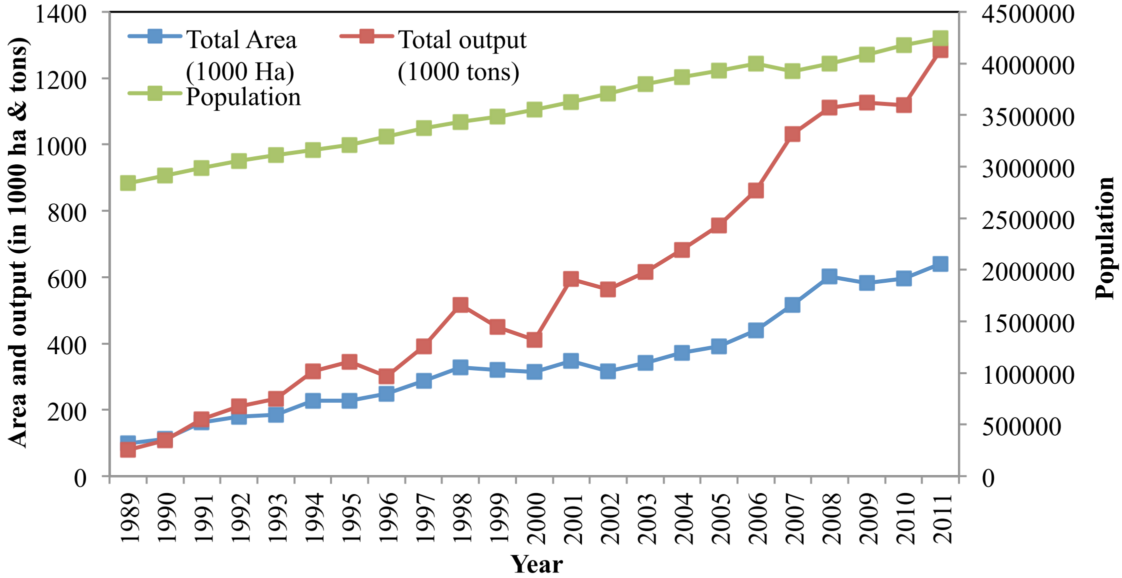

Figure 2.14: Cotton area and production for the Tarim region, 1980-2011 (XJSYB, 2012).

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 (Adams, et al., 2014).

Chinese Red Date Cultivation in the Tarim Basin

Along the southern rim of the Tarim Basin the fruit tree *Zyzyphus jujuba* has been promoted from the previous decade onward (Xin, 2012). Jujebe is one of the world's major fruit crops which is cultivuated in India, Russia, Middle East, southern Europe and especially in China (Yao, 2013). It has versitle use, aside from its fruits; it can also used as timber wood for furniture, fodder for cattles, honey and all the parts can be used in medicine (Yao, 2013). Since 2002, date planted area in Xinjiang showed rapid increase as shown in Fig 2.15.

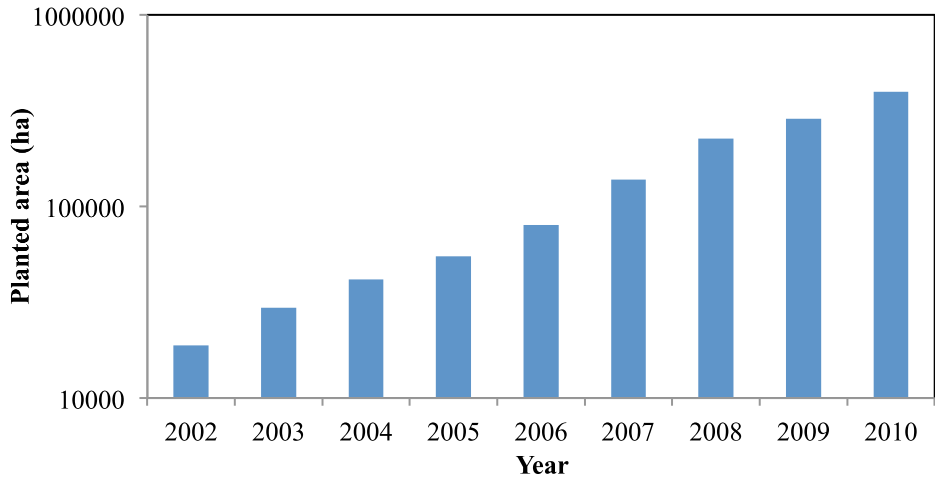

Figure 2.15: Date plantation in Xinjiang, 2002 and onwards (XYSYB, 2011).

The date is usually served as dry fruit, used in traditional medicine and acts as a nourishing food. Its plantations require dry and hot summers, but can also endure cold winters. As such, date trees are well-adapted to the desert conditions of the Tarim Basin (Shi & Song, 2005). In Xinjiang, there are several different varieties, categorized according to their color and their places of origin: the “Gray Date”, the “Red Date”, the “Zanhuang Date” and the “Jun Date”. The fruit yield in the first two or three years is usually very low. Afterwards, the yield increases steadily and comes to its peak when the tree is about 20 years old, after which the yield decreases until the tree dies. Today, *Z. jujuba* serves as the major cash crop and source of income for the locals in the oases of Qarqan and Qarklik.

Recently, *A. pictum* has attracted attention as a medicinal and fiber crop. *A. pictum* is a perennial herb, part of the natural riparian vegetation along the rivers of the Tarim Basin (Thevs, et al., 2012a), and will be central focus of this thesis.

2.7 Research sites in this study

2.7.1 Biomass and productivity of *Apocynum pictum*

A. pictum was investigated at five sites in the Tarim Basin: Bachu, Xayar 1 and 2, and Qongaral 1 and 2. Such a dispersion of sites allowed us to represent the western, central and eastern parts of the basin (Figure 2.16). Because the basin’s water is supplied from melt water and summer precipitation in the mountains, the Tarim River floods in the summer, with seventy-five percent of its annual discharge concentrated in the months of July, August and September (Song, et al., 2000). Thus, the four sites in Xayar and Qongaral are partly flooded in the summer. A notable example is the year 2010, when the site Xayar 2 was inundated completely. In general, the two sites in Xayar are flooded more often than the sites in Qongaral because of a dyke that was built along the section of the river adjacent to Qongaral (Tang & Deng, 2010).

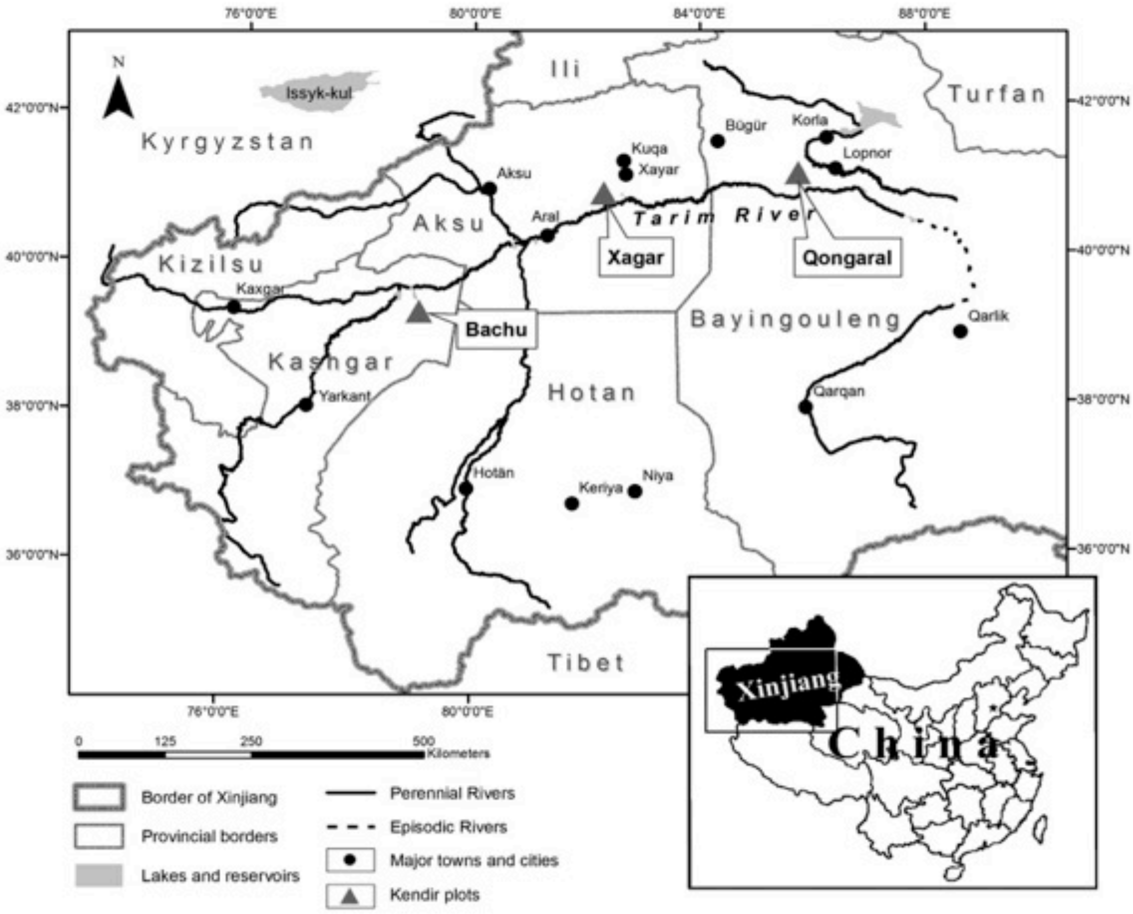

Figure 2.16: Map of biomass field measurement sites for *Apocynum*.

The sites in Qongaral and Xayar are covered by a mono-specific *A. pictum* vegetation, while in Bachu *A. pictum* occurs together with *Tamarix* spp., *Nitraria* sp., *Karelinia caspica* (Pall.) Less., *Alhagi sparsifolia* (B. Keller et Shap.) Shap., and *Phragmites australis* Trin. ex Staud. The sites at Qongaral are used for leaf and stem harvest. In late summer, this site is used for occasional grazing. The sites in Xayar were neither harvested nor grazed until 2010, but continuous grazing began in the spring of 2011. In Bachu, the *A. pictum* stand is only occasionally grazed.

2.7.2 Water use efficiency of *A. pictum*, cotton *(Gossypium hirsutum)* and Chinese date *(Z. jujuba)*

This section focuses on cotton, *A. pictum* and *Z. jujuba*, the ET_c measurements for which were conducted at the sites of Yingbaza, Qongaral, and Qarqan, respectively. The transect site Qongaral 1, discussed in the previous section, was also chosen for evapotranspiration measurement for *A. pictum* so as to measure its hourly stomata conductance, from which its evapotranspiration was calculated by the Penman-Monteith equation for every month of the vegetation seasons in 2011 and 2012. Qongaral is located in Korla City on the Layi River, a branch of the Tarim in its inland delta (Figure 2.16). *A. pictum* forms natural mono-species stands along the Layi River, growing to a height of 1 m with an above ground biomass of 0.6 to 0.92 t/ha. The *A. pictum* stands are occasionally grazed by sheep and goats. The groundwater level fluctuates around a mean of 5 m. The *A. pictum* stands are bordered by the *Tamarix* shrub vegetation.

The same round of measurements was also performed for cotton at Yingbaza, which is located in Bügür County about 200 km southwest of Korla on the middle reaches of the Tarim River. The study site at Yingbaza is a cotton field 5 km north of the village Yingbaza, with the field plot having a size of 100 m × 80 m. Cotton is planted under plastic mulch combined with drip irrigation as described by Zhou, et al. (2012), with one row of cotton seeds planted on both sides of each drip line. The two rows of cotton and the drip line are covered with one sheet of plastic foil as plastic mulch. The cotton is planted in April and harvested in September and October. The yields are around 1.5 t/ha of lint cotton.

Qarqan is an oasis town on the southern rim of the Tarim Basin (Figure 2.16), and one of the first oasis towns to promote the cultivation of *Z. jujuba* some ten years ago. The investigated site is an orchard surrounded by *Populus alba* tree rows as shelterbelt. The trees are planted in rows, the rows 4 m apart from each other. Within each row, the trees are spaced at intervals of 2 m. The tree height is 3 m. The soil is partly covered with grass vegetation, which is occasionally grazed by sheep and goats.

2.7.3 Economic analysis of *Apocynum*

Stakeholders involved in growing, selling, producing and retailing *Apocynum* and its related byproducts were interviewed in Urumqi, Korla, Yuli, Xayar and Altay via a semi-structured questionnaire and workshops.

3. Methods

3.1 Biomass and productivity of *Apocynum pictum*

3.1.1 Measurements of biomass, groundwater depth, and electrical conductivity

In this section, we discuss how the sampling of above-ground and below-ground biomass of *Apocynum*, groundwater and soil measurements, and subsequent nutrient analysis of the samples in the lab were carried out to find the carbon storage capacity of the plant. This analysis may offer a physical and production basis for alternate land use considerations.

The best and probably most commonly used method for the measurement of herbaceous biomass is to clip or harvest the total standing biomass (Bonham, 2013). On all five sites, the spatial distribution of *A. pictum* was mapped through field investigations. *A. pictum* distributions were elongated at all sites, reflecting periodic river branches. Qongaral was chosen as a major site for both biomass and evaporation measurement (Fig 3.1).

Figure 3.1: Wild *A. pictum* stands at Qongaral 1 (Photo: Rouzi, June 2011).

The fieldwork in Bachu was completed in September 2009, in Qongaral in June 2011, and in Xayar 2 in July 2011. Between three and five representative sampling plots were selected randomly at each site (Table 3.1) by applying the point-centered quarter method as described in Mueller-Dombois and Ellenberg (1974). The plots were arranged along cross sections running perpendicular to the river branches and cutting through the areas covered by *A. pictum*. At each plot, eight subplots of 1 m × 1 m were laid outand placed 30 m from the plot center in the eight cardinal/intercardinal directions (N, NE, E, SE, S, SW, W, and NW). The plant heights and crown diameters were measured at each subplot. Afterwards, the subplots were completely harvested in order to determine the biomass per area. The biomass was separated into stems and leaves, oven dried, and weighed.

At each site, soil profiles were drilled (Table 3.1) with a machine-driven soil borer and the depth to groundwater was measured. Soil samples were taken at 0-5 cm, 5-20 cm, 20-100 cm, and from the groundwater layer.

Soil salinity is generally characterized by determining the electrical conductivity (EC) of the soil solution (Rhoades, 1990), which may be seen as a proxy for salt content. The main methodological principle is that the soluble salt of the soil is as assumed to be a strong electrolyte (Schlichting, et al., 1995). The electric conductivity of each sample was measured using an extract from the water-saturated soil paste. The plant tolerance to salinity has been expressed based on EC values of a saturation paste extract (USDA, 1954; Mass & Hoffman, 1977).

Because the electrical resistance declines at rising salt ion concentrations, the electrical conductivity may be taken as a measurement of the dissolved salt ion concentration (Alaily, 2000). The soil samples were dissolved in water at a ratio of 1:5. The measurement of the soluble salts was made with a conductivity meter (LF 325) with nonlinear temperature compensation (25 °C standard temp.) as discussed in Rowell (1996). Because the literature data refers to EC values of saturated paste, the results were multiplied by 6.4 (Rowell, 1996) for EC (at saturated paste).

Table 3.1: Number of plots and soil profiles per site.

Site	**Number of plots per site**	**Number of soil profiles per site**
Bachu	5	5
Qongaral 1	3	1
Qongaral 2	3	1
Xayar 1	4	1
Xayar 2	4	2

The soil profile drilling was done concurrently with the plant and biomass sampling. In Qongaral and Xayar, the soil profiles were drilled in June and July so as to obtain data representative of the deepest groundwater level, which the plants must endure during the vegetation period. As there are no flood events in Bachu, the soil profiles drilled in September are representative of the standard groundwater level at which *A. pictum* must survive.

Above-ground biomass was sampled using the point-centered quadrant method in two transect locations, with each location having two transect sites. Two field locations were chosen in the Qongaral and Xayar counties to evaluate the biomass and productivity of *Apocynum*. With a total of four transect sites (Qongaral 1, Qongaral 2, Xayar 1, and Xayar 2), the above- and below-ground *Apocynum* biomass per square unit was measured, soil samples were taken, and the groundwater levels were measured (June of 2011).

Above-ground biomass sampling: At all five sites, the spatial distribution of *A. pictum* was mapped through field investigations. Afterwards, three to five representative sampling plots were selected at each site (Table 3.1). At each plot the stem and leaf biomass, plant height, and crown areas were measured. At each site, *A. pictum* shows an elongated distribution reflecting periodical river branches. The plots were arranged along cross sections running perpendicular to the river branches cutting through the areas covered by *A. pictum.*

The fieldwork in Bachu, Qongaral and Xayar 2 was done in September 2009, June 2011and July 2011, respectively. Xayar 1 was first investigated in 2010 and then again in July 2011, as a means to analyze the impact of the grazing.

At each plot, eight subplots of 1 m × 1 m each were laid out. The subplots were placed 30 m from the plot center in the directions N, NE, E, SE, S, SW, W, and NW. In each subplot, the plant height and crown diameter of the plants inside the plot were measured. Afterwards, the subplots were completely harvested, in order to measure the biomass per area. The biomass was separated into stem and leaf biomass, oven dried and weighted.

Groundwater and soil measurement: Soil profiles were drilled (Table 3.1) at each site with a machine-driven soil borer, going down to the groundwater layer and measuring the groundwater levels. Samples were taken along the soil profile at the depths of 0-5 cm, 5-20 cm, and 20-100 cm, as well as from the groundwater layer (Fig 3.2). The electric conductivity of each soil sample was measured for an extract from the water-saturated soil paste.

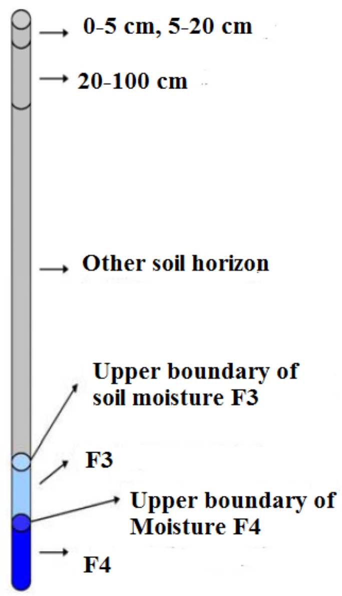

Figure 3.2: Soil sampling diagram.

The soil profiles were drilled together with the plant and biomass sampling. In Qongaral and Xayar the soil profiles were drilled in June and July, in order to reflect the deepest groundwater level, which the plants have to endure during the vegetation period. As there are no flood events in Bachu, the soil profiles drilled in September reflects the groundwater level, which *A. pictum* has to endure.

Statistical analysis: All statistical analyses were conducted with the statistical software R (version 2.15.2). Significance was evaluated at the $P < 0.05$ probability level. A one-way analysis of variance (ANOVA) in combination with the Tukey *post hoc* test was used to detect the differences in plant height, crown area and groundwater, as well as the differences in stem, leaf and total above-ground biomass between sites.

3.1.2 Above-ground biomass sampling for the plant allometric formula, 2012

A total of 30 *A. pictum* stands – 10 for each of the three plots –were measured and harvested in Qongaral 2 by using the nearest-neighbor method from plot center for calculating the plant allometric formula. Distances from the center point, plant heights and crown diameters in the NS & EW directions and plant stem basal diameter were all measured, together with the fresh total above-ground harvested biomass. Later, the dried biomass was separated into leaves and stems and weighed separately. Correlations between the measured plant parameters, such as height, crown diameter, basal diameter and stem and leaf biomass, were obtained together with the allometric formula.

3.1.3 Below-Ground Biomass Measurement

Below-ground and above-ground biomass sampling were carried out at the same time, with three 1 m × 1 m × 1 m cubes dug up at each study site in Qongaral and Xayar and with all the root and plant materials sifted and sampled (Fig 3.3). The fresh and dry weights were measured and later used for nutrient analysis.

Figure 3.3: Below ground biomass hole (Photo: A. Rouzi, June 2011).

3.1.4 Soil Nutrient Analysis

All of the collected above- and below-ground biomass and soil samples were classified for further treatment.

Sample treatment procedure

To measure the total carbon (C) and nitrogen (N) contents of the soil samples, the samples were grinded to a powder. Soil samples used for the determination of total nitrogen and the carbon-to-nitrogen (C: N) ratio were dried at 70 °C for 48 h and then grounded for 5 min with a centrifugal mill (Fritsch, Idar-Oberstein, Germany).

For the determination of carbon and nitrogen content and the total-carbon-to-nitrogen (C_{total} : N) ratio, an elemental analyser (Vario EL, Elementar Analysensysteme GmbH) was used. The sample material was grinded and oven dried at 105 °C for one hour and constantly kept dry onwards. There were slight variations in the sample masses, with an average weight of approximately 50 mg. The samples were weighed in thin tin capsules and flash combusted in the elemental analyser. Acetanilide was used as the calibration standard. The investigation of the C_{total} : N parameter referred methodologically to Buurman, et al. (1996).

During this procedure, ball mills (Planetary Mono Mill PULVERISETTE 6 Classic) were used to grind the soil, while cutting mills (from the Fritsch Germany factory) were used to grind biomass. Both samples were then put into an oven for 12 hours with a set temperature of 100 °C. After that, a sensitive balance (AC210S) was used to weigh the soil and biomass (60-65 mg for the soil and 15 mg for the biomass), after which the samples were stored in small tin boxes (Elementar Analysen Systeme GMBH company) for further analysis.

Soil samples were mixed by hand and oven dried (75 °C) immediately after fieldwork. Afterwards, the composite samples were sieved (2 mm) and grinded by hand in preparation for the pH and C : N measurements.

C, N determination by the Vario El analyzer

The Vario El analyzer (Elementar Analysensysteme GMBH) was used to determine the total carbon and nitrogen contents. Samples were dropped into the combustion tube automatically at user selected temperatures of up to 1200 °C. The use of tin vessels further elevated the sample's combustion temperature to values of up to 1800 °C. The complete combustion of all sample types was ensured with our special oxygen jet injection, with a unique program for each sample matrix combined with efficient post combustion. The oxygen content of the sample was determined by converting oxygen (O) to carbon oxide (CO) at 1150 °C on a carbon black contact. The organic carbon content of the soil was then calculated by subtracting the inorganic carbon content from the total carbon content (Schlichting, et al. 1995).

Soil chemical analysis

Soil pH affects plants, in part because the solubility of certain minerals varies with differences in pH. Plants absorb soluble mineral elements, but do not absorb insoluble forms. At a low pH, for example, the aluminum and manganese in soil water are more soluble and are sometimes absorbed by roots in toxic amounts. At a higher pH, certain mineral salts essential for plant growth, such as calcium phosphate, become less soluble and thus less available to plants (Berg & McClaugherty, 2008). Soil pH also has a great effect on the leaching of minerals. An acidic soil has less ability than an alkaline soil to bind positively charged ions because the soil particles also bind the abundant protons. As a result, certain minerals essential for plant growth, such as potassium (K^+), are leached more readily from acidic soil. The optimum soil pH for most plant growth is 6.5 to 7.5, as most essential elements needed by plants are available in that range (Berg & McClaugherty, 2008).

The pH measurement approach was performed based on the work of Hoffmann (1991). 10 ml of the soil samples and 50 ml of the suspension medium ($CaCl_2$, 0.01 mol/l) were mixed together and left overnight. Measurements were carried out using the instrument pH 340i (WTW). The pH was then determined as discussed in Rowell (1997) for a 0.01 M $CaCl_2$ suspension with a pH-electrode (pH 96 WTW, Weilheim) – using an automatic temperature correction with respect to the 25 °C standard temperature reference.

The spectrophotometric determination of the concentration of extractable phosphate (P_2O_5) was carried out using the molybdenum blue method (Murphy & Riley, 1962; Mantilla-contreras, et al., 2011).

To determine the relation of organic carbon to total nitrogen (C_{org}/N_t) in the soil, samples were finely grinded (0.2 mm) with a ball mill Pulverisette 14 (Fritsch) at 400 rpm for 4 minutes. 1012 mg fine soil was then used to analyze the C and N content with the elemental analyser Vario EL III (Elementar). Systematic analysis was executed according to the procedures of ISO 13878 (1998) and ISO 10694 (1995) (Margesin & Schinner, 2005). Since the soil contained no carbonate, the measured total carbon content was equivalent to the organic carbon content in the samples. Charcoal pieces found in the soil were excluded from the treatment.

The C/N ratio, carbonate, C_{anorg}, C_{org} and N were only investigated at the main root area of the individual soil pits, thus counting up to 75 samples. All samples were air dried, with analyses carried out after homogenization at the fine earth fraction (< 2 mm). For the determination of the $CaCO_3$ content and C/N ratio, all samples were further grounded in a centrifugal ball mill (Pulverisette 6, Fritsch Idar-Oberstein). All samples used in the determination of the C/N ratio were additionally oven dried (105 °C, one hour).

Calculation of organic carbon in the soil

As described in Buurman, et al. (1996), the inorganic carbon content (C_{anorg}) was calculated by dividing the $CaCO_3$ value by 8.32. The organic carbon content C_{org} was then determined indirectly by subtracting C_{anorg} from the C_{total} value. The organic carbon content for each layer of the soil was then obtained by following equation:

SOC (kg/m^2) = Soil depth * Soil density * Soil organic carbon content
Soil Bulk density = dry weight of fine soil material (g)/ fine soil volume in cylinder (100 cm^3),
Overall soil carbon Stock by this equation (3-1) (He, et al., 2002)

$$\mathrm{SOC} = \sum_i^n T_i * p_i * M_i \qquad (3\text{-}1)$$

T is soil thickness (cm), p is soil bulk density (g/cm^3) and M is organic carbon concentration (%). Soil Bulk density = dry weight of fine soil material (g)/ fine soil volume in cylinder (100 cm3).

3.2 Water use efficiency of *A. pictum* and cotton

3.2.1 Theoretical background

Crop water use is governed by two factors – evapotranspiration (ET) and the plant's ability to transport water from the soil to the atmosphere (Webber, 2008). Evapotranspiration (ET), defined as the water lost to the atmosphere by transpiration and evaporation (Fenton, 2010), is a key component of water balance and is closely linked to ecosystem productivity (Lu, et al., 2011). Accurate evapotranspiration values are particularly crucial for water resource management and planning for crops in arid climates.

Evapotranspiration consists of two physical processes: the evaporation of water from the soil surface and transpiration from plant leaves. The proportion of evaporation to transpiration varies depending on the plant growth stage and the soil water status, with evaporation dominating before the plant canopy is fully expanded or on the day following heavy irrigation or rainfall (Allan, et al., 1998).

A widely applied approach to determine crop and plant evapotranspiration is the reference evapotranspiration approach as described in the FAO Irrigation and Drainage Paper No. 56 (Allan, et al. 1998). According to the FAO 56 guide, the major impact factors for evapotranspiration include weather parameters, crop factors and the management and environmental conditions.

Reference crop evapotranspiration (ET_0): The evapotranspiration rate for a reference surface with sufficient water is called the "reference crop evapotranspiration" (or "reference evapotranspiration") and is denoted as ET_0. The reference surface is a hypothetical grass reference crop with specific characteristics. Climate parameters are the only factors that impact ET_0 (FAO 56).

All energy fluxes should be considered when deriving an energy balance equation. The equation for an evaporating surface can be written as

$$R_n - G - \lambda ET - H = 0 \qquad (3\text{-}2)$$

where R_n is the net radiation, H the sensible heat, G the soil heat flux and λET the latent heat flux.

The latent heat flux (λET), which represents the evapotranspiration fraction, can be calculated from the energy balance equation if all other components are known. The net radiation (R_n) and soil heat fluxes (G) can be measured or estimated from climatic parameters. H requires accurate measurement of temperature gradients above the surface.

Crop evapotranspiration under standard conditions (ET_c): The crop evapotranspiration under standard conditions, denoted as ET_c, is the evapotranspiration from disease-free, well-fertilized crops that are grown in large fields under optimum soil-water conditions and achieve full production under the given climatic conditions. Crop evapotranspiration can be calculated from climatic data and by integrating directly the crop resistance, albedo and air resistance factors into the Penman-Monteith approach. As there is still a considerable lack of information for different crops, the Penman-Monteith method is used for the estimation of the standard reference crop to determine its evapotranspiration rate, i.e., ET_0. Experimentally determined ratios of ET_c/ET_0, called crop coefficients (K_c), are used to relate ET_c to ET_0 via $ET_c = K_cET_0$ (FAO 56). Normally, ET_c is equal to the irrigation water demands of the plant.

Crop evapotranspiration under non-standard conditions (ET_{cadj}) is the evapotranspiration from crops grown under management and environmental conditions that differ from the standard conditions. The crop evapotranspiration under non-standard conditions is calculated by using a water stress coefficient Ks and/or by adjusting K_c for all kinds of other stresses and environmental constraints on crop evapotranspiration (FAO 56).

The Penman-Motieth equation,

$$\lambda \, \mathrm{ET} = \frac{\Delta \, (\mathrm{R}_n - \mathrm{G}) + P_a \, \mathrm{C}_p \frac{(\mathrm{e}_s - \mathrm{e}_a)}{\mathrm{r}_a}}{\Delta + \gamma \, (1 + \frac{r_s}{\mathrm{r}_a})}, \quad (3\text{-}3)$$

plays a fundamental role, with Rn (again) denoting the net radiation and G the soil heat flux. The difference es- ea represents the vapor pressure deficit of the air, ρa denotes the mean air density at constant pressure, cp the specific heat of the air, Δ the slope of the saturation vapor pressure and temperature relationship, γ the psychrometric constant and rs and ra the (bulk) surface and aerodynamic resistances, respectively.

In this section, the water consumptions of *A. pictum* and cotton are measured and compared so as to identify which is better suited to dry environments. This is done by measuring stomatal conductance.

By definition, stomatal conductance is the measure of the rate of passage of carbon dioxide (CO_2) or water vapor through the stomata of a leaf, i.e., the small pores on the top and bottom of a leaf that are responsible for taking in and expelling CO_2 and moisture from and to the outside air. The leaf porometer is the device that measures the rate at which this happens. Stomatal conductance is a critical factor that governs evapotranspiration and describes the ability of water vapor and carbon dioxide to pass through the stomata. It is known to be dependent on light, saturation deficit, and water availability. During conditions of large saturation deficit or limited water supply, the stomata may partially close, thus ensuring a mechanism to limit transpiration losses. This acts to reduce the rate of evapotranspiration.

The aerodynamic resistance is calculated as follows:

$$r_a = \frac{\ln\left(\frac{z_m - d}{z_{om}}\right)\ln\left(\frac{z_h - d}{z_{oh}}\right)}{k^2 u_2}, \quad (3\text{-}4)$$

where:

ra – Aerodynamic resistance [s/m]

zm – Height of wind measurements [m],

zh – Height of humidity measurements [m],

d – Zero plane displacement height [m],

zom – Roughness length governing momentum transfer [m],

zoh – Roughness length governing transfer of heat and vapor [m],

k – Von Karman's constant, 0.41,

uz – Wind speed at height z [m/s].

Finally, the bulk surface resistance is calculated as

rs = rl / LAIactive, (3-5)

where:

r_s – bulk stomatal resistance [s/m]

r_l – stomatal resistance of the well-illuminated leafs

LAIactive – illuminated leaf area index

Revised FAO Penman-Monteith equation for reference crop:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}, \qquad (3\text{-}6)$$

where ET_0 is the reference evapotranspiration [mm day-1], Rn the net radiation at the crop surface [MJ m-2 day-1], G the soil heat flux density [MJ m-2 day-1], T the mean daily air temperature at the 2-m height [°C], u2 the wind speed at the 2-m height [m s-1], es the saturation vapor pressure [kPa], e_a the actual vapor pressure [kPa], Δ the slope of the vapor pressure curve [k Pa °C-1], and γ the psychrometric constant [kPa °C-1].

Equation 6 has been simplified and adjusted to calculate the reference evapotranspiration.

ET_0 refers to a short grass vegetation of 100 % vegetation coverage and of 12-cm height, and which is not water stressed. Crop evapotranspiration (ET_c) is then calculated as

$$ET_c = ET_0 K_c \qquad (3\text{-}7)$$

where:

ET_c – crop evapotranspiration [mm/d]

ET_0 – Reference evapotranspiration [mm/d]

K_c – crop coefficient

Crop coefficients are documented and available for the world's major crops, including cotton and fruit trees (Allan, et al., 1998). However, the crop coefficients for *A. pictum* and *Z. jujuba* have not been defined or reported. The crop coefficients were primarily developed using sources from before 1989 (Snyder, et al., 1989), and as such the crop coefficient for cotton reflects average cotton cultivation with a low, if any, proportion of drip irrigation.

It is thus the objective of this section to investigate the crop evapotranspiration of these three plant species. While cotton and *Z. jujuba* depend on irrigation, *A. pictum*, as well as many other plant species of the natural riparian vegetation, is a phreatophyte (Chen, et al., 2006; Thevs, et al., 2008b). Phreatophytes are plantsthat establish continuous contact to the groundwater through well-developed root systems as a means of adapting to the arid climate (Smith, et al., 1998). The work in this section aims at determining the ETc values and crop coefficients of cotton, *A. pictum*, and *Z. jujuba* for representative sites of the Tarim Basin.

3.2.2 Measurement of stomata conductance and the collection of meteorological data

At each of the three sites, the ET_0 and ET_c values were determined based on field measurements. Equation 5 was solved for K_c in terms of ET_0 and ET_c. The ET measurement consists of two measurements: the meteorological data and the stomata conductivity of *A. pictum*, cotton, and *Z. jujuba*. The meteorological data and the stomata conductivity must be collected and measured from early morning (sunrise, i.e., 08:00 official China time) to the evening (sunset, i.e., 22:00 official China time) in order to obtain the ET values for all periods of the day (i.e., the early mornings and evenings with low temperature and high air humidity, noon when the temperatures are hot, etc.).

Stomatal conductance: The stomatal conductance is the amount of water that evaporates from the plant through the stomata of the leaves per area and time unit. It is measured in mmol water / m^2 s. Combined with the leaf area index, the actual ET (ET_a) values of one square meter of *A. pictum*, cotton, and *Z. jujuba* vegetation are calculated. **Meteorological data:** The meteorological data are collected so as to calculate the reference ET (ET_0) values of the Kendir, cotton, and Hongzao sites from the Penman-Monteith equation.

Stomatal conductance measurements and resistance calculation

While the climate station was being operated, a leaf porometer (SC-1, Decagon Devices) was used to measure the stomatal resistance of *Apocynum* and cotton on an hourly basis for a given day each month during the vegetation seasons in Qongaral and Yingbaza in 2011 and 2012, respectively (Fig 3.4). The porometer measures the stomatal conductance of leaves by putting the conductance element that is the leaf in series with two known-conductance elements. By measuring the humidity difference across one of the known conductance elements, the water vapor flux is then obtained. The conductance of the leaf can be calculated from these variables.

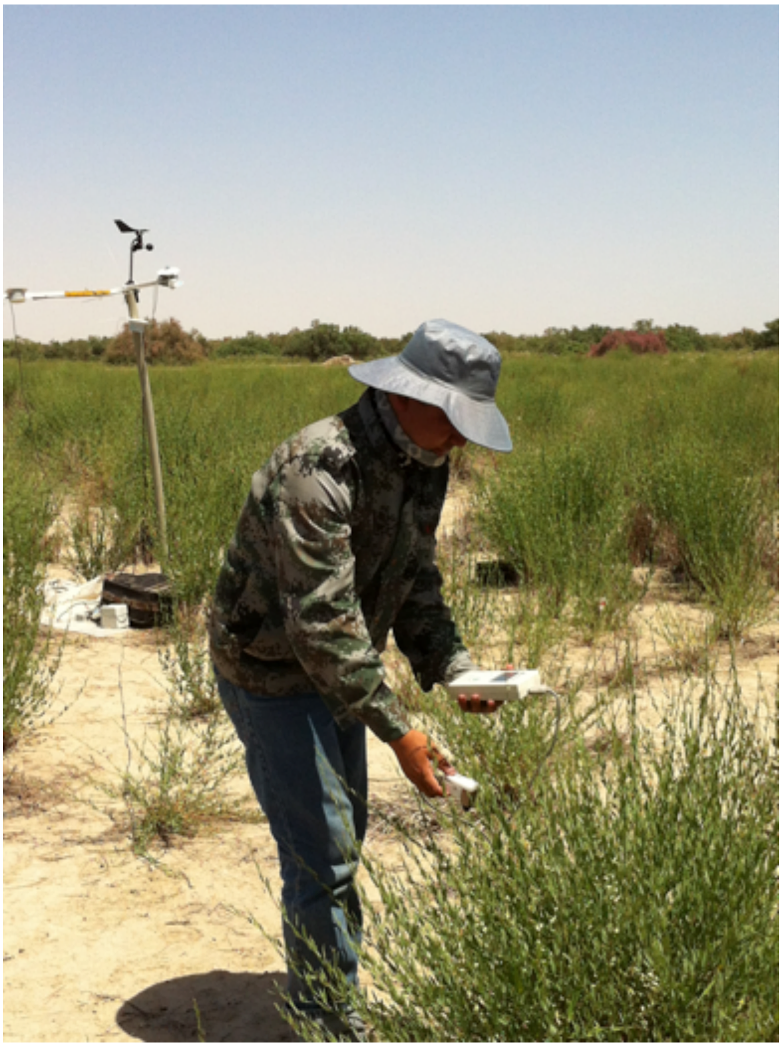

Figure 3.4: Measuring the stomatal conductance of *A. pictum* (Photo: A. Rouzi, 2013).

The humidity is measured in three places: in the leaf interior and at the locations of the two humidity sensors. The porometer automatically calculates the resistance between the inside and outside of the leaf, and thus the stomatal conductance, by measuring the resistances between the leaf and the top and bottom humidity sensors. The leaf porometer function diagram in Fig 3.5 depicts this measurement process.

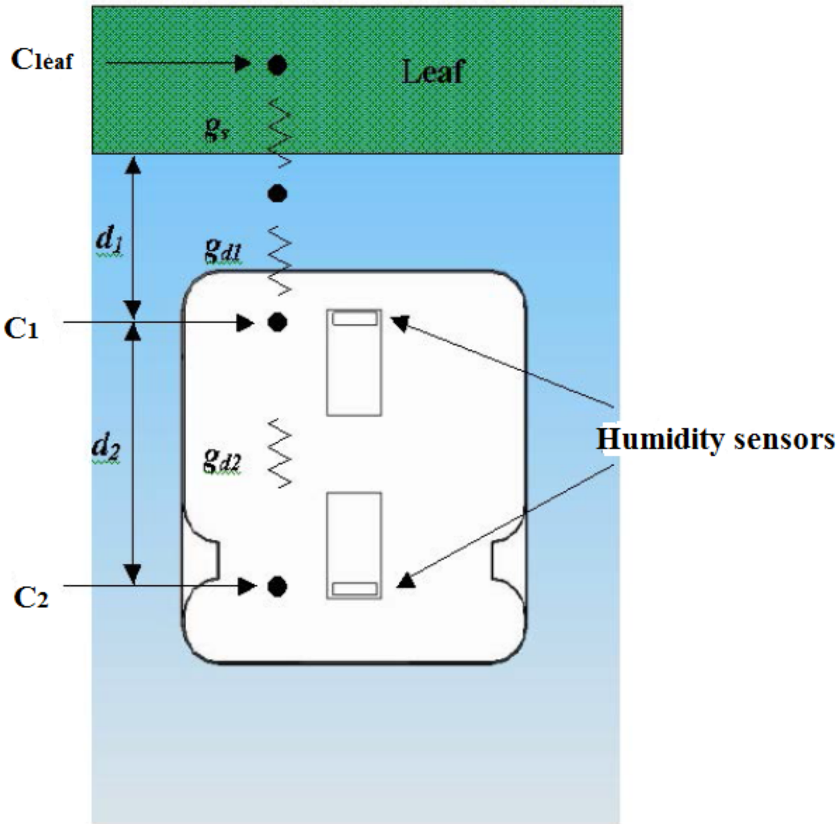

Figure 3.5: Leaf Porometer function diagram (Source: Decagon services).

The parameters used in the figure denote the following:

C_{leaf}: mole fraction of vapor inside the leaf

C_1: mole fraction of vapor at Node 1 RH leaf sensor

C_2: mole fraction of vapor at Node 2 RH filter sensor

g_s: stomatal conductance of the leaf surface conductance value measured

g_{d1}: vapor conductance of the diffusion path between the leaf surface and Node 1

g_{d2}: vapor conductance of the diffusion path between Nodes 1 and 2

d_1: distance between the leaf surface and the first humidity sensor

d_2: distance between the two humidity sensors

The stomatal resistance values are then obtained by taking the reciprocal of the stomatal conductance.

ET measurement for *A. pictum*:

Location and Site: Qongaral, Transect 1, Point 2 (Q1-2). GPS coordinates: (N 41˚18'27", E 85˚33'32").

Three *A. pictum* plants at 10 m distances from one another were studied, and with three leaves of different positions (high, middle, and low) selected for each plant. The stomatal conductivity of both sides was measured for each leaf. Furthermore, three stems were chosen in the vicinity of each plant and their stomatal conductivities were measured as well, by folding the stem 3-4 times and tweezing this folded bundle into the porometer clip.

ET measurement of cotton:

Site: Yingbaza, Cotton farm (N 41˚12'22", E 84˚ 13'16").

Plot: two adjacent cotton fields were chosen, with a climate station being installed in the first field.

A row of three cotton plants, separated from one another by 10 m intervals, were chosen for each field. Three leaves at different positions (high, middle, and low) were then selected for measurement for each plant. For each leaf the stomatal conductivity of both sides was measured.

ET measurement of Chinese red date (*Z. jujuba*):

Site: Qarchen, Red date farm (N 38˚ 08'49", E 85˚ 29'47")

Plot: One plot three trees in a row and 2m from each other was chosen with a climate station being installed in the field.

A row of three *Z. jujuba* tree, separated from one another by 5 m intervals, were chosen for each field. Three leaves at different positions (high, middle, and low) were then selected for measurement for each tree. For each leaf the stomatal conductivity of both sides was measured.

The variable of interest is the stomatal conductance, denoted by g_s. First, the vapor flux, and thus the evapotranspiration, along the diffusion path is determined by using the relative humidity difference between Nodes 1 and 2 as follows:

$$\mathrm{F}_{vapor} = \mathrm{g}_{d2}(\mathrm{C1}_1 - C_2), \quad (3\text{-}8)$$

where the C values are related to relative humidity as

$$\mathrm{C}_i = \frac{h_r e_s(T_a)}{P_{atm}}, \quad (3\text{-}9)$$

with h_r denoting the relative humidity, $e_s(T_a)$ the saturated vapor pressure for a given air temperature, and P_{atm} atmospheric pressure. The saturated vapor pressure is calculated by Tetens's formula with the appropriate coefficients for water vapor:

$$e_s(T_a) = 0.662exp\,(\frac{17.502\mathrm{T}}{\mathrm{T}+240.97}) \quad (3\text{-}10)$$

(note: T must be given in °C.)

Next, the value of g_{d2} is determined as

$$g_{d2} = \frac{\rho D_{vapor}}{d2}, \qquad (3\text{-}11)$$

where ρ is the molar density of the air and D_{vapor} is the diffusivity of water vapor. Both of these quantities are temperature- and pressure-dependent, although some of this dependency drops out when they are multiplied as in Equation 3. Specifically, they are defined as follows:

$$\hat{\rho} = 44.6\frac{P_a}{101.3}\left(\frac{273.15}{T}\right) \quad (3\text{-}12)$$

$$D_{vapor}(T, P_a) = D_{ref}(273.15, 101.3)\left(\frac{101.3}{P_a}\right)\left(\frac{T}{273.15}\right)^{1.75} \quad (3\text{-}13)$$

With

$$D_{ref}(273.15, 101.3) = 2.12x10^{-5}(m^2)/s) \quad (3\text{-}14)$$

it follows that

$$\hat{\rho}D_{vapor} = (44.6)(2.12x10^{-5})\left(\frac{T}{273.15}\right)^{0.75} \quad (3\text{-}15)$$

Using these *C* and *g* values we can now solve Equation 1 for the flux:

$$\mathrm{F}_{vapor} = \left[\frac{\hat{\rho}D_{vapor}}{d_2}\right]\frac{1}{P_{atm}}\left[h_{r1}e_s(T_{a1}) - h_{r2}e_s(T_{a2})\right] \quad (3\text{-}16)$$

Now that the vapor flux has been determined, it is possible to find the stomatal conductance, g_s. This requires some assumptions. First, we assume that the relative humidity within the leaf tissue is 1.0, so that

$$C_{leaf} = \frac{e_s(T_a)}{P_{atm}} \quad (3\text{-}17)$$

Next, it is assumed that all conductance values are in series, so that the flux is constant between any two nodes. It is also assumed that the temperature of the leaf is equal to the temperature at the first humidity sensor (the sensor block head has been constructed from aluminum to minimize the temperature difference). This means that we can write Equation 3-17 for Node 1 and the leaf node, and then set it equal to Equation 3-15.

$$\mathrm{F}_{vapor} = g_{s+d1}\left(C_{leaf} - c_1\right) \quad (3\text{-}18)$$

$$\mathrm{F}_{vapor} = g_{s+d1}\frac{1}{P_{atm}}\left[e_s(T_{a1})(1 - h_{r1})\right] \quad (3\text{-}19)$$

$$\frac{g_{s+d1}}{P_{atm}}\left[e_s(T_{a1})(1 - h_{r1})\right] = \frac{1}{P_{atm}}\left(\frac{\hat{\rho}D}{d_2}\right)\left[h_{r1}e_s(T_{a1}) - h_{r2}e_s(T_{a2})\right] \quad (3\text{-}20)$$

Solving for g_{s+d1} then yields

$$g_{s+d1} = \frac{\left(\frac{\hat{\rho}D}{d_2}\right)\left[h_{r1}e_s(T_{a1}) - h_{r2}e_s(T_{a2})\right]}{e_s(T_{a1})(1-h_{r1})} \quad (3\text{-}21)$$

One may then solve for g_s using the definition of total conductance for a set of conductors in series:

$$\frac{1}{g_s} = \frac{1}{g_{s+d1}} - \frac{1}{g_{d1}} \quad (3\text{-}22)$$

whence

$$\frac{1}{g_s} = \frac{e_s(T_{a1})(1-h_{r1})d_2}{\hat{\rho}D\left[h_{r1}e_s(T_{a1}) - h_{r2}e_s(T_{a2})\right]} - \frac{d_1}{\hat{\rho}D} \quad (3\text{-}23)$$

and, finally,

$$g_s = \frac{\hat{\rho}D_{vapor}}{\frac{e_s(T_{a1})(1-h_{r1})d_2}{h_{r1}e_s(T_{a1}) - h_{r2}e_s(T_{a2})} - d_1} \quad (3\text{-}24)$$

It is thus seen that g_s is a function of the distances between the humidity sensors, the temperature, and the two relative humidity readings. When the conductance is small, the humidity values are nearly the same, and the denominator of the first term of the denominator of the expression above goes to zero, causing problems. Multiplying the top and bottom by the denominator yields the equivalent expression:

$$g_s = \frac{\hat{\rho}D_{vapor}\left[h_{r1}e_s(T_{a1}) - h_{r2}e_s(T_{a2})\right]}{\left[e_s(T_{a1})(1-h_{r1})d_2\right] - \left[h_{r1}e_s(T_{a1}) - h_{r2}e_s(T_{a2})\right]d_1} \quad (3\text{-}25)$$

(Note: the resulting g_s is in mol/m^{2}s).

From the leaf porometer, we know that the two distances are:

d_1 = 3.35 mm and d_2 = 11.43 mm.

At each site, a mobile climate station was set up to operate from the morning to the evening on the days of data collection (Table 3.2). This mobile climate station consisted of an air temperature/air humidity sensor (PASSRHT from UMS, Munich), a wind speed sensor (Davis anemometer) and two pyranometers (GLOBAL-pyra 03 from Delta Ohm), the latter measuring incoming solar radiation and reflected radiation. Air temperature, air humidity and wind speed were recorded each minute by a data logger (EM50 from UMS, Munich), with recorded values being averages of the multiple readings taken over the course of each minute. The radiations were recorded by a data logger (GP1 from UMS, Munich) in the same fashion. The conversions of air humidity and air temperature into saturation vapor pressure deficit, as well as the calculation of the net radiation based on the incoming solar radiation and reflected radiation, were done in accordance with the FAO guidelines as given by Allan et al. (1998). These climate data and their conversion results were used for the ET_0 and ET_c calculations. The soil heat flux was assumed to be equal to 0.1 * R_n, as suggested by Allan, et al. (1998).

Table 3.2: Meteorological sensors of the climate station and the corresponding loggers.

Sensor	**Logger / Software**
Air temperature (PASSRHT)	EM50
Air humidity (PASSRHT)	EM50
Wind speed (Davis)	EM50
Incoming radiation (Delta Ohm)	Delta Link
Outgoing radiation (Delta Ohm)	Delta Link
Soil heat flux (HFP01)	Delta Link connected with amplifier AC100

ET_0 and ET_c were calculated from the compiled weather and porometer data, respectively, and the crop factor was derived from their relationship. The results of this section may offer a basis for calculating the amount of water needed to grow each of the aforementioned crops investigated in this study.

LAI Measurement: The Leaf Area Index (LAI) is a crucial parameter for estimating not only the productivity of the plant but also its water budget. In this work, *A. pictum* leaves were collected from the square units at each of the research sites at Yingbaza and Qongaral at the same time that ET measurements were being done. All of the leaves in the square units were harvested and later brought to a laboratory in Urumqi for weighing and subsequent photographing.

3.3 Economic analysis of *Apocynum*

During the past five decades, intensive exploitation of water resources, mainly by agricultural water consumption, has resulted in changes of 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. Because of the 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 where cotton is the major crop depends completely on irrigation (Hoppe, 1992; Thevs, 2011). In contrast, the natural vegetation relies on groundwater (Gries, et al., 2003; Thevs, 2011), which is recharged by the rivers of the Tarim Basin (Hou, et al., 2007; Thevs, 2011). Most plant species of the natural riparian vegetation along the Tarim River are so-called "phreatophytes" – i.e., they exploit the groundwater and can thus survive under the extremely arid climate (Greis, et al., 2003). Settlements and industry extract water from surface water bodies as well as from the groundwater (Tang & Deng, 2010).

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 sustainable given the current water situation and are at the same time cost effective when compared to the traditional cash crop of cotton. The supply chains and the cost and benefits of the two indigenous species *Apocynum venetum* L. and *Apocynum pictum* Schrenk are addressed.

A. venetum and *A. pictum* are promising land-use alternative candidates for cotton, with leaves that can be harvested for medicinal applications and stems that may be used as raw material for fiber production. Additionally, they serve as a honey plant and can be grazed (Thevs, et al., 2013), though this requires intensive irrigation. Our research intends to elaborate on the structure of Kendir (*Apocynum*) farming and its production and sales chain, before finally carrying out a cost-benefit analysis of Kendir farming so as to assess its competitiveness and the plausibility of its implementation as an alternative.

3.3.1 Analytical framework

In this section, we will employ Schlager & Ostrom's (1996) theory of "Property Rights and Natural Resources" and Tisdell's (2005) concept on institutions for Natural Resource Management types in order to identify property-rights schemes and management institutions, which offers foundations for analyzing the impact of the different institutional arrangements on the economic potentials of Kendir.

Property rights of natural resources

When Hardin (1968) proclaimed that natural resources are susceptible to overexploitation because of the "tragedy of the commons", potentially leading to the collapse of the whole ecosystem, he used grazing commons in England as an example. According to Schlager & Ostrom (1992), "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 de facto open access.

Schlager & Ostrom (1992) have also stated that "property rights is the authority to undertake particular actions related to a specific domain", comprised of the owner, proprietor, claimant and authorized user. The rights associated with natural resources include access and withdrawal, management, exclusion and alienation (Table 3.3). Only the owner has all of the associated rights to use the resources, including alienation and exclusion.

Table 3.3: Bundles of rights associated with positions (Schlager & Ostrom, 1996, modified).

	Owner	Proprietor	Claimant	Authorized user	Authorized entrant
Access	X	X	X	X	X
Withdrawal	X	X	X	X	
Management	X	X	X		
Exclusion	X	X			
Alienation	X				

The different rights are defined as follows (Schlager & Ostrom, 1996):
Access: The right to enter a defined physical area and enjoy nondestructive benefits (e.g., hiking, canoeing, sitting in the sun).
Withdrawal: The right to obtain the resource units or "products" (e.g., catching fish, appropriating water, etc.).
Management: The right to regulate internal usage patterns and transform the resources by making improvements.
Exclusion: The right to determine who will have access rights and how that right maybe transferred.
Alienation: The right to sell or lease collective-choice rights.

The different parties are hereby defined (Schlager & Ostrom, 1996):
Authorized entrants: Individuals who hold operational level rights of access.
Authorized users: Individuals who have both entry and withdrawal rights.
Claimants: Individuals who possess the rights as authorized users plus the collective-choice right to management.
Proprietors: Individuals who possess collective-choice rights to participate in both management and exclusion.

Owners: Individuals who hold the rights of alienation and can sell or lease their collective-choice rights.

During our investigation, the existing property rights schemes and actors for the Kendir plant were studied and identified. According to Berkes (1996), exclusion and regulation are fundamental to the management of natural resources. He then categorized three types of exclusion – open-access, private property, and communal and state property. Berkes also noted that the state property rights regime has the most enforcement issues. In this study, all of the different property-rights domains and their associated rights will be investigated with regard to the Kendir plant.

Resources Use Types

Institutional arrangements for the ownership and management of natural resources offer potential users with an institutional and logistical basis to exploit them (Tisdell, 2005). Tisdell has categorized natural resource management into three institutions: open access, ranching and farming. We review them below.

Open Access: In this case, everyone is free to use the resource (Tisdell, 2005). Individuals or groups of individuals gain no property rights from conserving the resource or undertaking investments to increase its economic value or productivity (Tisdell, 2005).

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 a Kaldor-Hicks social deadweight loss (Tisdell, 2005). As a consequence, common resources are prone to misallocation among the regions, as happens to be the case for the *Apocynum* in our study. As Tisdell (2005) puts it, "an open-access resource is unlikely to be conserved and sustained and invested in a way which maximizes the value of production" and this may lead to the extinction of that species.

Ranching: According to Tisdell (2005), "ranching involves the practice of capturing the young or collecting the eggs of a species and rearing these in captivity" and 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 to ranch may lead to reducutions in their population in the wild – Tisdell (2005) uses shrimp in Ecuador as a particular example.

Farming: 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 breeading to propagate and produce, but also gives the farmers private property rights (Tisdell, 2005).

3.3.2 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. As there is only a small number of *Apocynum* users, interviewees were approached in an explorative manner in 2012 (Ritchie & Lewis, 2003). In 2013, additional interviewees were approached by snowballing and chain-sampling methods (Ritchie & Lewis, 2003). A total of 17 household and expert interviews have been included here, conducted in the counties of Lopnor, Bügür, Xayar and Korla. Though not located in the Tarim Basin, one interview was also conducted in the Altai Region with the largest *Apocynum* 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 (Table 3.4).

The following information was obtained through a set of structured questions: (i) basic information about the interviewees, (ii) resource types relevant to *Apocynum* utilization (iii) all kinds of inputs, such as site establishment inputs, labor inputs, machines, lease and other fees for different resource types, (iv) prices of the different *Apocynum* raw materials and processed products, (v) practices and techniques in *Apocynum* planting.

Table 3.4: Number of interviews by occupation of the interviewees.

Occupation of interviewees	Number of interviews
Staff of Kendir tea and textile companies	10
Farmer (Kendir harvesters)	2
Staff of local administrations	2
Staff of Forestry & Pasture Land Administration	2
Kendir trader	1

Table 3.5: Number of interviews by location of the interviewees.

Location of the interviews	Number of interviews
Yuli	5
Korla	7
Urumqi	2
Altai	1
Xayar	1
Bügür	1

The profit of Kendir utilization is calculated as follows (Hilmi, 2006):

Profit = Value of production – Fixed costs – Variable costs. (3-26)

All revenues and costs were adjusted for inflation, with 2012 as the reference year (OECD Stat library, 2012):

$$V_{2012} = V_t \frac{CPI_{2012}}{CPI_t} \quad (3\text{-}27)$$

with

V_t - original value in the year t

CPI_{2012} - CPI of the year 2012

CPI_t - CPI of the year t

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

4. Results

4.1 Review on *Apocynum pictum*

This section was taken from review paper that has been co-authored by the author of this thesis which was published as *"Apocynum venetum L. and Apocynum pictum Schrenk* (Apocynaceae) *as multi-functional and multi-service plant species in Central Asia: a review on biology, ecology, and utilization"* in Journal of applied botany and food quality in 2012.

Etymology

Generally, Uyghurs and other Turkic peoples of central Asia have referred to *Apocynum* as "Kendir", which is often mistakenly known as *Apocynum cannabis* only ("Qige" in local dialects). In the Russian literature, "Kendyr" is used as the trivial name for *Apocynum* spec. (Berljand, 1950; Romanovich, et al., 1951). In China, the trivial names "Luobuma", translated into English as "Lop Kendyr" (or "Lop Kender"), is used for the genus *Apocynum*, while "Luobuhongma" and "Luobubaima" refer to *Apocynum venetum* and *Apocynum pictum*, respectively (Zhang, et al., 2006 and Thevs, et al., 2012). The genus *Apocynum* is also known as dogbane, Indian hemp or milkweed in English (http://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=30155).

Taxonomy of *Apocynum*

The genus *Apocynum* comprises nine species, which are distributed in the temperate regions of North America, Europe, and Asia. The two species *Apocynum venetum* and *Apocynum pictum* occur in Central Asia (Royal Botanic Gardens, 2012; Thevs, et al., 2012b). The genus *Apocynum* belongs to the family Apocynaceae, order Gentianales, class Dicotyledonae. Today, only the two *Apocynum* species *A. venetum* and *A. pictum* (Fig 4.1) are found in Central Asia (Royal Botanic Gardens, 2012 & Thevs, et al., 2012b).


Figure 4.1: *A. pictum* (left) and *A. venetum* (right) (Photo: A.Rouzi, 2011).

A. venetum is further split into several subspecies, of which *A. venetum* subsp. *lancifolium* Russanov and *A. venetum subsp. scabrum* Russanov may be found in Central Asia. The different synonymous names for the two *Apocynum* species and the two subspecies of *A. venetum* are given in Table 4.1

Table 4.1: Subspecies and synonyms for *A. venetum* and *A. pictum*, together with their locations (Thevs et al., 2012b, modified).

Species / subspecies	**Synonym**
Apocynum venetum L.	Homotypic synonyms: *Trachomitum venetum* (L.) Woodson
Apocynum venetum subsp. *lancifolium* Russanov Distribution: Siberia to China	Homotypic synonyms: *Apocynum lancifolium* Russanov, *Trachomitum lancifolium* (Russanov) Pobed. Heterotypic synonyms: *Nerium sibiricum* Medik., *Apocynum compressum* Moench, *Nerium antidysentericum* Lepech., *Apocynum sibiricum* Pall. ex Roem. & Schult, *Apocynum venetum var. microphyllum* Bég. & Beloserky, *Trachomitum venetum* var. *microphyllum* (Bég. & Beloserky) Woodson
Apocynum venetum subsp. scabrum Russanov Distribution: Asia to Pakistan	Homotypic Synonyms: *Apocynum scabrum* Russanov, *Trachomitum scabrum* (Russanov) Pobed., *Trachomitum venetum subsp. scabrum* (Russanov) Rech.f. Heterotypic Synonyms: *Apocynum venetum var. turkestanicum* Bég. & Belosersky
Apocynum pictum Schrenk. Distribution: Central Asia to Mongolia	Homotypic synonyms: *Poacynum pictum* (Schrenk.) Bail. Heterotypic Synonyms: *Apocynum hendersonii* Hook, *Apocynum grandiflorum* Danguy, *Poacynum hendersonii (*Hook*)* Woodson

In our review, we will only refer to the species as *A. venetum* and *A. pictum*. If there is any uncertainty regarding the name of a species, we will use *Apocynum*. A detailed history of the *Apocynum* taxonomical classification is provided by (Zhang, et al., 2006a; Thevs, et al., 2012b).

The two species have several visible disparities. *A. venetum* is taller and bigger than *A. pictum*, with the former growing as tall as 4 m and the latter only reaching 2 m. In open vegetation such as grasslands, *A. venetum* usually only grows to heights of 2 m, with each plant branching into 5-10 stems, but as an understory plant in the Central Asian floodplain forests it can grow up to 4 m while hardly branching off (Prozorovskii, 1932; Berljand, 1950; Romanovich, et al., 1951; Zhang, et al., 2006a; Thevs, et al., 2012b). The most obvious feature to distinguish the two species is that *A. venetum* has opposite leaves, while *A. pictum* has alternate leaves (Flora of China, 2011; Thevs, et al., 2012b). Additional morphological characteristics of the two *Apocynum* species are given in Table 4.2.

Table 4.2: Morphological characteristics of *A. venetum* and *A. pictum* (Thevs, et al., 2012).

	Apocynum venetum	***Apocynum pictum***
Stem	Up to 4 m tall, glabrous except for inflorescences. Branches and branchlets whitish gray, terete, finely striate.	Stems up to 2 m tall. Branchlets pubescent when young, soon glabrous.
Leaves	Leaves usually opposite. Petiole 3-6 mm. Leaf blade narrowly elliptic to narrowly ovate, 1-8 × 0.5-2.2 cm, base rounded or cuneate, margin denticulate, apex acute or obtuse, mucronate.	Leaves usually alternate; petiole 2-5 mm, rarely shorter; leaf blade oblong to ovate, 1.5-4 × 0.2-2.3 cm, closely denticulate, granulose.
Flowers	Sepals narrowly elliptic or narrowly ovate, ca. 1.5 mm. Corolla purplish red or pink; tube campanulate, 6-8 mm, granulose; lobes 3-4 mm. Disc fleshy, 5-lobed; lobes rounded, base adnate to ovary.	Sepals ovate or triangular, 1.5-4 mm. Corolla pink or purplish red, often with distinct darker markings; tube basin-shaped, 2.5-7 mm; lobes broadly triangular, 2.5-4 mm; corona inserted at base of corolla tube, lobes broadly triangular, apex long acuminate.
Fruit	Follicles slender, 8-20 cm × 2-3 mm.	Follicles slender, pendulous, 10-30 cm × 3-4 mm.
Seeds	Seeds ovoid or ellipsoid, 2-3 mm, coma 1.5-2.5 cm.	Seeds narrowly ovoid, 2.5-3 mm; coma 1.5-2.5 cm.

The root system consists of vertical and horizontal roots and rhizomes. The vertical roots connect to the groundwater and thus secure the water supply of the plant. Each autumn, buds start to grow at the upper part of the vertical rhizome, from which the new stems emerge the following spring. Nutrients are stored in the upper part of the vertical rhizome and in the entire horizontal rhizome. The horizontal rhizomes carry dormant buds (2-3 per cm), from which vertical roots and root suckers grow when the horizontal rhizome has been cut off from its mother plant. The horizontal roots of an *Apocynum* plant can extend up to 5-6 m (Berljand, 1950; Romanovich, et al., 1951 and Thevs, et al., 2012b). There are whitish to yellowish mycorrhiza knots on the roots of *Apocynum* (Berljand, 1950; Thevs, et al., 2012b). Vascular arbuscular mycorrhiza has been previously described for the plant order Gentianales, including Apocynaceae (Zhang, et al., 2003; Thevs, et al., 2012b).

Distribution of *Apocynum*

A. venetum is distributed over a vast area in Eurasia – from southeast Europe to Turkey, Iran, Turkmenistan, Uzbekistan, Kazakhstan, and Southern Siberia, to Mongolia, northern China, and Japan. In Central Asia, *A. venetum* is distributed in the floodplains and valleys along rivers such as the Amu Darya, Pandzh, Vakhsh, Syr Darya, Chu, Talas, Ili, Irtysh, Tarim with its tributaries, and Heihe (Romanovich, et al., 1951). Only the subspecies *A. venetum* subsp. *lancifolium* and *scabrum* (Table 4.1) are found in Central Asia.

A. pictum's distribution is restricted to southern Kazakhstan, the Ili Basin, Xinjiang, Gansu, and Inner Mongolia (Pavlov, 1942). Both species are part of the riparian vegetation along the rivers and streams in the dry lands of Central Asia. As such, they are distributed along perennial and episodic river courses, on alluvial plains, and at desert margins (Pavlov, 1942; Zhang, et al., 2003; 2005a).

In China, the two *Apocynum* species are mainly found in Xinjiang, Qinghai (Caidam Basin), Gansu, Inner Mongolia, Shanxi, Shaanxi, Hebei, Jilin, and Heilongjiang. *A. venetum* occurs in the semi-arid, semi-humid, and humid (annual mean precipitation of more than 250 mm) portions of these regions. By contrast, *A. pictum* is restricted to arid climates – i.e., those with an annual precipitation of less than 250 mm (Zhang, 2002; Zhang, et al., 2006a). Only in the Caidam Basin, which has a mean annual precipitation of less than 200 mmbut an elevation of higher than 2,600 m is *A. venetum* dominant over *A. pictum* (Tie & Liu, 2006; Tang, 2008). In Xinjiang, *A. pictum* is restricted to the more arid regions such as the Tarim Basin and the southern rim of the Zhungar Basin, while *A. venetum* appears in the less arid northern part of the Zhungar Basin and the foothills of the Altay Mountains (Zhang, 2002; Zhang, et al., 2006 b).

The total area of *Apocynum* vegetation for all of China, natural or artificial, amounts to approximately 1,330,000 ha (Tang, 2008). One third to a half of this area (approximately 600,000 ha) is located in Xinjiang (Zhang, et al., 2003). In the Caidam Basin, approximately 91,000 ha of natural *Apocynum* vegetation has been recorded (Tang, 2008). In this area, *Apocynum* is often accompanied by *Nitraria* spec. L. and *Phragmites australis* Trin. Ex Staud.

The areas considered here – in inner China, as well as in Xinjiang and the Caidam Basin – are not those that are *Apocynum*-dominated or even those that consist of single-species vegetation, but rather are areass where *Apocynum* is distributed as an accompanying or as a dominant species (Hong, et al., 2002). This is further illustrated by the distribution of *Apocynum* in the Aksu prefecture (Zhang, et al., 2003), where *Apocynum* is distributed as grasslands along the Tarim River on the higher river terraces and in a mosaic with Tugai forests. In the Aksu prefecture, the area of *Apocynum* vegetation is comprised of approximately 50,600 ha of reed, 17,100 ha of *A. venetum*, 800 ha of *A. pictum*, 1,600 ha of *A.venetum* and *Glycyrrhiza L.*, 4,400 ha of *Tamarix ramosissima* Ledeb. and *A. venetum*, 11,900 ha of *Tamarix ramosissima*, *A. venetum,* and *Alhagi spec.* Gagnebin, 3,600 ha of *Tamarix ramosissima, A. pictum*, and *Alhagi* spec., and 11,200 ha of *Populus euphratica* Oliv. and *A. venetum*.

Ren, et al., (2008) has also carried out investigations of *Apocynum* resources with respect to rivers in the Tarim Basin – notably, for the Tarim and Kashgar Rivers (Table 4.3). From this, one can see that the Bazhou prefecture has the largest area of *Apocynum* with approximately 109,400 ha, while the Kashgar and Aksu prefectures follow as the second and third largest, respectively. The Yuli (Lopnur), Bachu, and Shayar counties, as well as Korla city, have significant distributions and production of *Apocynum.*

Table 4.3: *Apocynum* reources in the Tarim Basin (Ren, et al., 2008).

Prefecture, County		**Total Area (mixed) (ha)**	***Apocynum* Area only (ha)**	***Apocynum* production (t)**			
				Total	**Stem**	**Leaf**	**Skin**
Bazhou	Yuli	99,380	79,333	101,299	70,646	22,185	8,468
	Korla city	26,733	23,000	29,792	20,777	6,524	2,491
	Bugur	7,467	7,067	9,099	6,346	1,992	761
	Sub total	133,580	109,400	140,190	97,769	30,701	11,720
Aksu	Kucha	1,267	867	13,145	917	288	110
	Shayar	44,333	24,800	43,431	30,289	9,511	3,631
	Aksu city	133	67	150	105	33	12
	Awat	1,400	1,373	2,012	1,403	441	168
	Sub total	47,133	27,107	46,918	32,724	10,273	3,921
Kashgar	Bachu	48067	42,533	55,683	38,833	12,195	4,655
	Makit	6800	2,173	1,345	938	294	113
	Sub total	54,867	44,706	57,028	39,771	12,489	4,768
Total		235,580	181,213	244,126	170,254	53,463	20,409

Life history

A. venetum and *A. pictum* are perennial plants with rhizomes, while the stems die yearly – i.e., they are geophytes according to (Raunkiaer, 1934; Thevs, et al., 2012a). New stems grow out of the roots every spring (Pavlov, 1942; Thevs et al., 2012), emerging from the rhizomes in March and April. The flowering season is from June to August, followed by the fruit season from September to October (Zhang, et al., 2005; Thevs, et al., 2012a). The stems show the fastest length growth before the onset of the flowering period, with the length growth ceasing during and after (Berljand, 1950; Thevs, et al., 2012a). *Apocynum* plants reach an age of 30 years (Prozorovskii, 1932; Thevs, et al., 2012a). The plant is not very prone to pests and illnesses (Tang, 2008; Thevs, et al., 2012a).

Ecology of *A. venetum* and *A. pictum* Climate adaptation

The above-ground parts of *A. venetum* do not withstand frost and die off. However, the root can withstand strong frosts of up to -30 °C when under a snow cover. The seedlings do not withstand frost at all (Berljand, 1950; Romanovich, et al., 1951).

Soil conditions: water and salt

As a phreatophyte, *Apocynum* is adapted to arid climates and dry periods (Berljand, 1950). The most productive sites of *A. venetum* are usually those with groundwater levels not deeper than 3 m and with salt contents between 1 and 10 g/L (Berljand, 1950; Zhang, 2002). Along the lower reaches of the Tarim River, which had been dry from the 1970s to 2000 (Song et al., 2000), *A. pictum* is mainly found in regions with groundwater levels of 4-6 m, with a maximum observed groundwater depth of 8 m (Hao, et al., 2008). *A. venetum*, on the other hand, is restricted to groundwater levels of no deeper than 4 m (Zhang, 2002).

Within its distribution area, *Apocynum* tends to form island-like mono-species stands or to dominate stands, but mostly occurs as an accompanying species in various plant communities (Prozorovskii, 1932; Hong, et al., 2002; Zhang, 2002). It often growths together with *Phragmites australis*, *Glycyrrhiza inflata*, *Alhagi sparsifolia* and *Tamarix* shrubs (Zhang, 2002; Hong, et al., 2002; Chen, at al., 2006a), with halophytes on salinized soils (Romanovich et al., 1951), or as understory in floodplain forests (e.g., built up by *Populus euphratica*) (Prozorovskii, 1932). *A. pictum* is able to endure deeper groundwater levels than *Phragmites australis* (Thevs, et al., 2008), similar groundwater levels to *Glycyrrhiza inflata* (Chen, et al., 2006a), but cannot exploit the groundwater as deep as *Populus euphratica, Tamarix ramossissima,* or *Alhagi sparsifolia* can (Chen, et al., 2006; Fan, et al., 2008). In addition to the ability to use groundwater, the stems and branches and leafs are covered with a wax layer, which has the effect of reducing evaporation (Romanovich, et al., 1951). *Apocynum* can withstand periods of submergence, although prolonged submergence or waterlogged soil inhibits its growth (Berljand, 1950). In these conditions, the majority of the roots become concentrated at the upper boundary of the reduced gleyic horizon in order to avoid prolonged anoxic conditions (Prozorovskii, 1932).

Apocynum is most productive on sandy (Fig 4.1) (Romanovich, et al., 1951) and silty (Prozorovskii, 1932), well-drained soils (Berljand, 1950). It cannot grow on clayey soils (Prozorovskii, 1932). The topsoil under *Apocynum* stands is often salinized, reaching salt contents of up to 20 %. However, at 30 cm below surface the salt content drops to only 1 % and less (Zhang, et al., 2003). This shows that *Apocynum* can grow on sites with pronounced surface salinization, provided that the subsoil and the groundwater are not strongly salinized. Under such conditions, flooding is harmful for *Apocynum* as it leaches salt into the subsoil, thus damaging the roots. *A. pictum* is more resistant to salinization than *A. venetum* (Zhang, 2002).

Figure 4.2: *A. pictum* stands in the sand dunes of Qongaral (photo by A. Rouzi, 2011).

Apocynum seedlings do not tolerate salt. Older plants with deeper roots reach non- or low-saline soil layers so that they can withstand the saline topsoil resulting from irrigation or natural soil salinization (Berljand, 1950; Zhang, 2002). The adult *Apocynum* plants tolerate salt better than cotton (Berljand, 1950).

A. venetum and *A. pictum* have adapted to survive even under the extreme arid climates of the Tarim or Aral Sea basins, with less than 50 mm mean annual precipitation, by exploiting the groundwater to cover their water demand. As such, these two species are phreatophytes (Gries, et al., 2003; Chen, et al., 2006a; Thomas, et al., 2006; Thevs, et al., 2012a). Consequently, *A. venetum* and *A. pictum* provide land utilization options that do not depend on irrigation. The two species also offer opportunities as fiber and medicinal plants.

According to Hao 2008, groundwater levels of 4-6 m are best suited for *Apocynum*, although levels as deep as 8 m may also be sufficient (Hao, et al., 2008). According to Zhang, et al., (2013), the most favorable conditions for *Apocynum* are with groundwater depths of 1.5-4 m and root depths of around 2-3 m.

Reproduction and planting techniques

Natural reproduction and germination

Under natural conditions, *Apocynum* predominantly recruits vegetatively through root suckers, with seed germination and successful seedling establishment rarely occurring (Romanovich, et al., 1951). The seeds require moist, non-saline, well-drained sandy to loamy sediments (Romanovich, et al., 1951), which can only be found at sites along riverbanks following flood events. After germination, the seedlings grow slowly above ground, but invest strongly in the root system – a behavior that is typical for phreatophytes. The seeds germinate easily, but the establishment of the seedlings by accessing a continuous connection to the groundwater poses a bottleneck for the generative recruitment (Prozorovskii, 1932; Tang, 2008). Thus, the recruitment of *Apocynum* is similar to that of *Populus euphratica* Oliv. (Thevs, et al., 2008b; Wiehle, et al., 2009).

The fruit are 12-20 cm long and have a diameter of 3-4 mm. When ripe, they turn brown. Each individual fruit contains 100-150 seeds. The seeds are 2.5 mm long with a diameter of 0.5 mm. The 1,000-grain weight of *Apocynum venetum* has been reported as ranging from 350 mg to 1,000 mg in the former Soviet Union (Romanovich, et al., 1951). In Shaanxi, which is the more humid part of the *Apocynum* distribution area in China, the 1,000-grain weight of *A. venetum* is 500-600 mg (Hu, et al., 1988). In the more arid regions of the distribution area – i.e., in Xinjiang and the southern part of Central Asia – the seeds of *Apocynum* are less than 1 mm long. There, the 1,000-grain weight of *A. venetum* ranges from 332 mg (Bai, et al., 2005) to 469 mg (Berljand, 1950). The 1,000-grain weight of *A. pictum* has been measured as 264 mg (Bai, et al., 2005). The seeds carry pappus-like hair (Berljand, 1950; Bai, et al., 2005).

From results obtained for seeds in Shaanxi, it was found that the seeds lose their germination ability rapidly. However, when stored in dry conditions with moisture content of 3-6 % and in air-sealed containers, 60 % of the seed samples have been shown to retain germination ability even after 8 years. When the moisture content exceeds 8 %, the seeds tend to lose their germination ability within two years. Under non-sealed conditions, the seeds have been observed to lose their germination ability within 2-3 years, even with moisture content of 4 %. It is not necessary to store the seeds under dark conditions (Hu, et al., 1988). The seeds ripened under moist and hot conditions and therefore did not develop a very hard shell. It was found that *A. venetum* requires at least 10 °C for germination. Frost has been noted to kill saplings (Prozorovskii, 1932; Berljand, 1950).

Cultivation and planting techniques

There are two reproduction methods for cultivation – seed propagation and vegetative propagation from root or plant parts (Berljand, 1950; Zhang, et al., 2005a). Direct seeding is the most labor-saving method to cultivate *Apocynum*. However, better results may be obtained if *Apocynum* seeds are sown in a nursery and the saplings are transplanted after the second year (Berljand, 1950; Tang, 2008). The most suitable seeding time is from mid-April to mid-May, as this avoids the spring frosts (Romanovich, et al., 1951; Tang, 2008). During the first year, irrigation should be applied 7-15 times with a total amount of 10,000 to 12,000 m^3/ha of water needed for *A. venetum*. Fields on which *A. venetum* is sown should have a groundwater level not deeper than 2 m. On the other hand, the soil must be well drained in order to avoid wet conditions (Romanovich, et al., 1951).

Apocynum germinated from seeds grows to 30-40 cm high, up until the end of the vegetation season of the first year. The root system grows faster than the above-ground part. After the first vegetation season, the roots reach 70-75 cm deep into the soil. In the second year, the sprouts grow out of the soil in March. At the end of the second vegetation season, *Apocynum* reaches a height of 100 cm. These stems start to yield fibers.

Fruit are formed only after the second year. In the fourth year, the stems reach a height of 2 m. In the third year and afterwards, the stems can be harvested before the onset of the flowering time. The horizontal roots penetrate the whole plantation area in the third year. The root system of *A. venetum* reaches a groundwater level of 1.5 m during the second year and 2 m in the third (Berljand, 1950).

For the establishment of *Apocynum* plantations root parts can be used as well. These may be obtained from wild *Apocynum* stands, though over-exploitation must be avoided. Root pieces of 10-15 cm in length are planted 10 cm deep into the soil. This implies a high work load, with 60,000 to 70,000 root pieces (1-2 ton) needed per hectare. The planting time can start at the end of March, a bit earlier than the seeding time, but spring frosts may also hamper root sprouting. During the first and second year, irrigation is necessary for the arid Central Asian climate and water has to be applied 5-6 times per year, summing up to 4,000 to 5,600 m^3 of water per year. If root pieces have been planted instead of seeds, the plant development is faster. At the end of the first vegetation season, the stems grow as high as 40-50 cm. By the end of the third year, the stems reach a height of 2 m (Berljand, 1950).

Insect pests do not pose a problem to *Apocynum* cultivation, but the fungus *Septaria* leaf spot damages *Apocynum* under moist and rainy conditions (Zhang, et al., 2005a). The most important pests for *Apocynum* are considered to be the fungus *Fusarium* spec. and the snail *Septaria* spec.

Utilization of *A. venetum* and *A. pictum*

A. venetum and *A. pictum* are used as medicinal and fiber plants. The leaves, harvested in June/July, serve as raw material for tea and drugs, while the stems, harvested in summer or autumn, serve as raw material for the fiber extraction. Furthermore, *Apocynum* as part of the natural riparian vegetation is grazed (Zhang, et al., 2003). Natural rubber has been extracted from *A. venetum* on an experimental scale, but due this utilization was given up rapidly because of the poor quality of the rubber (Pavlov, 1942).

The fibers of *Apocynum* are bast fibers, like hemp or flax (Romanovich, et al., 1951). The fiber bundles of *Apocynum* are stronger than bundles of flax by a factor of 10-30 (Pavlov, 1942). The strong bast fibers obtained from the inner bark are used in making cloth, strings, sails, fishing nests, and high quality paper (Zhang, et al., 2006b). In addition to the fibers from the stems, *A. venetum* also yields a floss fiber from the seeds (Zhang, et al., 2006b). The fiber quality for both *Apocynum* species reviewed here are similar (He, et al., 1997).

The cultivation of *A. venetum* for fiber production started as early as 1930 in the former USSR. Just after World War II, there were plans in the USSR to set aside large areas for the cultivation of *A. venetum* as a fiber plant. In China, *Apocynum* fibers are used for textiles, mainly for underwear.

In China, *A. venetum* grows as high as 3.6 m. In the Caidam Basin, the above-ground fresh biomass weights were measured as 1798 and 1964 kg/ha for *A. pictum* (Tang, 2008). From a plantation near Tashkent, an average yield of 5-6 t/ha with a stem density of 300,000 plants per hectare has been reported (Pavlov, 1942). The annual demand for *Apocynum* fibers for all of China has been estimated at 50,000 kg over the past years. This demand is covered by the *Apocynum* stands in China. On the other hand, the demand for leaves as raw material for tea and medicine cannot be met (Tang, 2008). Berljand (1950) states that *Apocynum* can be harvested 2-3 years after planting. The productivity and yields decrease only after 10 years (Pavlov, 1942).

Hygiene and medicinal effects of *Apocynum* fibers

Apocynum fibers possess an anti-microbial effect, with the inhibition rates on *Staphylococcus aureus, Pseudomonas aeruginosa, Escherichia coli*, and *Candida albicans* reported at 47.7 %, 69.0 %, 56.6 %, and 40.1 %, respectively. Under an electron microscope, it has been observed that the cell walls of the bacteria were destroyed upon contact with the *Apocynum* fibers (Lü, et al., 2006). This can be attributed to the finding that the stem cells of *Apocynum* contain tanning agents, which makes the fibers resistant to microbial decomposition (Romanovich, et al., 1951).

Medicinal applications of *A. venetum* and *A. pictum*

Tea from *A. venetum* and *A. pictum* is used as a type of traditional Chinese medicine, consumed mainly in northwest China, with anti-hypertensive and anti-hyperlipidemic effects being attributed (Ma & Chen, 1999). In 1977, *Apocynum* was officially listed as Chinese medicine in China (Zhang, 2004).

A. venetum leaves are rich in ash elements and minerals, such as Ca, Fe, and Na, but differ from green tea leaves in that they contain no caffeine (Yokozawa, et al., 2002). The leaves of *A. venetum* and *A. pictum* have a high flavonoid content (Sakushima, et al., 1978; Kamata, et al., 2008).

Aqueous *A. venetum* extracts have displayed an anti-hypertensive effect on hypertensive rats. This anti-hypertensive effect was observed after treatment with aqueous extracts from roasted and non-roasted leaves (Kim, et al., 2000). The anti-hypertensive effect was mainly attributed to improved kidney function – i.e., to increased excretions of urine and urine electrolytes. Such a diuretic effect of aqueous *A. venetum* extracts had been reported before (Qing, et al., 1988). Furthermore, a vascular relaxation effect after the treatment of rat aortas with an *A. venetum* extract in an *in vitro* experiment has been observed. This vascular relaxation effect plays a role with regard to the anti-hypertensive effects of *Apocynum* tea (Kwan, et al., 2005). *Apocynum* extract has also been observed to cause vasodilation on tissues (Tagawa, et al., 2004).

Aqueous *A. venetum* extracts have been reported to decrease the total serum cholesterol, the LDL-cholesterol levels, and the atherogenic index, as well as the hepatic total cholesterol level, in an experiment with hypercholesteraemic rats, with HDL cholesterol levels reported to have been increased.

The decrease of cholesterol values was stronger when using roasted *Apocynum* leaves to prepare the extract (Kim, et al., 1998). The leaves yield up to 5 % gum, which is used for making rubber as well as a medicine used as a sedative and to treat hypertension (Zhang, et al., 2006a).

An extract of *A. venetum* leaves reduced significantly the immobility of rats in a forced swimming test, whence it was concluded that such an *A. venetum* extract possesses antidepressant properties (Butterweck, et al., 2001; Butterweck, et al., 2003; Zhou, et al., 2007). Furthermore, *A. venetum* extracts contain antioxidants, with the antioxidative effects attributed to condensed tannin compounds. The radical scavenging activity of *A. venetum* extracts was determined to be similar to that of *Gingko biloba* L. As such, *A. venetum* extracts may serve as protective reagents against the oxidative stress in nerve cells due to lipid peroxidation (Cao, et al., 2003; Yokozawa & Nakagawa, 2004; Shirai, et al., 2005).

4.2 Biomass and productivity of *Apocynum pictum*

4.2.1 Above-ground biomass analysis

The highest stem biomass values (1.14 t/ha) were found at Xayar 1 and were significantly greater than at Qongaral 1 (0.34 t/ha), with the remaining sites intermediate (Table 4.4). The highest leaf biomass of 0.43 t/ha was found in Qongaral 2 in 2011, while the lowest was observed in Xayar 2 (0.07 t/ha) .The highest total above-ground biomass stands at 1.25 t/ha in Xayar 2, with the lowest occurring in Qongaral 1 with 0.6 t/ha.

Table 4.4: Plant height, crown area, stem and leaf biomass, ratio of stem / leaf biomass, and ground water depth of *Apocynum pictum* at five Tarim Basin sites. The numbers of subplots investigated are given in parentheses. The superscript letters indicate significant differences between sites at $p < 0.05$ (Tukey's post hoc comparison).

Site	Plant height [m]	Crown Area [m^2]	Stem Biomass [t/ha]	Leaf Biomass [t/ha]	Total Above Ground Biomass [t/ha]	Ratio stem / leaf biomass	Ground water depth [m]
Bachu	NA	NA	0.75±0.39^{b} (38)	0.38±0.21^{b} (38)	1.13±0.53^{acd}	2	4.66±0.13 (5)
Qongaral-1	0.89±0.21^{b} (57)	0.55±0.4^{ab} (57)	0.34±0.25^{e} (57)	0.26±0.19^{bc} (57)	0.6±0.42^{bce}	1.3	5.2 (2)
Qongaral-2	1.01±0.2^{ab} (21)	0.6±0.32^{ab} (21)	0.49±0.32^{bde} (21)	0.43±0.6^{abc} (21)	0.92±0.67^{c}	1.1	5.2 (2)
Xayar-1	1.12±0.22^{a} (35)	0.72±0.41^{a} (35)	1.14±0.89^{a} (35)	0.11±0.05^{d} (35)	1.25±0.91^{acd}	10.4	4.3 (2)
Xayar-2	1.01±0.24^{ab} (35)	0.4±0.28^{b} (35)	0.65±0.51^{bc} (35)	0.07±0.05^{de} (35)	0.72±0.55^{bce}	9.3	1.6±0.18 (2)

In Xayar 2, we found the lowest leaf biomass values (0.07 t/ha). The plant height followed the pattern of the stem biomass, with the highest plants (in mean height) found in Xayar 1 (2011), and the height at Qongaral 1 being significantly lower. The remaining two sites had intermediate values (Table 4.4). With regard to the crown area, the lowest value measured was at Xayar 2, which also corresponds to the lowest leaf biomass (Table 4.4).

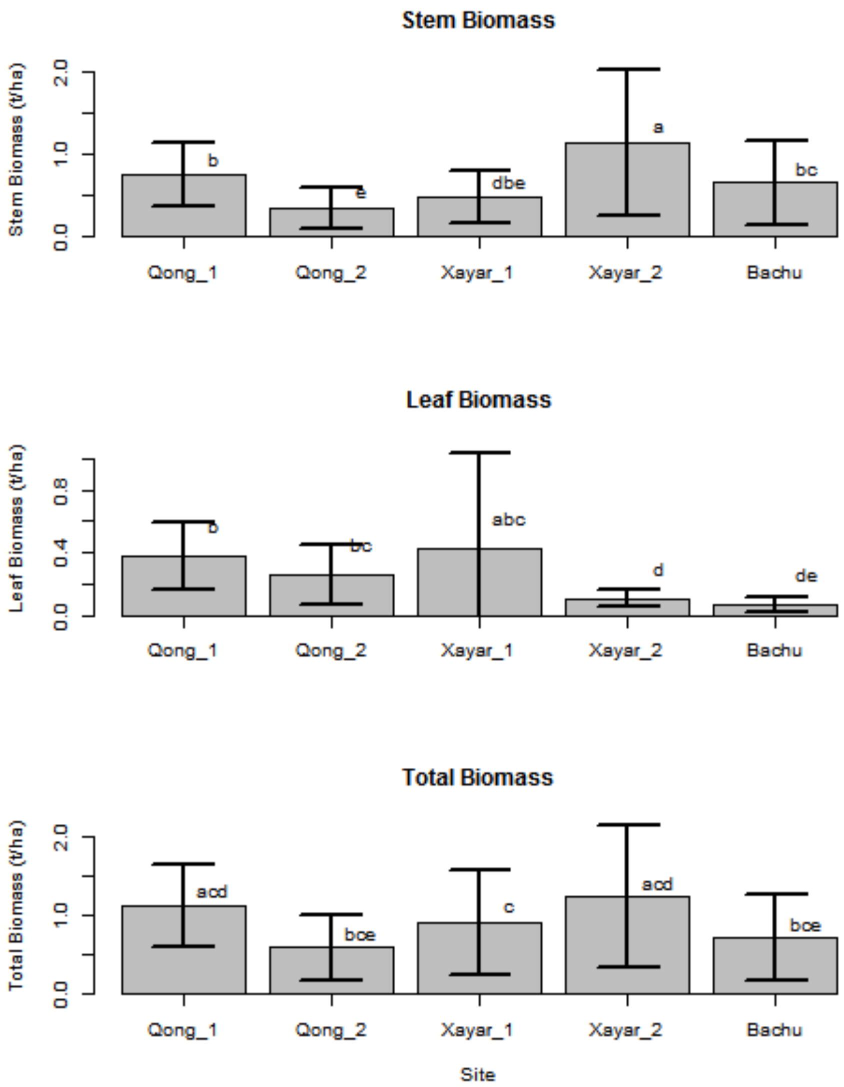

Figure 4.3: Means of stem, leaf and total biomass for the five Tarim Basin sites. Within each characteristic, bars with the same letter do not differ ($p < 0.05$, Tukey post hoc test).

On the three sites with only occasional grazing (Qongaral 1, Qongaral 2, and Bachu), the stem-to-leaf biomass ratio ranges between 1.1 and 2, while it is 9.3 and 10.4 on the regularly grazed Xayar 1 and Xayar 2, respectively (Table 4.4). The height and crown area of *A. pictum* are very important with regard to carbon accumulation, as shown in Fig 4.4.

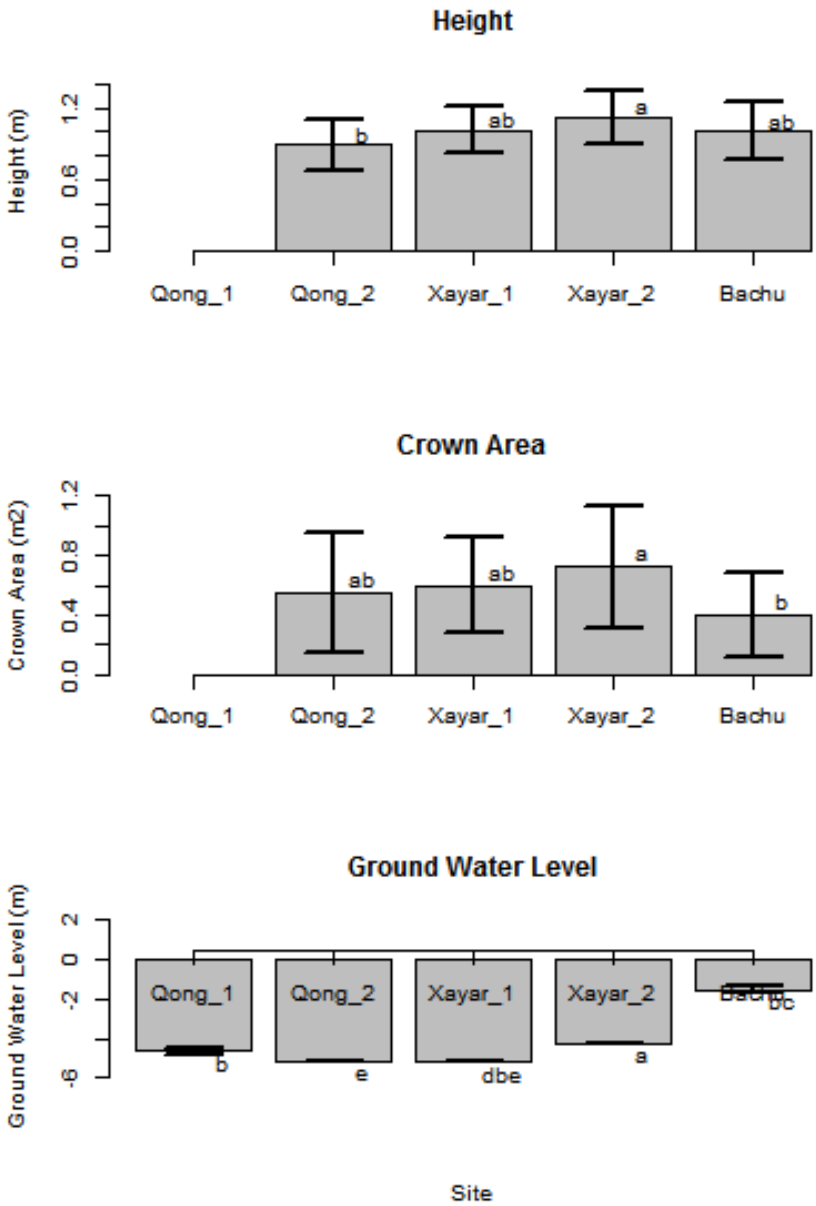

Figure 4.4: Means of height, crown area and ground water levels at the five Tarim Basin site. Within each characteristic, bars with the same letter do not differ (p <0.05, Tukey post hoc test).

The groundwater depths ranged from 1.6 to 5.2 m (Table 4.4), with the highest groundwater levels found in Xayar 1 and Xayar 2. The highest stem biomasses of 2.65 and 1.14 t/ha were found for groundwater levels of 4.25 and 4.3 m, respectively.

The soil EC value in Bachu was the highest with 20 mS/cm for the 0-5 cm layer, followed by Qongaral 1 and Qongaral 2, with Xayar 1 and Xayar 2 having considerably lower values. In the upper 5 cm, the EC values measured in Bachu and Qongaral were almost double the corresponding EC value in Xayar (Table 4.5). Soil electric conductivity was still the highest for Bachu in the 5-20 and 20-100 cm layers, with Xayar and Qongaral having similar values in the 5-20 cm layer. However, Qongaral had significantly lower EC values than Xayar in 20-100 cm layer.

The EC values of Xayar at the surface as well as in the groundwater layer were significantly lower than the corresponding EC values in Bachu and Qongaral. This is consistent with the flood regime – i.e., with the fact that Xayar is flooded more often than Qongaral or Bachu.

Table 4.5: Electric conductivity values within the soil profiles in Bachu, Xayar, and Qongaral.

Soil Depth & Ground water	Bachu	Xayar 1	Xayar 2	Qongaral 1	Qongaral 2
EC [mS/cm]					
0-5 cm	20 ± 0^{a} (5)	8.83 ± 8.16^{b} (4)	10.45 ± 2.62^{b} (4)	18.7 ± 2.63^{a} (3)	16.54 ± 2.72^{a} (3)
5-20 cm	16.29 ± 4.61^{a} (5)	10.39 ± 6.7^{b} (4)	13.68 ± 5.8^{b} (4)	13.43 ± 5.96^{ab} (3)	10.08 ± 5.88^{b} (3)
20-100 cm	12.16 ± 7.32^{a} (5)	8.63 ± 6.04^{b} (4)	9.75 ± 6.01^{b} (4)	3.78 ± 1.16^{c} (3)	4.68 ± 0.99^{c} (3)
Ground water (m)	2.28 ± 2.34^{b}(5)	0.88 ± 0.32^{a} (2)	1.36 ± 0.28^{a} (2)	1.57 ± 0.76^{a} (2)	1.86 ± 1.68^{b}(2)

Plant allometric formula

As seen in Fig 4.5, there is a significant correlation between plant height and above-ground biomass, with an R^2 value of 0.624 (for a p value of 0.05).

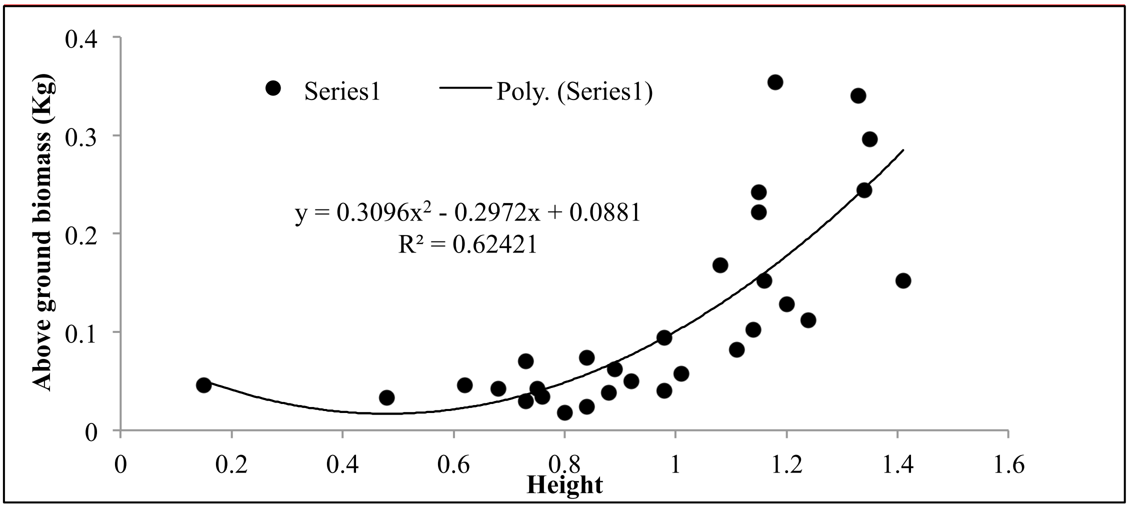

Figure 4.5: Plant height and aboveground biomass correlation of *A. pictum*, 2012.

From Fig 4.6, one sees that there is also a significant correlation between plant crown area and above-ground biomass, with an R^2 value of 0.562 (for a *p* value of 0.05).

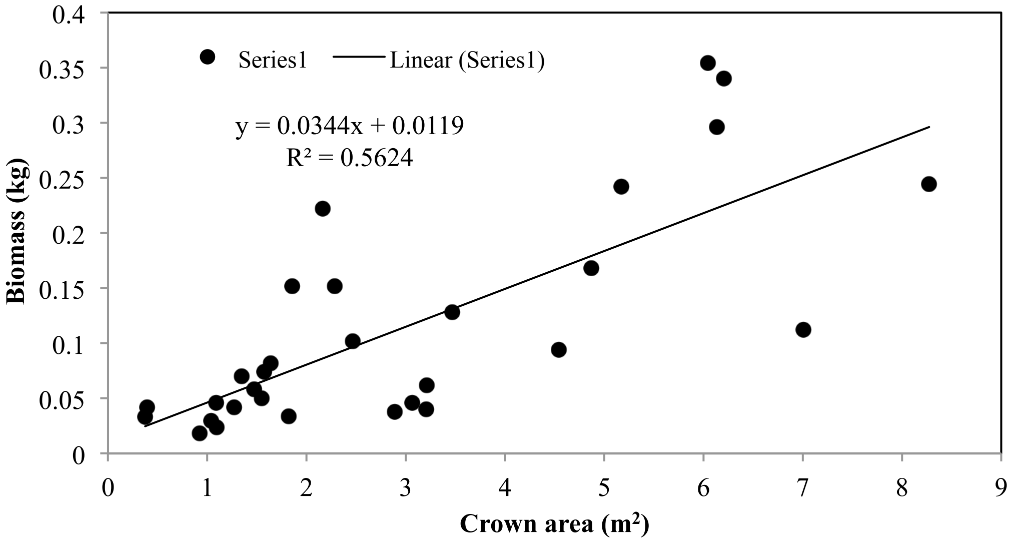

Figure 4.6: Plant crown area and total above-ground biomass correlation of *A. pictum*.

4.2.2 Below ground biomass

A total of 9 transect plots were sampled when collecting below ground root biomass of *A. pictum*, with the average below ground biomass in our study area determined to be 1.126 kg/m^3. The plot at Q1-1 had the highest below ground biomass withvalue (1.825 kg/m^3), while the plot at X 1-4 had the lowest (0.267 kg/m^3) (Fig. 4.7 Overall, the plots in Xayar had higher below ground biomass values, with the exception of X 1-4. From Qongaral, Q 1-1 and Q1-2 haveved relatively higher values.

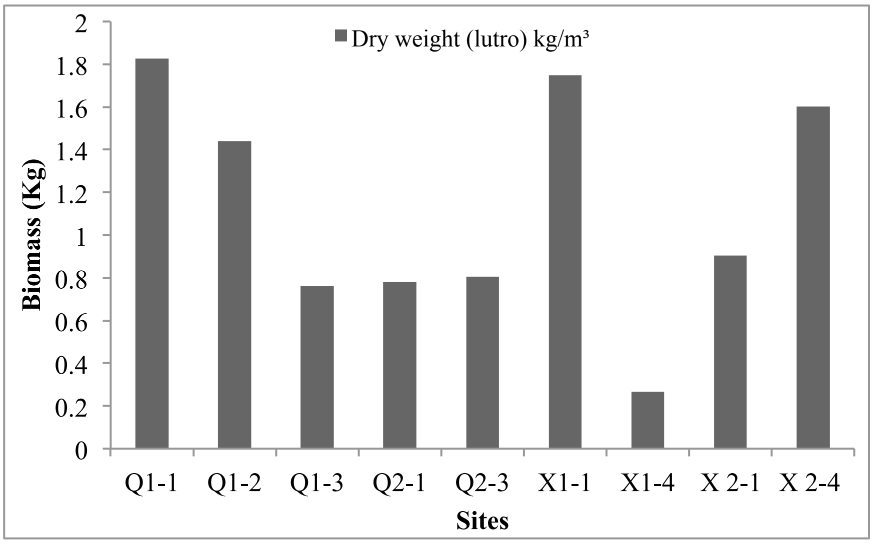

Figure 4.7: Below ground biomass of *A. pictum* at Qong Aral and Xayar.

4.2.3 Soil Nutrient Analysis

Absolute carbon and nitrogen in the soil

The mean absolute nitrogen content of the soil samples differed among sites and depths. As shown in Fig 4.8, soil from Xayar has demonstrated higher absolute nitrogen values than that from Qongaral, with the exception of the 20-to-100 cm underground layer, where they had almost identical values (probably because of a much larger sampling range).

Plants normally receive nitrogen in the soil by nitrogen mineralization and nitrogen fixation (Bardgett, 2005) by soil microbes and bacteria. Grazing intensity and water availability are major factors when it comes to the accumulation of nitrogen. Sites in Xayar are located near the middle reaches of the Tarim and always have running water available, which makes dissolution of nutrients in the soil much easier. Based on our field observations, we have also tentatively concluded that this site is less disturbed and intruded upon by the local herdsmen's livestock, as the local administration's strict implementation of the grassland rules have made the site inaccessible for grazing. Meanwhile, sites in Qongaral is located downstream and are rarely recharged, with both the remoteness and less strict protection making it easy for grazing, which takes away the nitrogen accumulated in the leaves and stems and decreases the nitrogen available to the soil. At both sites, the 0-to-5 cm layers were noted to have the highest nitrogen accumulations, with the 5-to-20 cm and 20-to-100 cm layers following in order. Consequently, higher nitrogen accumulation would lead to high *A.pictum* biomass accumulation (Diekow, et al., 2005). Intensive grazing seems to have negative impact total biomass accumulation as well, with a direct impact on the yield of *A. pictum* and its ability to sequester carbon. Moisture, soil texture and vegetation types play important roles in the accumulation of carbon and nitrogen in the soil.

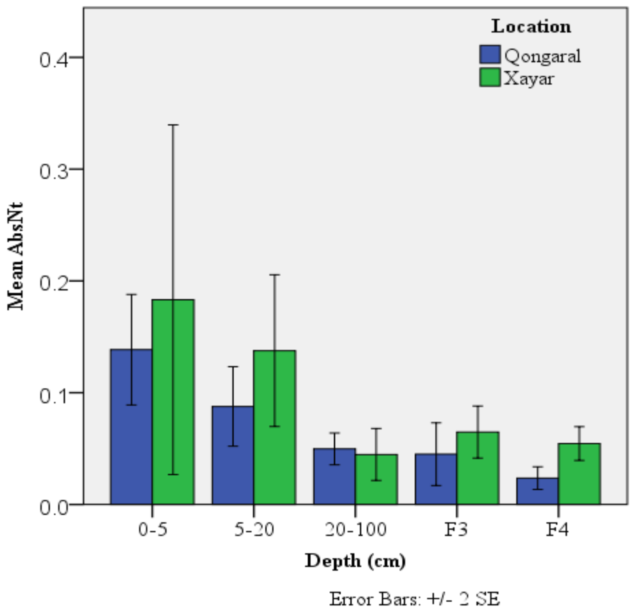

Figure 4.8: Mean absolute Nitrogen values for the different soil layers at the study area.

Mean absolute carbon values for the soil samples at Qongaral and Xayar have shown (Fig 4.9) that Xayar has slightly higher mean absolute carbon than Qongaral does, with the exception of 20-to-100 cm underground layer, although this difference is not great.

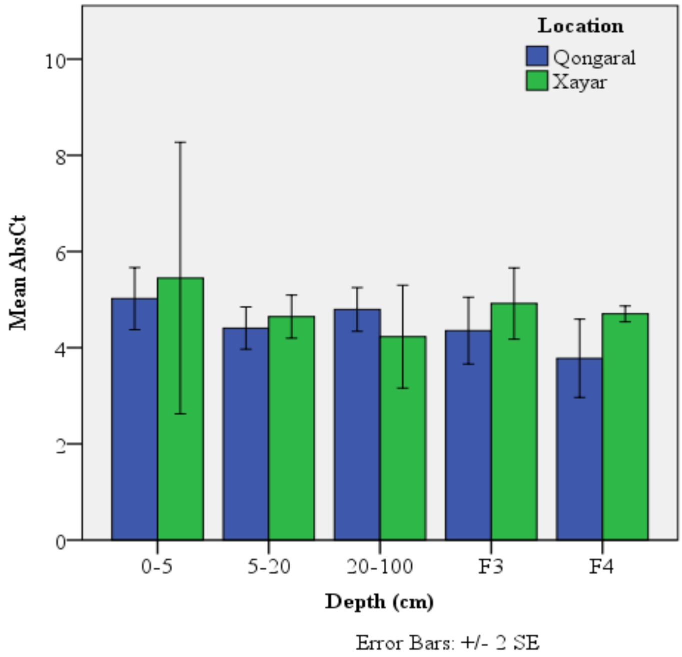

Figure 4.9: Mean abosulte Carbon values for the different layers at the study area.

Carbon-to-nitrogen ratio

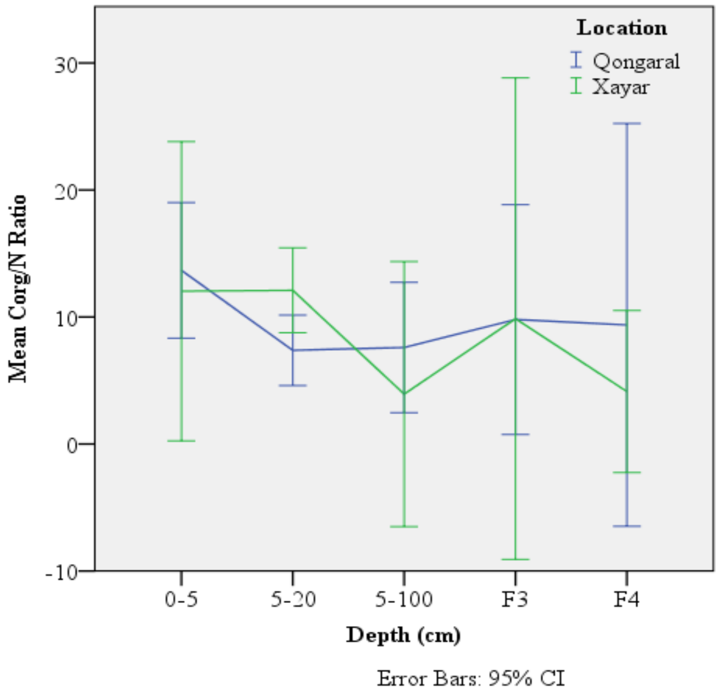

Figure 4.10: Mean Corg/N values.

Quoting White, 2006: "During decomposition, essential elements are converted from organic combination to simple inorganic forms, a process called mineralization. **Mineralization**, especially the release of CO_2, is vital for the growth of succeeding generations of green plants."

"The remainder of the substrate C used by the micro-organisms is incorporated into their cell substance or microbial biomass, together with a variable proportion of other essential elements such as N, P and S. This incorporation makes these elements unavailable for plant growth until the organisms die and decay, so the process is called **immobilization**. The residues of the organisms, together with the more recalcitrant parts of the original substrate, accumulate in the soil. The various interlocking processes of synthesis and decomposition by which C is circulated through soil, plants, animals and air – collectively the biosphere – comprise the carbon cycle."

"Generally, when the substrate **C: N ratio is > 20**, net immobilization is likely, whereas at **ratios < 20** net mineralization is favored."

As we can see from Fig 4.11, the C: N ratio at our study sites ranges from 6 to 14. As it is consistently lower than 20, conditions are favorable for the soil to have net mineralization with plants receiving the necessary nutrients from the soil, and with few dead plants left over. This might be explained by the property that arid regions generally have a higher decomposition rate.

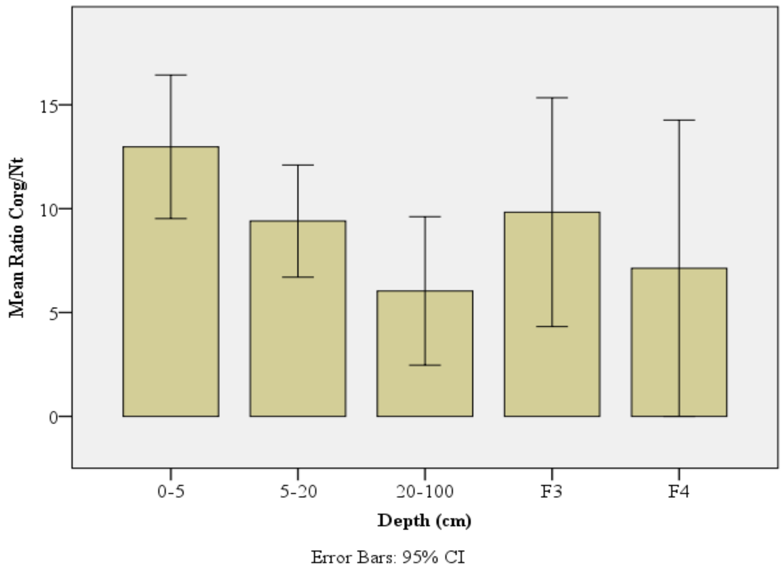

Figure 4.11: Mean Corg/N values for different layers.

All of the soil layers in our study area displayed moderate alkalinity, with pH values of around 8 (Fig 4.12).

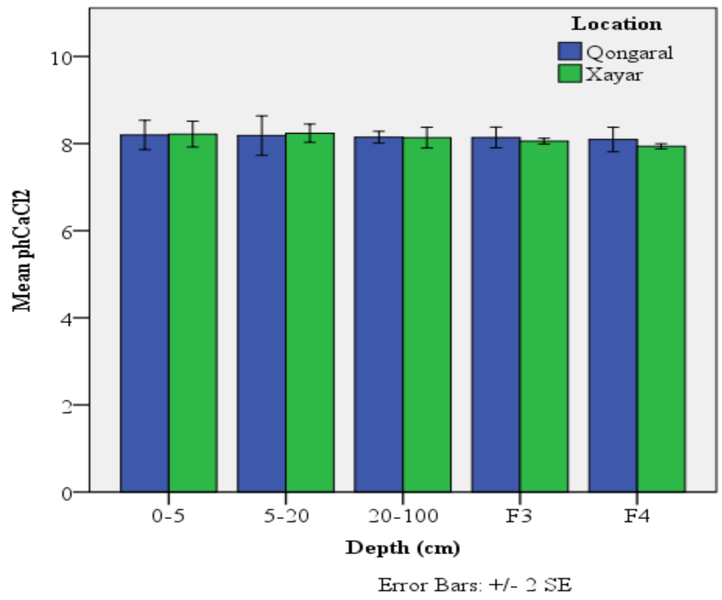

Figure 4.12: Mean pH values of the different soil layers.

As was observed with other nutrients, the total phosphate content in soil also gradually declined with increasing depth.

Phosphate availability is strongly influenced by the pH value (Bardgett, 2005) and phosphate is released during agricultural fertilization.

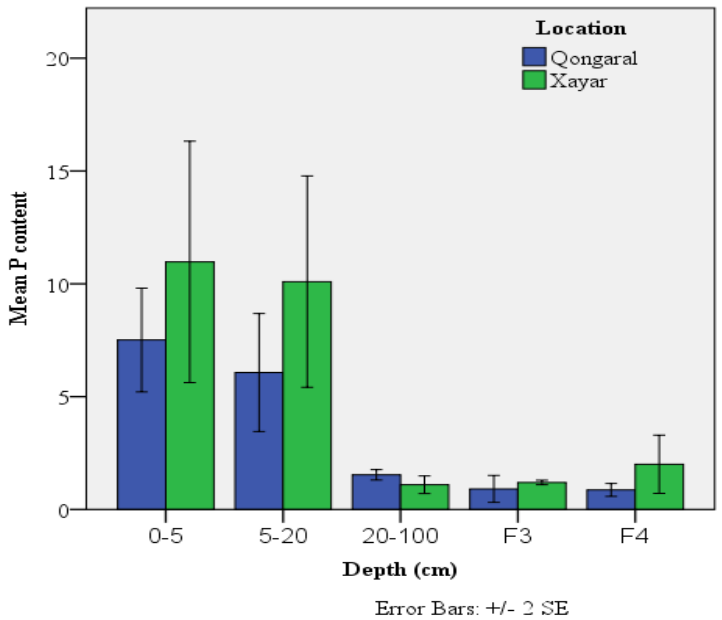

Figure 4.13: Mean phosphathe content in the soil layer.

Soil Organic Carbon

Soil organic matter (SOM) is defined as “the plant and animal remains at different stages of decomposition and the substances derived from the biological activity of the soil-living population” (Kutsch, et al., 2009). Soil organic carbon (SOC) is the carbon content of SOM, and is usually between 50 and 60 % of the SOM (Kutsch, et al., 2009). The SOC values for our study area are given in Table 4.6.

Table 4.6: Soil organic carbon in the soil (t/ha).

Layer (cm)	Mean	Std. Deviation
0-5	7.924	6.197
5-20	19.207	13.767
20-100	25.971	16.3

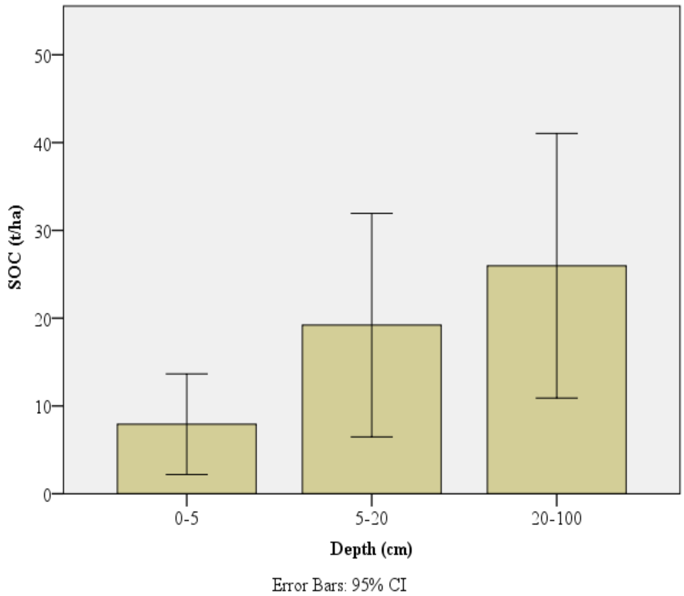

Figure 4.14: Soil organic carbon values of *A. pictum* for different layers.

The SOC values at Qongaral differed significantly from those at Xayar. The values were much higher for Xayar in the 0-to-5 cm and 5-to-20 cm layers than the corresponding values at Qongaral. Qongaral did, however, display a much higher value for the 20-to-100 cm layer, which corresponds to greater nitrogen and carbon accumulation.

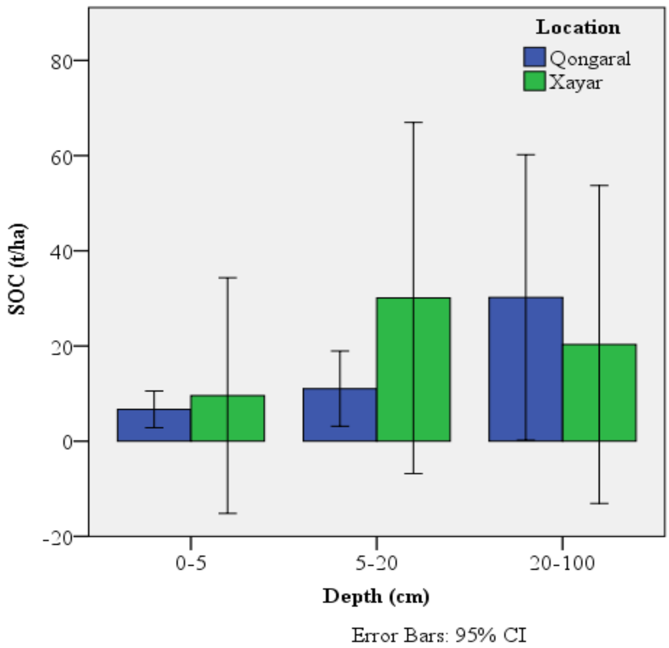

Figure 4.15: Soil organic carbon values at the different sites.

4.3 Water use efficiencies of *Apocynum pictum* and cotton

As can be seen from Table 4.7, the air temperature and radiation were in the same range across all three sites, despite the fact that air humidity is much higher for *Z. jujuba* than for cotton, with *A. pictum* air humidity being the lowest. This may be explained by the presence of irrigation at *Z. jujuba* and cotton sites, with natural *A.pictum* stands meanwhile relying solely on natural flood waters and groundwater. The wind speed was also much lower in the *Z. jujuba* orchard (below 0.25 m/s) as compared to the cotton field and the *A. pictum* stand investigated. For the latter two sites, the wind speed was regularly above 1.5 m/s. The LAI active values differed considerably between the three plant species. *Z. jujuba*, being a tree, had an active LAI value of between 0.42 and 0.46 throughout the measurement period (Table 4.7). The active LAI values of *A. pictum* leaves and stems did not exceed 0.13 and 0.06, respectively, throughout the growing season. The active LAI value of cotton was 0.04 during the initial-stage measurement in mid-June. Afterwards, it increased sharply, reaching a value of 1.75 in August (Table 4.7).

Table 4.7: Climate station and crop data for the days when stomatal conductance was measured. For the climate station data, the hourly mean values are given. The sum of radiation per hour during the time of measurement is given for the solar radiation only. For *A. pictum*, two LAI values are given, that of the leaves and that of the stems (in this order).

Crop & Date	Temperature [°C]	Relative air humidity [%]	Wind speed [m/s]	Solar radiation [MJ/m^2]	Albedo	Crop height [m]	LAI active
Cotton							
15-Jun	25.6	36	4.2	15.2	0.23	0.2	0.04
13-Jul	30.2	31	2.3	25.9	0.19	1	0.46
18-Aug	32.1	30	1.7	24	0.21	1	1.75
20-Oct	13.7	13	1.8	16.6	0.23	1	1.5
A. pictum							
24-May	26.4	20	1.7	20.3	0.21	0.7	0.09/0.04
12-Jun	28.7	27	2.6	9.5	0.23	0.84	0.13/0.06
11-Jul	34.3	22	1.1	24.1	0.22	1	0.13/0.06
24-Aug	30.7	28	1.6	22.8	0.21	1	0.13/0.06
18-Oct	15.9	17	2.2	15.4	0.21	1	0.11/0.06
Z. Jujuba							
17-Jun	30.9	31	0.13	27.4	0.19	3	0.43
15-Jul	29.4	40	0.09	20.8	0.15	3	0.46
20-Aug	30.9	30	0.22	14.8	0.15	3	0.46

The stomatal resistances of cotton and *A. pictum* leaves increased during the course of the growing season. Additionally, cotton leaves displayed a lower measured stomatal resistance in the morning than in the afternoon/evening. This trend was most pronounced for the measurements taken in August and October. By contrast, *Z. jujuba* did not display such a trend, although in studying the June and July measurements one observes that the noon and early-afternoon stomatal resistances were the highest – namely, the stomatal resistances increased from 764 s/m and 348 s/m in the morning to 1446 s/m and 833 s/m between 12:00 and 13:00 in June and July, respectively. At 18:00, the stomatal resistances of *Z. jujube* were recorded as 539 s/m in June and as 708 s/m in July.

While the stomatal resistance of cotton was lower in June (the daily mean for June 15 was 118 s/m) than the corresponding values for *A. pictum* leaves, *A. pictum* stems and *Z. jujuba* (for which the corresponding measurements were 222 s/m, 470 s/m and 927 s/m, respectively), cotton did attain higher daily mean stomatal resistances (885 s/m) than *A. pictum* leaves (742 s/m) and *A. pictum* stems (419 s/m) in October.

Corresponding to the low active LAI in June, the hourly ET_c of cotton was lower than that of *A. pictum* and *Z. jujuba* (Fig 4.16). In the July measurements, the hourly ET_c of cotton exceeded the ET_c of the other two plant species. Cotton and *Z. jujuba* showed a peak in ET_c around noon, with *A. pictum* only showing such a peak in the May, July and October measurements (Fig 4.16).

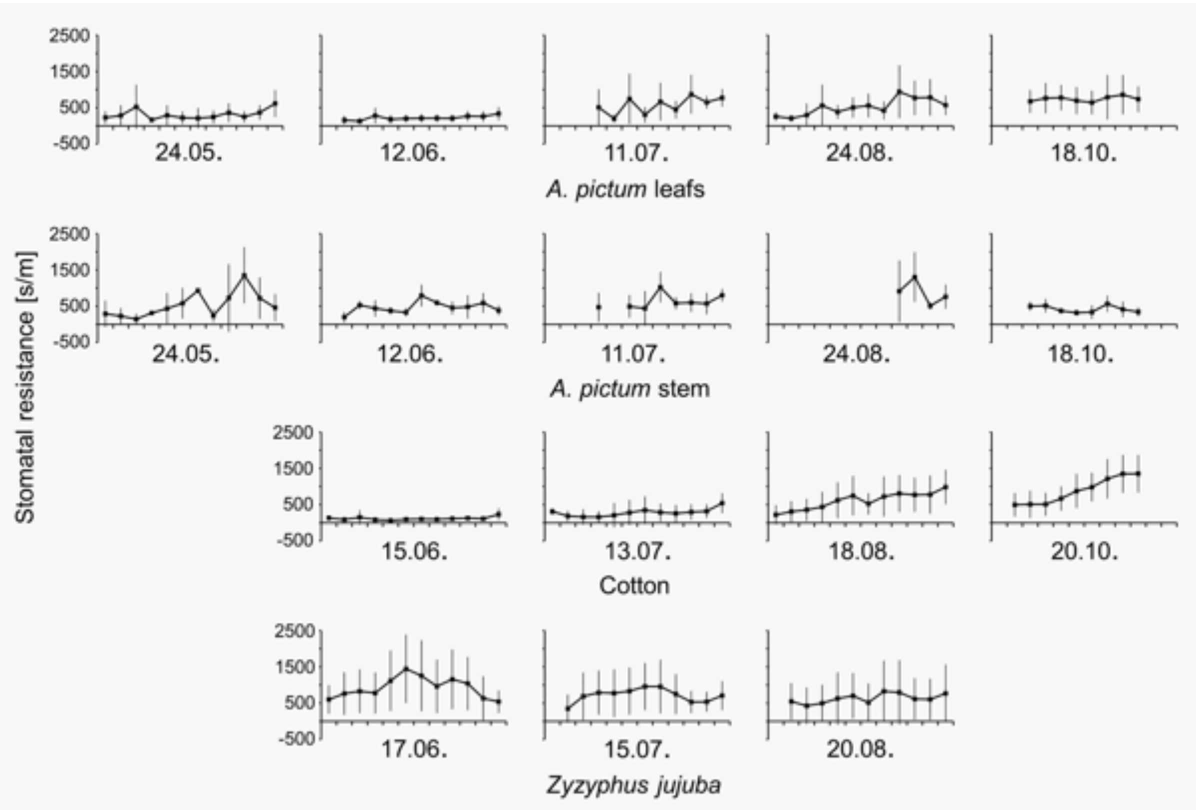

Figure 4.16: Hourly mean values and standard deviation of the stomatal resistance [s/m] on the days of measurement. All x-axes refer to a time span of 07:00 to 19:00 Xinjiang time (i.e., geographical time), which is equivalent to 09:00 to 21:00 Beijing time.

The ET_0 values at the *A. pictum* stand and the cotton field were in the same range throughout the growing season (Table 4.9) – e.g., between 6.1 mm/d and 8.1 mm/d from June to August.

The ET_0 of the *Z. jujuba* orchard was less than half of those values (2.8 mm/d to 3.5 mm/d from June to August). This corresponds with the considerably lower wind speed in the *Z. jujuba* orchard as compared to the other two sites.

Corresponding to the LAI development, the ET_c of cotton was the lowest of the three plant species in June (0.6 mm/d), but increased sharply afterwards, reaching 6.3 mm/d in August. Accordingly, the K_c values also saw a sharp increase from 0.09 in June to 0.79 in August. The K_c values of *A. pictum* fluctuated between 0.13 and 0.26 from May to August and decreased to 0.1 in October (Table 4.8). The corresponding ET_c values ranged between 1 mm/d and 1.8 mm/d from May to August and dropped to 0.3 mm/d in October. The ET_c of *Z. jujuba* was between 2.4 mm/d and 2.7 mm/d during the time period from June to August. As such, it had the highest ET_c values of the three plants in the spring and had values that ranged between those of cotton and *A. pictum* from June onwards. The estimated ET_c values for the entire growing seasons for cotton, *A. pictum*, and *Z. jujuba* were 524.7 mm, 217.2 mm, and 339 mm, respectively (Table 4.8).

Table 4.8: Daily ET0 [mm], ETc [mm], and Kc values of cotton, Apocynum pictum, and *Zyzyphus jujuba* during the months of May to October, 2012.

Month	May	June	July	August	October	Total growing season [mm/year]
Cotton						
ET_0 [mm]		7.3	8.1	7.9	2.5	524.7
ET_c [mm]		0.6	4.1	6.3	1.3	
K_c		0.09	0.51	0.79	0.52	
Date		15-Jun	13-Jul	18-Aug	20-Oct	
A. pictum						
ET_0 [mm]	6.2	7.8	7.3	6.3	3.2	217.2
ET_c [mm]	1.5	1.8	1.8	1	0.3	
K_c	0.24	0.26	0.26	0.16	0.1	
Date	24-May	12-Jun	11-Jul	24-Aug	18-Oct	
Z. jujuba						
ET_0 [mm]		3.5	2.9	2.8		339
ET_c [mm]		2.4	2.7	2.4		
K_c		0.67	0.91	0.85		
Date		17-Jun	15-Jul	20-Aug		

4.4 Economic analysis of *Apocynum*

4.4.1 Property rights in China

Quoting Barbier(2007), "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 Kendir grows are critical to understanding the plant's property rights.

Following the establishment of People's Republic of China in 1949, the Chinese government nationalized all of the land, thereby leaving farmers with no individual rights to its use. Instead, "people's communes" collectively owned and managed the land until 1979 (Dean & Damm-Luhr, 2010), when Deng Xiaoping's "reform and opening up" policy introduced the household responsibility system that allocated land use rights to individual households on a contractual basis (Dean & Damm-Luhr, 2010), known as Jiātíng liánchǎn chéngbāo zérènzhì in Chinese. Since then, there have been a number of legal and regulatory measures adopted by the government to clarify property rights for the people. According to the Chinese constitution of 1982, all land is state-owned unless proven to have collective ownership, with state-owned lands including arable lands, forestlands, grasslands and wastelands. In 2004, certain constitutional amendments were added, stating that "legally obtained private property of the citizens should not be violated" (Xu, 2014). 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.

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 (Dean & Damm-Luhr, 2010). The 2007 version of the Land Administration Law of 1986 states that "land owned by farmers shall be contracted out to be run by members of the collective economic organization for use in crop farming, forestry, animal husbandry and fisheries production under a term of 30 years" (Dean & Damm-Luhr, 2010). Furthermore, the Rural Land Contracting Law of 2002 provided the rights to transfer land to contractual management and defined the transferability of land use rights. 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 (Dean & Damm-Luhr, 2010), though 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 (Dean & Damm-Luhr, 2010).

As Kung (2002) explained, both agricultural and forest lands in China are subject to "quasi-private" property rights (Mullan, et al., 2011). Liu, et al., (1998) 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". Rural land is managed via the Household Responsibility System (HRS) by the households that are allocated land use rights. Under this system, land officially remains under collective ownership, but is allocated among village households to cultivate as they choose (Dean & Damm-Luhr, 2010).

Apart from general land-related laws, the Chinese government has also created different land-specific laws, such as laws specific to grasslands, forests, etc. The Chinese Grassland Law, initiated in 1985, is the official grassland policy that attempts to devolve use rights and liability from the state and collectives to the individuals from former communal ownership (Ho, 2005). Under the principle that grasslands are owned by either the state or the collective, households and collectives are allowed to lease the use of grasslands on a "long term" basis in a manner similar to that of the agricultural lease system (Ho, 2005).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, of which the Kendir is one example (Ho, 2005).

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) (Ho, 2005).The term "wasteland", however, is misleading, as a great portion of this land is used by peasants for animal grazing, small-scale forestry and the exploitation of forest by-products, such as Matsutake mushrooms, medicinal herbs and animals. The direct use of wastelands generally yields low economic returns and its ecology is often fragile (Ho, 2005). The property rights structure of wastelands comes under the same legal arrangements as that of grasslands and forests: it is state-owned unless collective ownership can be proven (Ho, 2005). Grasslands located further away from the collectives are often considered state property, yet remain in use by the different villages or neighboring areas (Ho, 2005). Many of the wild Kendir areas in our study area are very remote and therefore regarded as state property.

Due to its remote location in marginal areas, most of the natural Kendir distributed areas along the Tarim River are regarded as grasslands or wastelands, and as such 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 Kendir distributed areas so as to harvest and sell it without legal consequences.

4.4.2 Resource Use Types of Kendir

All three types of institutional arrangement (Tisdell, 2005) are present in our study at various levels, as shown in Fig 4.17 below. *Apocynum* is used in the three management types of open access, ranching and farming (Tisdell, 2005).

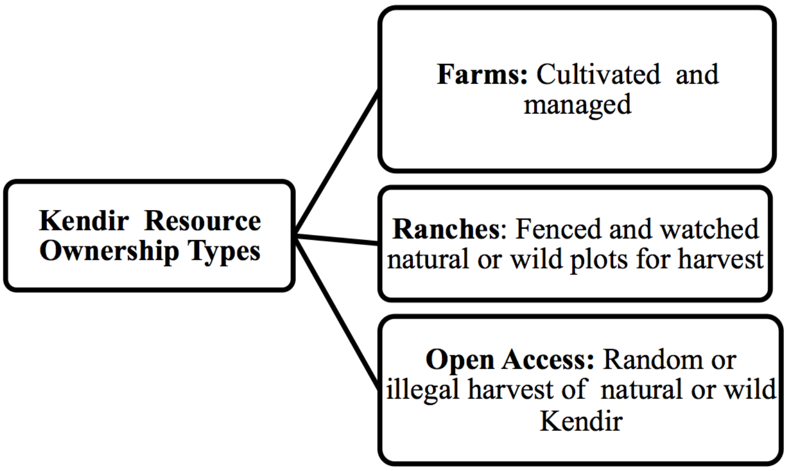

Figure 4.17: Kendir resource ownership and resource types.

Open access: The *Apocynum* in this study have extensive natural or wild distributions in the remote areas of river banks, oases, and towns along the Tarim River. Here, people freely or illegally access *Apocynum* to harvest and trade (Fig 4.18), resulting in a "tragedy of the commons" scenario due to wild *Apocynum* stands being harvested in an open-access manner.

This kind 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, together with the lands' remote location, results in a vacuum where people access the wild Kendir areas with and without consent of the local officials, harvesting and exploiting the Kendir during the vegetation season.

Figure 4.18: Wild unclaimed *A. pictum* in Xayar (Photo: A. Rouzi, June 2011).

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

The harvesters also harvest other medicinal plants, like *Cistanche deserticola* and *Glycyrrhiza inflate*, along with the Kendir. 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 the depletion of grassland resources. Additionally, this shadow structure makes it harder to investigate supply chains in the market. As Tisdell has pointed out, open access resources such as *Apocynum* are not likely to be conserved and sustained and invested in in a way that maximizes the value of production.

Ranching: In this case, the company or farmer makes an agreement with the local pasture administration to harvest certain wild-Kendir areas (Fig 4.19). These Kendir 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 *Apocynum* land. They can thus be classified as “proprietors”.

Breeding or growth control such as fertilizer and pesticide are not applied, which tends to result in faster growth rate and higher biomass for *Apocynum* 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 release water into their fields or plots. Therefore, this style is not investment intensive, 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 Kendir use will have the right to use the land. In some cases, bribary is also involved. Although the profitability of growing wild *Apocynum* in fenced-off areas should theoretically increase the demand for other wild-*Apocynum* 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 4.19: Fenced-off *A.pictum* plot in Yuli county (Photo: A. Rouzi, June 2011).

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, hiring labor for harvesting so as to maximize production. The companies and individual farmers operating these farms often use Kendir 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 Fig 4.20.

Figure 4.20: Cultivated *A. pictum* farm in Altai, owned by the Gebao company (Photo: A. Rouzi, June 2012).

This is a full-scale and well-established scheme in need of greater investment and better allocated labor and management practices. The farmers and companies can also affect and control the yield and quality via different submanagement schemes. One issue present here is that because of a lack of sufficient Kendir farming experience and skills, farmers could fail to grow Kendir well and may not meet expected yields in the initial years. Since the market for Kendir 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, and so can be classified as "owners". Since there is no private ownership of land in China, people cannot sell the land as property (see the discussion in the previous section).

Farming could potentially alleviate the pressures from harvesting and prevent extinction of *Apocynum*, although it could still become extinct in the wild. However, farming could also alter the genetic stocks of *Apocynum*, while the continuing success of farming depends on the genetic diversity sustained in the wild (Tisdell, 2005).

In some cases, it was found that farming and business were well integrated, with the parent companies of Kendir farms also engaged in production and sale of processed Kendir products (Fig 4.21).

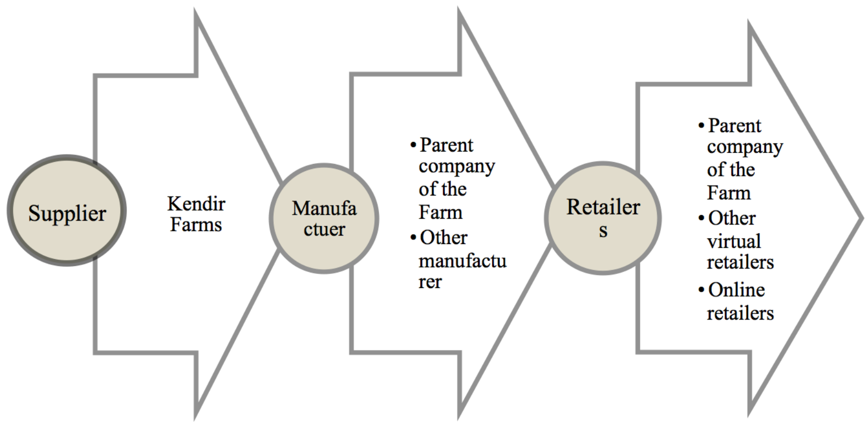

Figure 4.21: Flow chart of cultivated and well-manged Kendir farms.

4.4.3 Cost-revenue analysis

Apocynum venetum and *Apocynum pictum* are chiefly used as medicinal and fiber plants. 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. Textiles produced from *Apocynum* have high hygiene and medical benefits. Furthermore, *Apocynum* spec. is grazed as part of the natural riparian vegetation (Zhang, et al., 2003). 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, which coincides with what is said by Zhang, et al., 2003. The flowers are used for tea as well.

The yields of dry stem biomass, leaf biomass, and flower biomass were reported by the interviewees as 205 kg/mu, 112 kg/mu, and 26 kg/mu, respectively. The 205 kg/mu of stem biomass yields 22 kg/mu of fiber. The 112 kg/mu of leaf biomass yields 75 kg/mu of tea (Table 4.9).

Table 4.9: Raw and processed yields from *Apocynum*.

	Stem	Leaf	Flower	Tea	Fiber
Yield (kg/Mu)	205	112	26	75	22
Sample size	6	10	6	5	4

The prices and revenues generated from *Apocynum* are given in Table 4.10. Although the flowers are the raw material that can be sold for the highest price of approximately 36.18

yuan/kg so as 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 3267.63 Yuan/mu, but this reduces to 2084.28 yuan/mu when the flowers are not harvested.

However, processed tea and fiber have much higher revenues with added values. *Apocynum* tea, in particular, can be sold at 10989 Yuan/mu, which is much higher than the price of the other raw parts of the plant.

Table 4.10: Revenues and profits of Kendir products (Inflation ajusted to 2012 in accordance with consumer price index published by OECD, 2012).

Parts	**Yields (Kg/Mu)**	**Single Price Yuan/kg**	**Potential total revenue = Production × single price (Yuan/mu)**
Stem	205.00	7.79	1596.95
Leaf	112.00	7.81	874.72
Flower	22.00	36.18	795.96
Raw Material Total	339.00		**3267.63**
Tea	75.00	146.52	10989.00
Fiber	22.00	97.59	2146.98

The costs associated with obtaining Kendir biomass are listed separately for open access, ranching, and farming in Table 4.11. In the case of open access, there are only variable costs for labor (i.e., the people who harvest the Kendir) and for the transportation of the harvested biomass. Ranching involves these variable costs and the additional fixed costs of fencing (Table 4.11). Farming involves more inputs and more variable costs, including the additional costs of water, fertilizer, and weeding.

As can be seen from the table, open access is the most profitable way (with a cost of only 213.5 Yuan/mu) of using *Apocynum* 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 231.5 Yuan/mu.

Table 4.11: Cost revenue table for different *Apocynum* resource type.

Farming	**Costs**	**Ranching**	**Costs**	**Open Access**	**Costs**
Fixed costs		**Fixed Costs**		**Variable costs**	
Land Lease	0	Land Lease	0	Harvest Labor	157.48
Tractor	0	Fencing (Yuan/ Mu)	133.00	Transportation	73.99
Variable costs		**Variable costs**		**Per Mu total costs**	231.47
Planting and site establishment Yuan/Mu (Includes labor)	81.6	Harvesting Labor Yuan/Person/a day/Mu	157.48		
Harvest labor Yuan/Person/a day/Mu	157.48	Transportation Yuan/Mu of yield	73.99		
Water fee Yuan/ Mu/ Irrigation	199.9	**Per Mu total costs**	364.47		
Transport Yuan/Mu of yield	73.99				
Fertilizer Yuan / Mu	270.38				
Irrigation and weeding labor	300				
Per Mu total costs	1083.35				

Apocynum farming has both fixed and variable costs, but due to the ambiguous implementation of grassland rules in marginal areas, farmers or Kendir 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 1083.4 Yuan/mu.

5. Discussion

5.1 Biomass and the productivity of *Apocynum pictum*

5.1.1 Analysis of biomass

The stem and leaf biomass of the investigated *A. pictum* ranged from 0.34 t/ha to 1.14 t/ha and from 0.07 t/ha to 0.43 t/ha, respectively. The stem biomass at Xayar 1 was the highest, attributed to the fact that its height and crown area were also the largest. At the same time, Xayar 1 had lower leaf biomass, which could be attributed to its grazing intensity. Qongaral 1 had the lowest stem biomass, correlating with its height. Although crown area appears to correlate with leaf biomass, different grazing patterns also have major influence on biomass (discussed in a later section). The total above-ground biomass ranged from 0.6 t/ha (Qongaral 1) to 1.25 t/ha (Xayar 1). As the above-ground parts of *A. pictum* die each year (Berljand, 1950), the measured biomass reflects the annual biomass production. Hong, et al. (2002) measured the total above-ground biomass of a meadow of *A. pictum*, *Phragmites australis,* and *Karelinia caspica* at the northern rim of the Tarim Basin and reported a value of 0.93 t/ha, which is similar to that recorded for Qongaral 2. Bachu and Xayar 1 had higher biomass values, while Qongaral 1 and Xayar 2 had lower ones (Table 4.4). In the Caidam Basin, the fresh weight of the total above-ground biomass of *A. pictum* was measured as ranging from 1.8 t/ha to 2 t/ha. It should be noted that annual precipitation is much higher here than in the Tarim Basin (Tang, 2008).

Since the biomass measured in the Caidam Basin is fresh, it can be considered to be comparable to the total above-ground biomass of Xayar 1 or Bachu (Table 5.1). *A. pictum*'s above-ground biomass corresponds with the measured biomass of temperate desert steppes in northern and northwestern China (Fan, et al., 2008). The relatively moderate biomass of *A. pictum* as compared to other steppe and desert ecosystems reflects the strains of soil and water conditions for plant growth in the desert margins. In contrast to the *Artemisia*, *Stipa* and *Leymus* species listed in Table 5.1, *A. pictum* grows in more arid and salinized environments, with significantly less precipitation that results in less accumulation of biomass.

Table 5.1: Biomass of selected species and ecosystems in China.

Species or ecosystem	Location	Above ground biomass (t/ha)	Source
Apocynum pictum Schrenk.	Tarim Basin, Xinjiang, China Annual precipitation less than 50 mm	0.6 - 1.25	This study
Meadow of *A.pictum*, *Phragmites australis,* and *Karelinia caspica*	Northern rim of Tarim basin, Xinjiang, China	0.93	Hong, et al. (2002)
A. pictum	Annual precipitation less than 50 mm Caidam Basin, China, Annual precipitation < 210 mm	1.8-2 (fresh)	Tang, 2008
Artemisia ordosica	Ordos Plateau, Inner Mongolia, China Annual precipitation 345.2 mm	7–12.4	Jin, et al. (2007)
A. ordosica, fixed dunes	Ningxia, China	3.4 ± 0.3*	Li & Xiao (2007)
A. ordosica, shifting dunes	Annual precipitation 388 mm	0.25 ± 0.04*	
Leymus chinensis steppe	Xilingol, Inner Mongolia, China	1.9	Xiao, et al. (1995)
Stipa grandis steppe	Annual precipitation 300 mm	1.4	
Temperate desert-steppe Temperate steppe-desert Temperate desert	North and Northwest China	0.5± 3.39* 0.45± 2.42* 1.17± 1.29*	Fan, et al. (2008)

*Total biomass, i.e., above- and below-ground biomass.

Groundwater and electric conductivity analysis

Plant biomass is dependent on appropriate soil structure and nutrient conditions. In particular, it is dependent on adequate soil aeration from root growth and sufficient soil water availability during the vegetative period (Mueller, et al., 2005). *Apocynum* needs high nutrient availability because it grows rather fast. From the second half of the summer onward, *Apocynum* stores nutrients in its root system (Berljand, 1950). On four out of five sites, *A. pictum* grew on groundwater levels between 4.25 m and 5.2 m below the soil surface. These groundwater depths correspond with those reported by Hao, et al., (2008), who reported that the *A. pictum* growing along the Tarim River was mainly found where groundwater levels were 4-6 m, with a maximum groundwater depth in the Tarim Basin being 8 m. *Apocynum venetum*, by contrast, is generally restricted to groundwater levels no deeper than 4 m (Zhang, 2002), underlining the general property that *A. pictum* is adapted better to the conditions along periodic river courses, where the groundwater layer is not refilled regularly. Compared to other plant species of the riparian vegetation along the Tarim River, *A. pictum* tolerates deeper groundwater levels than *Phragmites australis*, *Calamgrosti spseudo phragmites* (Haller f.) Koeler, and the annual plants (Thevs, et al., 2007). The groundwater depths endured by *A. pictum* are similar to *Halimodendron halodendron* (Pall.) Druce, *Glycyrrhiza inflate* Batalin, and *Karelinia caspica*, but does not reach the groundwater depths endured by the *Tamarix ramosissima* Ledeb. and *Populus euphratica* Oliv. (Chen, et al., 2006a; Hao, et al., 2008; Thevs, et al., 2008). With the exception of Xayar 2, the stem biomass was seen to increase with higher groundwater levels, attributable to the water supply to the *A. pictum* stands improving. Although Xayar 2 had the highest groundwater level, it did not have the highest stem biomass. One likely explanation is grazing. However, a higher groundwater level associated with high soil moisture in the root zone could also lead to reduced growth.

The topsoil under *Apocynum* stands is often salinized, reaching salt contents of up to 20 % under the *Apocynum*, with contents of 1 % or less 30 cm below the surface (Zhang et al., 2005). This corresponds with our results, which show that the electric conductivity decreases from the soil surface downward into the soil profile. This also essentially shows that *A. pictum,* like many other plant species of the riparian vegetation along the Tarim River (e.g., *Phragmites australis*, *Halimodendron halodendron* or *Glycyrrhiza inflata*), can grow on sites with a pronounced surface salinization as long as the groundwater is not too salty (Thevs, et al., 2007). The EC of the soil material from the groundwater layer found in this study, i.e., 0.88 mS/cm to 2.28 mS/cm, is low compared to that found for other plant species of the riparian vegetation. However, the electric conductivity of the soil material of all soil layers meets the saline soil definition of the US salinity laboratory – i.e., as those with a saturated paste extract electrical conductivity (EC_e) of > 4 mS/cm (Gregory & Nortcliff, 2013). Qongaral 1 at the depth of 20-100 cm is the only exception. Thevs, et al. (2008) have also measured the EC values of the soil from the groundwater layer, obtaining 3.1 mS/cm for *Phragmites australis*, 8.2 mS/cm for *Populus euphratica* and 20.2 for *Tamarix ramosissima*. Still, *A. pictum* can withstand the saline topsoils that would result from irrigation or natural soil salinization (Berljand, 1950) and consequently, as *A. pictum* tolerates salt better than cotton, it might be used in fields that have been salinized by cotton production (Berljand, 1950). The topsoil salinization under all sites is higher than the threshold above which cotton suffers from reduced yields (an EC value of 7.7 mS/cm). On the salinized soils in Bachu, Qongaral and Xayar cotton yields would decrease by 50 % (Maas & Hoffmann, 1977), leading us to conclude that most of the sites in our study are not suitable for growing cotton on a large scale while maintaining maximum productivity and efficiency.

Land use impact on aboveground biomass

We attribute the major differences in biomass to be due to grazing and soil salt content. The stem-leaf biomass ratio reflects the grazing intensity, because cattle prefer leaves to stems as fodder. At Xayar 2, the cattle likely consumed more stem biomass than at Xayar 1, as this site lies closer to the herders' settlement from which the cattle are driven into the *A. pictum* stand.

Next to grazing, we conclude that salt affects productivity more than groundwater depth, seeing as the total biomass in Xayar 1 is about three times higher than in Bachu and five times higher than in Qongaral, despite the groundwater depths only differing by a meter. However, Xayar 1, having the highest biomass, also has the lowest salt content in topsoil. Though Xayar 2 has the highest groundwater level, it does not have the highest stem biomass. Here, the major reason is grazing, although a high groundwater level associated with high soil moisture in the root zone also may lead to reduced growth.

The below-ground biomass of *A.pictum* is at 1.125 ± 0.541 kg/m^2, which is higher than the temperate desert steppe value of 0.339 ± 0.191 kg/m^2 (Fan, et al., 2008). The relatively higher below-ground biomass may reflect the sophisticated root system of *A. pictum*, although it may also be due to a smaller sample size.

5.1.2 Soil nutrient analysis

Apocynum needs considerable amounts of nutrients from the soil because of its fast growth. From the second half of the summer onward, *Apocynum* stores nutrients in its root system (Berljand, 1950). The net primary production of vegetation dominated by *Apocynum* in the Tarim amounts to 0.93 t/ha (Hong, et al., 2002). For the *A. venetum* leaves in Xinjiang, the contents of the nutrients K, Ca and Mg are 8.1 mg/g, 1.13 mg/g and 5.01 mg/g, respectively. The Na content is 6.2 mg/g (Fan, et al., 2006).

Ground water availability and soil salinity were the observed major factors in the accumulation of carbon and nitrogen fluxes for all layers in this study. The soil organic carbon accumulated in the A Horizon (0-5 cm) was 7.924 t/ha, which is lower than the value of 10.74 t/ha observed for the Loess Plateau in Shaanxi Province (Wang, et al., 2012). Our study also suggests that a generally higher accumulation of soil organic carbon in the 0-5 m layer would lead to higher above-ground biomass, as evidenced by the results at the sites in Xayar as compared to those at Qongaral. Our study shows that the soil C: N ratio declines with depth.

5.2 Water use efficiency of *Apocynum pictum* and cotton

The vegetation-season water consumptions of major riparian vegetation types of Central Asia are listed in Table 5.2, the data for which was extracted from the MODIS satellite images by using the S-SEBI remote-sensing method (Thevs, et al, 2013b). As can be seen from the table, the water consumption of *Populus eurphrtica* stands is at 192-392 mm/year, while for *Tamarix ramosissima* stands it is at 92-180 mm/year. These are both key stone species of Tugai vegetation along the Tarim River and have much smaller water demands than other semi-arid riparian species in Central Asia. The *A. pictum* along the Tarim River, with a coverage of more than 50 %, has a water consumption of 31-142 mm/year (based on the MODIS calculation).

Table 5.2: Water consumption (E_a) of riparian vegetation types in Central Asia during the vegetation season (Thevs, et al., 2013b).

Vegetation type	**ET_a (mm/year)**	**Source**	**Corresponding vegetation in this study**
Populus euphratica, Tarim Basin (China), groundwater 4 m, tree density 2300-3400 trees/ha	192-392	Thomas, et al. (2006)	10 % - 20 % total coverage
Tamarix ramosissima, Tarim Basin (China)	92-180	Thomas, et al. (2006)	10 % - 20 % total coverage
Populus euphratica, Ejina (Heihe Basin, Inner Mongolia, China)	447	Hou et al. (2010)	20 % - 30 % total coverage
Elaeagnus angustifolia, Khorezm, Uzbekistan, planted on shallow (0.9-2 m) ground- water	1250	Khamzina, et al. (2009)	Exceeds MODIS ET_a of natural vegetation with total coverage of 70 % and more
Populus euphratica, Khorezm, Uzbekistan, planted on shallow (0.9-2 m) groundwater	1030	Khamzina, et al. (2009)	Exceeds MODIS ET_a of natural vegetation with total coverage of 70 % and more
Tamarix ramosissima, Rio Grande (USA), LAI = 2.5, not flooded	740	Cleverly, et al. (2000)	50 % - 70 % total coverage in 2009, i.e., no summer flood
Tamarix ramosissima, Rio Grande (USA), LAI = 3.5, flooded	1220	Cleverly, et al. (2000)	Total coverage 70 % and more in 2011, i.e., vegetation partially submerged.
A. pictum along the Tarim River	31-142	Thevs et al., 2014	Total coverage 50 % > pixels in MODIS images

The daily ET_0 values for cotton and *A. pictum* (Table 4.8) were similar to those reported by Cai, et al. (2007) for Ejina in the Heihe River Basin of Inner Mongolia, China, where the climate is not unlike that of the Tarim Basin. The ET_c during the cotton growing season (Table 4.8) is below the values given by Chapagain, et al. (2006) and Carr, et al. (2013), but in the same range as the norms for water consumption from the Soviet times (i.e., 550–600 mm) (Nechaeva & Nikolayev, 1962) and the values given by Thevs, et al. (2014b) for

Turkmenistan.

The crop coefficients of cotton as given by Allan, et al. (1998) are: $K_{c\ ini}$ = 0.35, $K_{c\ mid}$ = 1.15-1.2, and $K_{c\ end}$ = 0.5-0.7. The K_c values for cotton as found in this study follow this pattern, as there is an increase from K_c from June to July to August, followed by a decrease in October (Table 4.10). However, it should be noted that the K_c values in this study are lower than those of Allan, et al. (1998) throughout the growing season. This is especially true of the K_c in June, the initial stage of cotton, which at 0.09 is much lower than the corresponding $K_{c\ ini}$ of 0.35 as listed by Allan, et al. (1998). This difference may be due to the application of plastic mulch combined with drip irrigation, as the plastic mulch covers the soil that, wetted during irrigation from the drip lines, has inhibited evaporation from the soil surface due to the mulch. The drip irrigation may also explain the other differences in the K_c values, as well as the low ET_c in general.

Z. jujuba displayed K_c values in the range of the Rosaceae fruit trees listed by the FAO irrigation and Drainage Paper 56 (Allan, et al., 1998). The low hourly and seasonal ET_c of *Z. jujuba* as compared to those of cotton (Fig 5.1 and Table 4.8) is likely due to the low ET_0 of *Z. jujuba* (Table 4.8). The low ET_0 in the *Z. jujuba* orchard is explained by the wind speed, which is much lower than that in the cotton field or the *A. pictum* stand. The orchard is embedded in a narrow web of shelterbelt tree lines, which reduces the wind speed, whereas there are no obstacles, such as vegetation, for wind in the cotton field and the *A. pictum* site.

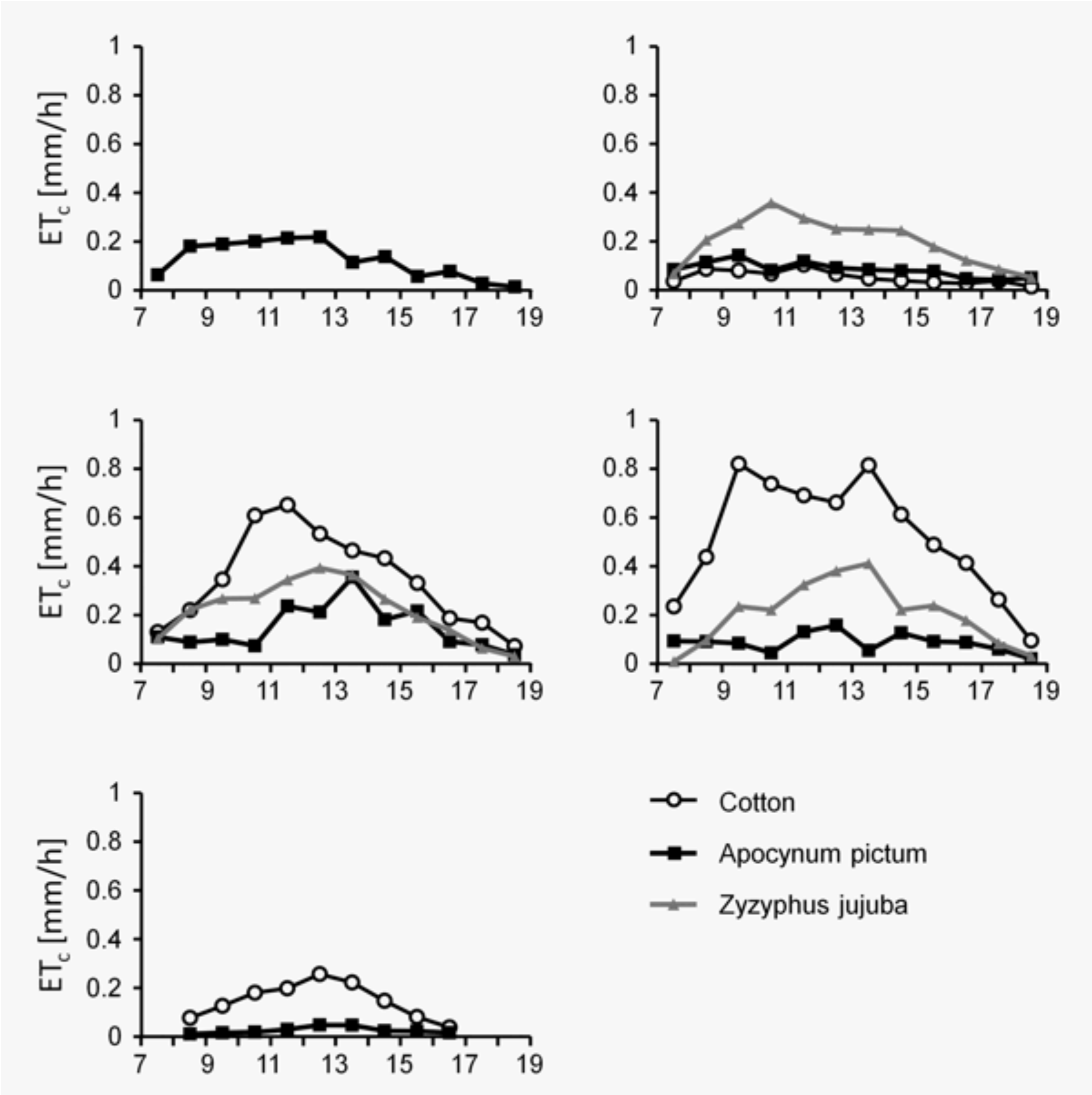

Figure 5.1: Hourly ET_c during the days of measurement for cotton, *A. pictum* and *Z. jujuba*. The time on the X-axis is the local geographical time (Xinjiang time), which is two hours behind Beijing time.

The ET_c over the *A. pictum* growing season is in the same range as the water use of *Alhagi sparsifolia* and *Tamarix ramosissima*, which are plant species of the natural ecosystem of which *A. pictum* is a part (Thomas, et al., 2006). The K_c values of *A. pictum* are lower than all the crop coefficients listed by Allan, et al. (1998). This is due to the low active LAI, which corresponds with the anatomy of *A. pictum* and the low vegetation coverage. *A. pictum*, though it is part of the natural riparian vegetation of the Tarim Basin and thus adapted to the arid climate there, does not have a higher stomatal resistance than the other two crops investigated. As a phreatophyte, *A. pictum* adapts to the arid climate by establishing contact with the groundwater (Chen, et al., 2006a; Thevs, et al., 2008b). As such, *A. pictum* survives in the arid climate by securing the water supply rather than by storing water other desert plants do. If *A. pictum* grew with a higher vegetation coverage (i.e., higher plant density) or if the *A. pictum* plants grew larger, it follows that the ET_c and K_c would increase.

The cotton examined in this study attained a high yield, as compared to the world average (http://faostat.fao.org/), at a rather low ET_c. Areas with similar ET_c values in Turkmenistan have shown smaller cotton yields, thus indicating that the water use efficiency is significantly lower (Thevs, et al., 2014b). The cotton in our study area consumed 525.7 mm of water in a year, which is notably higher than Chen 2014's MK-simulated test result of 464 mm. This increase in water use efficiency was achieved via a shift from flood to drip irrigation, the utilization of plastic mulch and the breeding of cotton varieties. The issue of garbage pollution in the drip line and the plastic mulch, as well as their recycling, is beyond the scope of this study, however.

5.3 Economic analysis of *Apocynum*

Discussion on resource use types

The open-access resource model would not be beneficial to the conservation and sustainability of Kendir as a resource. In particular, open access would become problematic as the demand for Kendir grows and would become a significant economic and ecological concern for the Tarim Basin. Therefore, the efficient utilization of Kendir 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 resource and must also be taken into consideration. Currently, the demand for Kendir is low, and so 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 (Schlager & Ostrom, 1992) associated with Kendir.

Although ranching is certainly economically more efficient than open access with regard to profitability, it would not fulfill an increase in demand due to limitedness of naturally distributed Kendir areas.

Kendir farming can effectively deal with issues inherent to open access and may prevent the exhaustion of the resource in the wild. In the long run, however, farming would lead to a loss of genetic diversity, which in turn would decrease the Kendir yields in the future.

Discussion on the cost-revenue analysis

As discussed in a previous chapter, 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 cotton dominated irrigated agriculture (Thevs, et al., 2014a) in 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 then more willing to import cheap cotton from overseas (Macdonald, et al., 2015). 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 (Macdonald, et al., 2015).

As can be seen from Table 5.3, cotton in Xinjiang costs 1926.58 Yuan/mu to produce while generating 2474.33 Yuan/mu of revenue. With the resulting gross profit of 547.75 Yuan/mu, it is the least profitable of all major cash crops and fruit compared in this study. Although the nationwide cost of producing cotton (1939.73 Yuan/mu) is very similar to that of Xinjiang, the revenues generated from cotton nationwide are much smaller (1964.99 Yuan/mu) and result in a significantly lower overall profit (25.26 Yuan/mu). This is largely due to the fact that most of China does not enjoy the cotton subsidies that Xinjiang does and also Xinjiang has relatively higher productivity. This apparent profitability of cotton production in Xinjiang, heavily dependent on government support, is now wavering in light of cheaper imported cotton.

"Hongzao" – the Chinese 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. *Apocynum* costs 1083.35 Yuan/mu, generates 3267.63 Yuan/mu of revenue from raw materials and brings a profit of 2184 Yuan/mu, making it the most profitable of the three cash crops compared.

Table 5.3: Cost-revenue comparison of the major cash crops in Xinjiang China in 2012.

Name	**Cotton (Xinjiang)**	**Cotton (China)**	**Hongzao (Xinjiang)**	**Apocynum**
Cost (Yuan/mu)	1926.58	1939.73	2893.13	1083.35
Revenue (Yuan/mu)	2474.33	1964.99	3747.36	3267.63
Profit (Yuan/mu)	547.75	25.26	854.23	2184.28
Output (Kg/mu)	114.65	166.1	141.87	339
Source	Xinjiang Agri-cultural cost -revenue material 2013	Chinese Rural Statistical Yearbook 2013	Xinjiang Agricultural cost-revenue material 2013	This study

Cotton has the highest costs and the lowest returns – this is due to its labor and investment intensity. Various government policies and a mature global market made cotton a reliable cash crop in this region for many years, but rising costs and changes in government policy, together with competition from cheap imported cotton, has made it less attractive. As shown in Fig 5.2, although the material and land costs of cotton have increased steadily from 2003 to 2012, the labor costs per area have risen dramatically from 317.25 Yuan in 2003 to 1170.71 yuan in 2012, thus driving up the production costs. The cotton price has fluctuated during this period, with profits shrinking to mere 25 Yuan/mu 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 (Macdonald, et al., 2015). Because of 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.

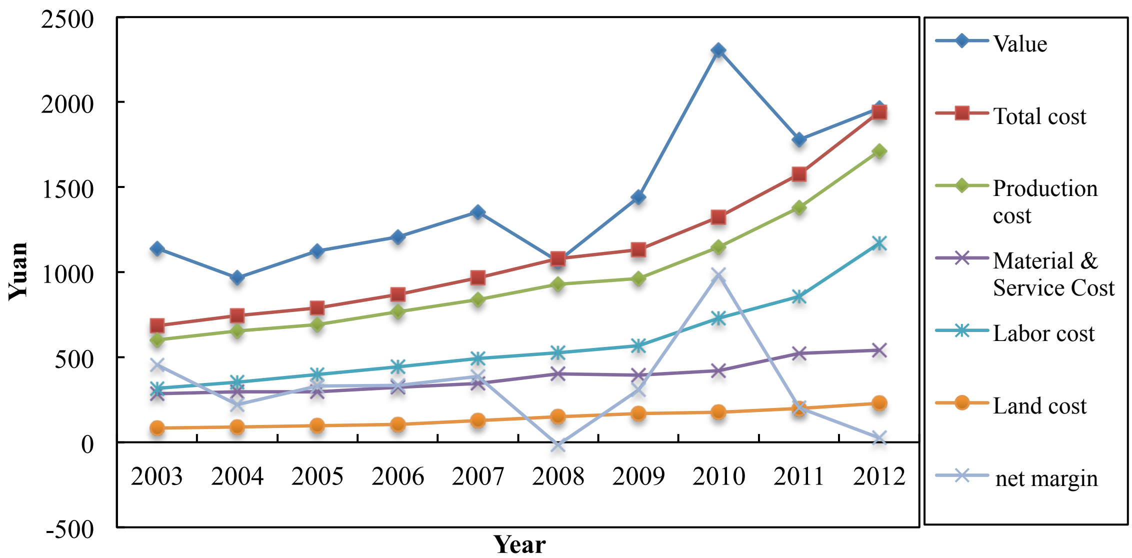

Figure 5.2: Cost-revenue trend for cotton in China, 2003-2012 (China Rural Statistical Year Book).

The number of fruit tree plantations has increased tremendously in recent years, due largely to a high demand, market demand from eastern China, and the government policy of “tui geng huan lin” (“returning crop land to the forests”), with farmers obtaining subsidies 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. 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 200 Yuan/mu subsidy for the 5 years while the newly planted trees produce fruit.

Although Fruit trees, like red date (*Z. jujuba*) are leading alternative to cotton for the moment, *Apocynum* could also be strong alternative with its low cost and high profitability when sufficient government support put in place. High quality fibers extracted from *A.pictum* could also become valuable textile material for its heygenic features. Hongzao prices are also in decline because of oversupply, costs are rising as labor prices increasing and diversifying the region’s agricultural sector is key to long-term sustainable development.

6. Conclusion

The relatively moderate biomass of *A. pictum* as compared to other steppe and desert ecosystems reflects the strains of soil and water conditions for plant growth in desert margins. Most of the sites are salinized and not suitable for large-scale cotton growth at maximum productivity and efficiency.

A. pictum needs only 217 mm/a which is about half of cotton (524.7 mm/a) and also less *Z. jujuba* (339 mm/a). As I described in Chapter 2.6, Tarim basin is subject to strict water quota by Tarim River water commission, therefor substituting cotton with *A. pictum* would save almost of half of water that could allivate water scarcity and make region's agriculture more sustainable.

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. *Apocynum* costs 1083.35 Yuan/mu, generates 3267.63 Yuan/mu of revenue from raw materials, and brings a profit of 2184 Yuan/mu, the latter being the highest among all of the three cash crops compared, thereby demonstrating the growth of this crop to be economically viable. Given cotton's declining profitability and its heavy reliance on subsidies, *A. pictum* may be seen as a promising candidate substitute. It should be noted that *A. pictum* may also generate income via tea production, as well as via its uses as fibers and fodder for livestock.

Finally, we conclude that *A. pictum* offers opportunities for the restoration of vegetation in riparian ecosystems on salinized sites under the arid conditions in the Tarim Basin.

References

Adams, G., Boyd, S. & Huffman, M. (2014). The economic outlook for US cotton 2014. http://www.cotton.org/econ/reports/upload/2014-Annual-Outlook.pdf.

Aishan, T., Halik, Ü., Cyffka, B., Kuba, M., Abliz, A. & Baidourela, A. (2013). Monitoring the hydrological and ecological response to water diversion in the lower reaches of the Tarim River, Northwest China. *Quaternary International*, *311*, 155–162.

Alaily, F. (2000). Carbonate und Salze." *Handbuch der Bodenkunde*.

Allan, R.G., Pereira, L.S., Raes, D. & Smith, M. (1998). Crop Evapotranspiration Guidelines for Computing Crop Water Requirements. FAO Irrigation and Drainage Paper 56. FAO, Rome.

Bai, L., Luo, M.B., Chuan, L.C., Wang, S.L., A, M.N. (2005). Short Report on planting techniques of *Apocynum venetum*. *Chinese Wild Plant Resources,* 24, 65-68.

Barbier, E. (2007). *Natural resources and economic development*. New York, Cambridge University Press.

Bardgett, R. (2005). *The biology of soil: a community and ecosystem approach.* Oxford University Press.

Becquelin, N. (2000). Xinjiang in the Nineties. *The China Journal*, *44*(July), 65–90.

Berkes, F. (1996). Social Systems, Ecological Systems and Property rights. *In Rights to Nature*: Ecological, Economic, Cultural, and Political Principles of Institutions for the Environment, eds. S. S. Hanna, C. Folke, and K.-G. Mäler, 127–156. Washington, DC: Island Press.

Berg, B. & McClaugherty, C. (2008). Plant litter." *Decomposition, humus formation, carbon sequestration. 2nd Ed Springer*.

Berljand, S.S. (1950). Agro-Technology of Kendir. NAUK, Moscow. (in Russian)

Bonham, C. D. (2013). *Measurements for Terrestrial Vegetation*. John Wiley & Sons, Ltd, Oxford.

Butterweck, V., Nishibe, S., Sasaki, T. & Uchida, M. (2001). Antidepressant effects of *Apocynum venetum* leaves in a forced swimming test. *Pharmaceutical Society of Japan,* 24, 848-851.

Butterweck, V., Simbray, K., Seo, S., Sasaki, T. & Nishibe, S. (2003). Longterm effects of an *Apocytum venetum* extract on brain monoamine levels And b-AR density in rats. Pharmacol. Biochem. *Behaviour,* 75, 557-564.

Buurman, P., Lagen, B. & Velthorst, E.J. (1996). *Manual of soil and water analysis*. Leiden, Backhuys Publishers Leiden.

Cai, J. B., Liu, Y., Lei, T. W. & Pereira, L.S. (2007). Estimating reference evapotranspiration with the FAO Penman–Monteith equation using daily weather forecast messages. *Agricultural and forest Meteorology*, 145, 22-35.

Cao, Y., Chu, Q. & Ye, J. (2003). Determination of hydroxyl radical by capillary Electrophoresis and studies on hydroxyl radical scavenging activities of Chinese herbs. *Analytical and Bioanalytical Chemistry,* 376, 691-695.

Carr, M. K. V. (2013). Crop Yield Response to Water. FAO Irrigation and Drainage Paper 66. By P. Steduto, TC Hsiao, E. Fereres and D. Raes. Rome, Italy: Food and Agriculture Organization of the United Nations

(2012), pp. 500, US $100.00. ISBN 978-92-5-107274-5. The whole report can be downloaded from: http://www. fao. org/docrep/016/i2800e/i2800 e00. htm. *Experimental Agriculture*, 49(02), 311-311.

Chapagain, A. K., Hoekstra, A. Y., Savenje, H. H. G. & Gautam, R. (2006). The water footprint of cotton consumption: An assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries. *Ecological Economics*, 60, 186-203.

Chen, Y., Chen, Y., Xu, C., Ye, Z., Li, Z., Zhu, C. & Ma, X. (2010). Effects of ecological water conveyance on groundwater dynamics and riparian vegetation in the lower reaches of Tarim River , China. *Hydrological Processes*, *24*, 170–177.

Chen, Y. (2014). *Water Resources Research in Northwest China*. (Y. Chen, Ed.). Dordrecht: Springer Netherlands.

Chen, Y. N., Ziliacus, H., Li, W. H., Zhang, H. F. & Chen, Y. P. (2006a). Ground-water level affects plant species diversity along the lower reaches of the Tarim River, Western China. *Journal of Arid Environments*, 66(2), 231-246.

Chen, Y., Takeuchi, K., Xu, C., Chen, Y. & Xu, Z. (2006b). Regional climate change and its effects on river runoff in the Tarim Basin, China. *Hydrological Processes*, 20(10), 2207–2216

Chen, Y., Xu, C., Chen, Y., Liu, Y. & Li, W. (2013). Progress, challenges and prospects of eco-hydrological studies in the Tarim river basin of Xinjiang, China. *Environmental Management,* 51(1), 138–53.

Climate data (http://en.climate-data.org/location/2426)

Cyffka, B., Rumbaur, C., Kuba, M. & Disse, M. (2013). Sustainable management of river oases along the Tarim River (P . R . China) and the ecosystem services approach. *Sustainabilty*.

Dean, R. & Damm-Luhr, T. (2010). Current Review of Chinese Land-Use Law and Policy: A Breakthrough in Rural Reform. *Asia Pacific Rim Law & Policy Journal,* 19(1), 121–1

Decaggon servivces: http://manuals.decagon.com/Manuals/10711_Leaf%20Porometer_Web.pdf (accessed on April 20th, 2015)

Deng, S. M., Chen, X. J. & Zhu, X. M. (2001). Water resources and environment issues in the Tarim River basin. *China Water Resources,* 4, 20-24. (In Chinese)

Diekow, J., Mielniczuk, J., Knicker, H., Bayer, C., Dick, D. P. & Kögel-Knabner, I. (2005). Soil C and N stocks as affected by cropping systems and nitrogen fertilisation in a southern Brazil Acrisol managed under no-tillage for 17 years. *Soil and Tillage Research*, 81, 87–95.

Dong, Z.J. (1958). *Luobuma*. Science Press, Beijing. (In Chinese)

Ellenberg, D. & Mueller-Dombois, D. (1974). *Aims and methods of vegetation ecology*. New York, NY: Wiley.

Fan, J., Zhong, H., Harris, W., Yu, G., Wang, S., Hu, Z. & Yue, Y. (2008). Carbon storage in the grasslands of China based on field measurements of above-and below-ground biomass. *Climatic Change*, 86(3-4), 375-396.

FAO. (2012). Coping with Water Scarcity. FAO Water Reports 38. FAO, Rome.

Farah, H.O., Bastiaanssen, W.G.M. & Feddes, R.A. (2004). Evaluation of the temporal variability of the evaporative fraction in a tropical watershed. *International Journal of Applied Earth Observation Geoinformation.* 5, 129-140.

Feike, T., Mamitimin, Y., Li, L. & Doluschitz, R. (2014). Development of agricultural land and water use and its driving forces along the Aksu and Tarim River, P.R. China. *Environmental Earth Sciences*. doi:10.1007/s12665-014-3108-x

Fenton, L. (2010). *Evapotranspiration of kentucky bluegrass*. Utah State University.

Flora of China, URL http://www.efloras.org/browse.aspx?Flora_id=2& Name_str =Apocynum&btnsearch=Search (accessed on 02. February 2012)

F.M., Zhang, X.M., Runge, M. (2003). Growth and water relation of *Tamarix ramosissima* and *Populus euphratica* on Taklamakan desert dunes in relation to depth to a permanent water table. *Plant Cell Environment,* 26, 725-736.

Giese, E., Bahro, G. & Betke, D. (1998). Umweltzerstörungen in Trockengebieten Zentralasiens (West- und Ost-Turkestan): Ursachen, Auswirkungen, Maßnahmen. Steiner. Stuttgart.

Giese, Ernst, D. M. Mamatkanov & Run Wang. (2005). Wasserressourcen und deren Nutzung im Flussbecken des Tarim (Autonome Region Xinjiang/ VR China), Gießen: Zentrum für Internationale Entwicklungs- und Umweltforschung, Universität Gießen.

Gregory, P.J. & Nortcliff., S. (2013). *Soil Conditions and Plant Growth*. John Wiley & Sons, Ltd, Oxford.

Gries, D., Zeng, F., Foetzki, A., Arndt, S. K., Bruelheide, H., Thomas, F. M., Zhang, X. M. & Runge, M. (2003). Growth and water relation of *Tamarix ramosissima* and *Populus euphratica* on Taklamakan desert dunes in relation to depth to a permanent water table. *Plant, Cell and Environment,* 26: 725-736.

Halik, Ü. (2003). Stadtbegrünung im ariden Milieu: das Beispiel der Oasenstädte des südlichen Xinjiang/VR China; unter besonderer Berücksichtigung ökologischer, sozioökonomischer und kulturhistorischer Aspekte. Technische Universität Berlin.

Halik, Ü., Chai, Z., Kurban, A. & Cyffka, B. (2009). The positive response of some ecological indices of Populus euphratica to the emergency water transfer in the lower reaches of the Tarim River. *Resources Science*, 31(8): 1309–1314. (In Chinese)

Hao, X., Chen, Y. & Li, W. (2008). Indicating appropriate groundwater tables for desert river-bank forest at the Tarim River, Xinjiang, China. *Environmental Monitoring and Assessment,* 152, 167-77.

Hao, X., Chen, Y., Xu, C. & Li, W. (2007). Impacts of Climate Change and Human Activities on the Surface Runoff in the Tarim River Basin over the Last Fifty Years. *Water Resources Management*, *22*(9), 1159–1171.

Hardin, G. (1968). The tragedy of the commons. *Science,* 162: 1243-1248.

He, N. P., Yu, Q., Wu, L., Wang, Y. S. & Han, X. G. (2002). Carbon and nitrogen store and storage potential as affected by land-use in a Leymus chinensis grassland of northern China, Soil Biol. *Biochemistry*, 40, 2952–2959, 2008.

He, R.Y., Chu, J.P. & Chen, G.L. (1997). Chinas Fibre Crops. *China's fiber Crops*, 19, 21-23.

Hilmi, M. (2006). Economic concepts in market-oriented farming (Revised ed., pp. 15–16). Wageningen: Agromisa 2004.

Ho, P. (2005). *Institutions in Transition Land Ownership, Property Rights, and Social Conflict in China*. New York: Oxford University Press.

Hoffmann, G. (1991). *Die Untersuchung der Böden*. Band 1, 4. Auflage, Darmstadt.

Hong, Z., Shangyu, G. & Qiuhong, Z. (2002). Responses of NPP of salinized meadows to global change in hyper arid regions. *Journal of Arid Environments,* 50, 489-498.

Hoppe, T. (1992). Chinesische Agrarpolitik und Uyghurische Agrarkultur im Widerstreit. Das sozio-kulturelle Umfeld von Bodenversalzungen und -alkalisierungen im nördlichen Tarim-Becken (Xinjiang). Institut für Asienkunde. Hamburg.

Hou, P., R. J. S. Beeton, R. W. Carter, X. G. Dong, & X, Li .(2007). Response to Environmental Flows in the Lower Tarim River, Xin- jiang, China: Ground Water, in: *Journal of Environmental Management*, 83, 371-382.

Hu, R. (1988). Discussion on growth pattern of Apocynum. *Chinese Wild Plant Resources,* 17, 35-49.

Hu, R., Zhang, S., Guan, Q., Qian, X., Zhu, H., Hao, Y. & Jiang, L. (1988). Studies on seed storage of *Poacynum hendersonii* and *Apocynum venetum*. *Acta Agronomica Sinica,* 14, 28-35.

Hu, C., Wang, Y., Gou, Q. & Hu, G. (2005). *Fluvial process and regulation of the main stem Tarim River China*. Beijing, China: Science Press: Beijing. (In Chinese)

Huang, X., Chen, Y., Ma, J. & Chen, Y. (2010). Study on change in value of ecosystem service function of Tarim River. *Acta Ecologica Sinica*, 30(2), 67–75.

Jiang, L., Tong, Y., Zhao, Z., Li, T. & Liao, J. (2005). Water resources, land exploration and population dynamics in arid areas—the case of the Tarim River Basin in Xinjiang of China. *Population and Environment*, 26 (6), 471–503.

Kamata, K., Seo, S. & Nakajima, J.I. (2008). Constituents from leaves of *Apocynum venetum* L. *Journal of Natural Medicines,* 62.

Kim, D.W., Yokozawa, T., Hattori, M., Kadota, S. & Namba, T. (1998). Effects of aqueous extracts of *Apocynum venetum* leaves on Hypercholesterolaemic rats. *Phytotherapy Research*, 12, 46-48.

Kim, D. W., Yokozawa, T., Hattori, M., Kadota, S., & Namba, T. (2000). Effects of aqueous extracts of *Apocynum venetum* leaves on spontaneously hypertensive, renal hypertensive and NaCl-fed-hypertensive rats. *Journal of ethnopharmacology,* 72(1), 53-59.

Kutsch, W. L., Bahn, M., & Heinemeyer, A. (2009). *Soil carbon dynamics: an integrated methodology*. Cambridge University Press.

Kwan, C.Y., Zhang, W.B., Nishibe, S. & Seo, S. (2005). A novel in vitro Endothelium dependent vascular relaxant effect of *Apocynum venetum* leaf extract. *Clinical and Experimental Pharmacology and Physiology*, vol. 32, 789-795.

ICTSD. (2013). *Cotton : Trends in Global Production , Trade and Policy*. Geneva, Switzerland. (Retrieved from www.ictsd.org http://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=30155)

Li, G. & Chen, Y. (2012). *Physioecology of Apocynum*. Beijing, China: Science Press of China. (In Chinese)

Li, X., Li, L., Guo, L., Zhang, F., Adsavakulchai, S. & Shang, M. (2011). Impact of climate factors on runoff in the Kaidu River watershed: path analysis of 50-year data. *Journal of Arid Land*, *3*(2), 132–140.

Li, Y., Chen, Y., Zhang, Y. & Xia, Y. (2009). Rehabilitating China's largest inland river. *Conservation Biology : The Journal of the Society for Conservation Biology*, *23*(3), 531–6.

Liu, J. Z., Chen, Y. N., Chen, Y. J., Zhang, N. & Li, W. H. (2005). Degradation of populus euphratica community in the lower reaches of the Tarim River, Xinjiang, China. *Journal of Environmental Sciences*, 17(5), 740–747.

Liu, S., Carter, M. R. & Yao, Y. (1998). Dimensions and diversity of property rights in rural China: Dilemmas on the road to further reform. *World Development*, 26(10), 1789-1806.

Liu, T., Fang, H., Willems, P., Bao, A. M., Chen, X., Veroustraete, F. & Dong, Q. H. (2013). On the relationship between historical land-use change and water availability: the case of the lower Tarim River region in northwestern China. *Hydrological Processes*, *27*(2), 251–261.

Lu, N., Chen, S., Wilske, B., Sun, G. & Chen, J. (2011). Evapotranspiration and soil water relationships in a range of disturbed and undisturbed ecosystems in the semi-arid Inner Mongolia, China. *Journal of Plant Ecology*, 4(1), 49–60.

Lu, X., & Pan, C. (2009). Analysis on Correlation between Day Process of Stem Diameter and Sap Flow Variations of *Apocynum venetum* L. and Their Environmental Factors. *Xinjiang Agricultural Sciences*, 46 (1), 8-12.

Lü, R., Su, D.M., Meng, L. & Zheng, L.S. (2006). Antibiotic properties of *Apocynum venetum*. *Acta Academiae Medicinae Qingdao Universitatis,* 42, 71-72.

Ma, Y.X. & Chen, S.Y. (1999). Observation on the antiaging, anti-hypertensive and anti-hyperlipidemic effect of *Apocynum venetum* leaf extract. *Chinese journal of modern developments in traditional medicine*, 9, 335-337.

Maas , E. & Hoffman, G. (1977). Crop salt tolerance, current assessment. *Journal of Irrigation and Drainage division*, 115-134.

Macdonald, S., Gale, F. & Hansen, J. (2015). *Cotton Policy in China*. Washington.

Mantilla-contreras, J., Schirmel, J. & Zerbe, S. (2011). Influence of soil and microclimate on species composition and grass encroachment in heath succession. *Journal of Plant Ecology*, 1–11.

Margesin, R., & Schinner, F. (Eds.). (2005). *Manual for soil analysis-monitoring and assessing soil bioremediation* (Vol. 5). Springer Science & Business Media.

Mullan, K., Grosjean, P. & Kontoleon, A. (2011). Land Tenure Arrangements and Rural–Urban Migration in China. *World Development*, *39* (1), 123–133.

Mueller-Dombois, D. & Ellenberg, H. (1974). *Aims and Methods of Vegetation Ecology*. Wiley, New York, NY.

Mueller, L., Behrendt, A., Schalitz, G. & Schindler, U. (2005). Above ground biomass and water use efficiency of crops at shallow water tables in temperate climate. *Agricultural Water Management,* 75, 117-136.

Murphy, J. & Riley, J. (1962). A modified single solution method for the determination of phosphate in natural waters. *Anal Chim Acta,* 27:31–6.

NBSC [National Bureau of Statistics of China]. (2011). *Chinese Statistical Year Book* 2013.

Nechaeva, N. T. & Nikolaev, W. N. (1962). Pojasnitelnnyjtekst k kartepastbishravninnoj Turkmenii. Turkmenskij Nauchno-Issledovatelskij Institut Zhivotnovodstva I veterinarii, Ashgabat.

Ning, J., Zheng, Q., Yang, S., Zou, X., Sun, L., & Chen, Y. (2010). Impact of high salt stress on *Apocynum venetum* growth and ionic homeostasis. *Journal of applied ecology,* 21(2), 325-330.

OECD (Organization for Economic Co-operation and Development) Stat library, 2012.http://stats.oecd.org/Index.aspx?querytype=view&queryname=221

Ostrom, E. & E. Schlager. (1996). The Formation of Property Rights. In *Rights to Nature*: Ecological, Economic, Cultural, and Political Principles of Institutions for the Environment, eds. S. S. Hanna, C. Folke, and K.-G. Mäler, 127–156. Washington, DC: Island Press

Ouyang, J.Q. (2008) Analysis and countermeasure of the supply and need of water resources in Xinjiang. *Economic Tribun*e, (24), 40-42. (In Chinese)

Pavlov, N.V. (1942). Dikiepoleznye i tehnicheskierastenija SSSR.KazahskijGozudarstbennyi Universitetim. S.M. Kirova and Kazahskij Filial Akademii, Nauk, Moscow. (In Russian)

Peng, H., Thevs, N. & Ott, K. (2014). Water Distribution in the Perspectives of Stakeholders and Water Users in the Tarim River Catchment. *Journal of Water Resource and Protection*, *6*(April), 543–555.

Prozorovskii, A.W. (1932). Iliyskiy Kendyr. Kazahskij Institut Udobrenii Agropochvovedehija, Almaty.

Qi, F., Wei, L., Jianhua, S., Yonghong, S., Yewu, Z., Zongqiang, C. & Haiyang, X. (2005). Environmental effects of water resource development and use in the Tarim River basin of northwestern China. *Environmental Geology*, 48(2), 202–210.

Qing, Z. N., Song, L. H. & Gu, Z. L. (1988). An experimental observation on the Diuretic effect of an extract of Luobuma (*Apocynum venetum)* leaves. *Bulletin of Chinese Medicine*, 13, 44-46. (In Chinese)

Raunkiaer, C. (1934). *The life forms of plants and statistical geography*. Clarendon Press, Oxford.

Reig, P., Luo, T. & Proctor, J. N. (2014). *Global shale gas Development*.

Ren, H., Jun-mai, C. A. O., Yan-yun, C. H. E. N. & Guo-qi, L. I. (2008). Current Research State and Exploitation of *Apocynum venetum* L. *Northern Horticulture*, 7, 037. (In Chinese)

Rhoades, J. (1990). Determining soil salinity from measurement of electrical conductivity. *Communications in Soil Science and Plant Analysis,* 21, 861-901.

Ritchie, J. & Lewis, J. (2003). *Qualitative Research Practice*. London: SAGE Publications.

Romanovich, v., Sharii, n.j., zubzova, z.d., Kazenas, l.d. (1951). Kendyr v Kasahstanie. Kazah.Goz.Ezd., Almaty. (In Russian)

Rowell, D.L. (1996). *Soil Science: methods and applications*. Longman, UK

Royal Botanic Gardens. (2012). URL http://apps.kew.org/wcsp (accessed On 02. February 2012)

RSEID of NBS (2013). *China Rural statistical yearbook*, National Bureau of Statistics. China Statistical Press, Beijing .

Rumbaur, C., Thevs, N., Disse, M., Ahlheim, M., Brieden, A., Cyffka, B., Doluschitz, R., Duethmann, D., Feike, T., Frör, O. & Gärtner, P. (2014). Sustainable management of river oases along the Tarim River in North-Western China under conditions of climate change. *Earth System Dynamics Discussion*, 5(2), 1221–1273.

Rumbaur, C., Thevs, N., Disse, M., Ahlheim, M., Brieden, A., Cyffka, B., Duethmann, D., Feike, T., Frör, O., Gärtner, P. & Halik, Ü. (2015). Sustainable management of river oases along the Tarim River (SuMaRiO) in Northwest China under conditions of climate change. *Earth System Dynamics*, 6, 83–107.

Sakushima, A., Nishibe, S., Hisada, S. (1978). Studies on the constituents of Apocynaceae plants. Isolation of flavonol glycosides and other components from the leaves of *Apocynum venetum* L. Var. Basikurumon Hara. *Pharmaceutical Society of Japan,* 98, 1395-1397.

Schlager, E. & Ostrom, E. (1992). Property-rights regimes and natural resources: A conceptual analysis. *Land Economics*, *68*(3), 249–262.

Schlichting, K., Blume, H. & Stahr, K. (1995). Bodenkundliches Praktikum. Parey, Berlin, Germany.

Shangguan, D., Liu, S., Ding, Y., Ding, L., Xu, J. & Jing, L. (2009). Glacier changes during the last forty years in the Tarim Interior River basin, northwest China. *Progress in Natural Science*, 19(6), 727–732.

Shen, Y., & Lein, H. (2005). Land and water resources management problems in Xinjiang Uygur Autonomous Region, China. *Norsk Geografisk Tidsskrift-Norwegian Journal of Geography*, 59(3), 237-245.

Shen, Y. (2009). The social and environmental costs associated with water management practices in state environmental protection projects in Xinjiang, China. *Environmental Science & Policy*, *12*(7), 970–980.

Shi, Y. & Song, F. (2005). Development prospect and counterplan of *Ziziphus jujube* in Xinjiang. *Xinjiang Agricultural Sciences,* 6 (2005): 014. (In Chinese)

Shirai, M., Kawai, Y., Yamanishi, R. & Terao, J. (2005). Approach to novel functional foods for stress control: 5. Antioxidant activity profiles of antidepressant herbs and their active components. *Journal of Medical Investigation,* 52, 249-251.

Smith, S. D., Devitt, D. A., Sala, A., Cleverly, J. R. & Busch, D.E. (1998). Water relations of riparian plants from warm desert regions. *Wetlands,* 18, 687-696.

Snyder, R. L., Lanini, B. J., Shaw, D. A. & Pruitt, W. O. (1989). Using reference evapotranspiration (ET_0) and crop coefficients to estimate crop evapotranspiration (ETc) for agronomic crops, grasses, and vegetable crops. Berkeley: Univ. California, Cooperative Extension, Leaflet No. 21427.

Song, Y.D., Fan, Z.L., Lei, Z.D. & Zhang, F.W. (2000). *Research on water Resources and ecology of Tarim River, China*. Xinjiang Peoples Press, Urumqi.

Su, H., Ma, M. & Li, X. (1997). A comparative anatomy of different populations on *Apocynum venetum* and *Poacynum hendersonii*. *Acta Botanica Boreali-occidentalia Sinica*, 17, (3), 348-354.

Tagawa, C., Kagawa, T., Nakazawa, Y., Onizuka, S., Nishibe, S. & Kawasaki, H. (2004). Studies on antihypertensive effect of Luobuma (*Apocynum venetum* L.). Leaf Extract. *Pharmaceutical Society of Japan,* 124, 851-856.

Tang, D. & Deng, M. (2010). *On the Management of Water Rights in the Tarim River Basin*. Beijing, China: Water Power Press. (In Chinese)

Tang, X. (2008). Study on the resource of wild A. *pictum* Ball. and planting technology in Chaidam Basin. *Qinghai Agriculture,* 17, 48-50.

Tao, H., Gemmer, M., Bai, Y., Su, B. & Mao, W. (2011). Trends of streamflow in the Tarim River Basin during the past 50years: Human impact or climate change? *Journal of Hydrology*, *400*(1-2), 1–9.

Tisdell, C. A. (2005). *Economics of Evironmental Conservation, Second Edition* (2nd ed.). Cheltenham, UK: Edward Elgar, 2005.

Tie, G. & Liu, H. (2006). Characters and utilization value of wild *Apocynum Venetum*. *Pratacultural Science,* 23, 46-47.

Thevs, N. (2011). Water Scarcity and Allocation in the Tarim Basin: Decision Structures and Adaptations on the Local Level. *Journal of Current Chinese Affairs,* 40, 113-137.

Thevs, N. (2007). *Ecology, Spatial Distribution, and Utilization of the Tugai Vegetation at the Middle Reaches of the Tarim River, Xinjiang, China*, Göttingen, Germany: Cuvillier.

Thevs, N., Buras, A., Zerbe, S., Kühnel, E., Abdusalih, N. & Ovezberdiyeva, A. (2012a). Structure and wood biomass of near-natural floodplain forests along the Central Asian rivers Tarim and Amu Darya. *Forestry* 85, 193-202.

Thevs, N., Ovezmuradov, K., Zanjani, L. V. & Zerbe, S. (2014b). Water consumption of agriculture and natural ecosystems at the Amu Darya in Lebap Province, Turkmenistan. *Environmental Earth Sciences*, DOI: 10.1007/s12665-014-3084-1.

Thevs, N., Peng, H. Y., Rouzi, A., Zerbe, S. & Abdusalih, N. (2014a). Water allocation and water consumption of irrigated agriculture and natural vegetation in the Aksu-Tarim river basin, Xinjiang, China. *Journal of Arid Environments*, DOI: 10.1016/j.jaridenv.2014.05.028.

Thevs, N., Rouzi, A. & Kubal, C. (2013b). Water consumption of agriculture and natural ecosystems along the Tarim river, China. *GEOÖKO*, XXXIV, 50–76.

Thevs, N., Zerbe, S., Gahlert, F., Mijit, M. & Succow, M. (2007). Productivity of reed (*Phragmites australis* Trin. ex. Staud.) in continental-arid NW China in relation to soil, groundwater, and land-use. *Journal of Applied Botany and Food Quality,* 81**,** 62-68.

Thevs, N., Zerbe, S., Peper, J. & Succow, M. (2008b). Vegetation and vegetation dynamics in the Tarim River floodplain of continental-arid Xinjiang, NW China. *Phytocoenologia,* 38, 65-84.

Thevs, N., Zerbe, S., Kyosev, Y., Rouzi, A., Tang, B., Abdusalih, N. & Novitskiy, Z. (2012b). *Apocynum venetu*m L. and *Apocynum pictum* Schrenk (Apocynaceae) as multi-functional and multi-service plant species in Central Asia: a review on biology, ecology, and utilization. *Journal of Applied Botany and Food*

Quality, 85, 159-167.

Thevs, N., Zerbe, S., Schnittler, M., Abdusalih, N. & Succow, M. (2008a). Structure, reproduction and flood-induced dynamics of riparian Tugai forests at the Tarim River in Xinjiang, NW China. *Forestry*, 81(1), 45–57.

Thomas, F.M., Foetzki, A., Arndt, S.K., Bruelheide, H., Gries, D., Li, X., Zeng, F., Zhang, X. & Runge, M. (2006). Water use by perennial plants in the transition zone between river oasis and desert in NW China. *Basic and Applied Ecology,* 7(3), 253-267.

USDA. (1954). Diagnosis and improvement of saline and alkali soils. U.S.Dept. of Agriculture Handbook no. 60.USDA, Washington, DC.

Walter, H. & Breckle, S. W. (1999). Vegetation und Klimazonen. Ulmer. Stuttgart.

Wang, D., Li, G., & Liu, Y. (2011). Anatomical research on nutritive organs of two species of Apocynum and their ecological adaptability. *Plants of Guangxi*, 31(5), 588-594.

Wang, Z., Liu, G. B., Xu, M. X., Zhang, J., Wang, Y. & Tang, L. (2012). Temporal and spatial variations in soil organic carbon sequestration following revegetation in the hilly Loess Plateau, China. *Catena*, 99, 26-33.

www.weatherbase.com

Webber, H. A. (2008). *Improving irrigated agriculture in the Fergana*. McGill University.

Westermann, J. (2005). Dendrochronological analysis of the age structure of *Populus euphratica* forests in the Tarim river flood plain in Xinjiang/China. Diploma Thesis. TU-Berlin.

Westermann, J., Zerbe, S. & Eckstein, D. (2008). Age structure and growth of degraded *Populus euphratica* floodplain forests in NW China and perspectives for their recovery. *Journal of Integrative Plant Biology,* 50 (5): 536-546.

White, R. (2006). *Principles and practice of soil science: the soil as a natural resource.* John Wiley & Sons.

Wiehle, M., Eusemann, P., Thevs, N. & Schnittler, M. (2009). Root Suckering patterns in *Populus euphratica* (Euphrates poplar, *Salicaceae*). *Trees,* 23, 991-1001.

World Bank. (2007). Project Performance Assessment Report People's Republic of China: Second Loess Plateau Watershed Rehabilitation Project (loan 4477 & credit 3222) and Xiaolangdi Multipurpose Project I & II (loans 3727 & 4200) and Tarim Basin II Project (loan 4341 & credit 3093), Washington: World Bank.

Xinjiang UAR Devlopment and Reform Committee. (2013). Xinjiang Agricultural Cost-revenue Material.

XJSYB. (1980–2012). *Xinjiang statistical yearbook*. National Bureau of Statistics. China Statistical Press, Beijing .

Xie, W., Zhang, X., Wang, T. & Hu, J. (2012). Botany, traditional uses, phytochemistry and pharmacology of *Apocynum venetum* L. (Luobuma): A review. *Journal of Ethnopharmacology*, 141(1), 1–8.

Xin, J. (2012). Developing red dates to promote Xinjiang agricultural innovation. *In International Conference on Environment~ Agriculture and Food Sciences (pp. 11-12).*

Xu, C. (2014). The Fundamental Institutions of Chinas Reforms and Development. *Journal of Economic Literature,* 1076-1151.

Xu, C., Chen, Y., Li, W. & Chen, Y. (2006). Climate change and hydrologic process response in the Tarim River Basin over the past 50 years. *Chinese Science Bulletin*, *51*(S1), 25–36.

Xu, J., Xu, Y. & Song, C. (2013). An Integrative Approach to Understand the Climatic-Hydrological Process: A Case Study of Yarkand River, Northwest China. *Advances in Meteorology*, 2013, 1–9.

Xu, H., Ye, M. & Li, J. (2008). The water transfer effects on agricultural development in the lower Tarim River, Xinjiang of China. *Agricultural water management*, 95(1), 59-68.

Yang, W., Gao, H. & Liu, Z. (2011). POD Isozyme Analysis of Inner Mongolia *Apocynum venetum* Linn . *Journal of Anhui Agricultural Sciences*, 39(11), 6345-6346.

Yang, X., Dong, J. & White, P. D. (2006). The key role of water resources management in ecological restoration in western China. *Geographical Research*, 44(2), 146-154.

Yao, S. (2013). Past , Present , and Future of *Jujubes* — Chinese Dates in the United States. *HortScience,* 48(6), 672–680.

Yokozawa, T., Kashiwada, Y., Hattori, M. & Chung, H.Y. (2002). Study On the components of Luobuma with Peroxynitrite-Scavenging Activity. *Biological and Pharmaceutical Bulletin*, 25, 748-752.

Yokozawa, T. & Nakagawa, T. (2004). Inhibitory effects of Luobuma tea and Its components against glucose-mediated protein damage. *Food Chemistry and Toxicology,* 42, 975-981.

Yu, P., Xu, H., Ye, M., Liu, S., Gong, J., An, H., & Fu, J. (2011). Effects of ecological water conveyance on the ring increments of Populus euphratica in the lower reaches of Tarim River. *Journal of Forest Research*, *17*(5), 413–420.

Zhang, C. X. (2001). Cotton Disaster and Disaster Prevention and Reduction Techniques. China Agricultural Scientech Press, Beijing. (In Chinese)

Zhang, G., Qian, X. & Gu, G. (2005a). *Apocynum venetum* L. Resources in Shanxi, Hubei, Henan and Shandong Provinces and its cultivation Techniques. *Chinese Wild Plant Resources,* 25, 26-28.

Zhang, L., Li, H.Q. & Yi, H.Y. (2003). Botanical characteristics, distribution and application of Lopnur Kender resources in Aksu prefecture. *Xinjiang Agricultural Sciences,* 40, 172-174.

Zhang, S. (2002). The division of geographical on distribution region of Kendyr in China. *Plant Journal of Northwest China,* 22, 1-5.

Zhang, W., Xiao, Z., Gu, G., Zhang, G., Qian, X. (2006). Study on Morphology and Anatomy of *Apocynum* - And discuss the classification of *A. pictum*. Chinese *Wild Plant Resources 25*, 11-15.

Zhang, W. M., Xiao, Z. C., Zhang, G. L. & Gu, G. P. (2006b). Study on ecotype of Apocynum in Xinjiang and its fibre quality. *Chinese Wild Plant Resources*, 25, 33-37.

Zhang, X. (2008). Quantitative Characters of Reproductive Ramets in *Apocynum venetum* Population. *Arid land Research,* 25(5), 668-672.

Zhang, X., Chen, Y., Li, W., Yu, Y. & Sun, Z. (2013). Restoration of the lower reaches of the Tarim River in

China. *Regional Environmental Change*, 13(5), 1021–1029.

Zhang, X., Yang, D., Xiang, X. & Huang, X. (2012). Impact of agricultural development on variation in surface runoff in arid regions: a case of the Aksu River Basin. *Journal of Arid Land*, *4*(4), 399–410.

Zhang, Y. M., Chen, Y. N. & Pan, B. R. (2005b). Distribution and floristics of desert plant communities in the lower reaches of Tarim River, southern Xinjiang, People's Republic of China. Journal of Arid Environments, 63(4), 772–784.

Zhang, Y., Li, G., Zhang, Q., Zhang, H., Zhu, L. & Wan, H. (2007). The preliminary research on photosynthetic characteristics of *Apocynum venetum* under different shading. *Chinese Wild Plant Resources*, 26(5), 50-53.

Zhang, Z., Hu, R. & Qian, X. (2000). Regional differentiation of *Apocynum* distribution in China. *Chinese Wild Plant Resources*, 19(4), 20-22.

Zhang, Z. J. (2004). Therapeutic effects of herbal extracts and constituents in Animal models of psychiatric disorders. *Life Science,* 75, 1659-1699.

Zhang, Z., Ni, Y. & Wang, Y. (2001). The development of Kender Health Care Towel Yarn. *Shandong Fangzhi Keji,* 4, 11-12. (In Chinese)

Zhao, R., Chen, Y., Shi, P., Zhang, L., Pan, J. & Zhao, H. (2012). Land use and land cover change and driving mechanism in the arid inland river basin: a case study of Tarim River, Xinjiang, China. *Environmental Earth Sciences*, 591–604.

Zhao, X. & Tisdel, C. (2009). The Sustainability of Cotton Production in China and in Australia: Comparative Economic and Environmental Issues (No. 157).

Zhou, B., Feng, Q., Li, X., Wang, H., Liu, M., Huang, G. & Hu, X. (2007). Screening of antidepresent fractions of the leaves of *Apocynum venetum* L. *China Pharmacist,* 10, 1173-1175.

Zhou, H., Zhang, X., Xu, H., Ling, H. & Yu, P. (2012). Influences of climate change and human activities on Tarim River runoffs in China over the past half century. *Environmental Earth Sciences*, 67(1), 231–241.

Zhou, Z. Y. & Chen, P. J. (1992). *Biostratigraphy and Geological Evolution of Tarim*. Science Press. Beijing.

Zhu, X., Wu, L., Obul, O. & Habibulla, A. (2006). The Regulation of the Tarim River System, in: Thomas Hoppe, Bir- git Kleinschmit, Bruce Roberts, Niels Thevs, and Ümüt Halik (eds.), Watershed and Floodplain Management along the Tarim River in China's Arid Northwest, Aachen: Shaker, 77-90.

Zhu, Z. & Lei, Ju. (2003). Problems and Countermeasures on Withdrawing from Farming to Afforesting in Xinjiang, China [Xinjiang tui geng huan lin gongcheng guanjianwenti yu duice]. *Arid Land Geography,* 26 (4), 385–390. (In Chinese)

Appendix

Questionnaire on economy and utilization of Kendir

Name of interviewee:

Place:

Date:

1. Please describe the distribution of Kendir / Qige in the Tarim Basin and in your county.

2. Please describe the utilization of Kendir / Qige in the Tarim Basin and in your county.

3. Which yields [kg/mu] of stem biomass, fibres, leafs, and tea can be harvested from one mu of Kendir / Qige stands

	Stem	Fibers	Leafs	Tea	flowers
Tarim Basin					
your county					
your plot of land					

4. Which prices do you / do people attain for one kg of harvested Kendir / Qige

For stems

For fibres

For leafs

For flowers

For tea

5. Which relationship are there between site conditions and yields, product quality, and prices of Kendir / Qige ?

6. Are there differences regarding yields, quality, and selling prices between natural Kendir /Qige and planted Kendir /Qige ?

7. When and how do you harvest Kendir /Qige?

Leafs

Stems

Flowers

8. Which inputs are needed for Kendir / Qige utilization and what are the costs of each input:

Planting and site establishment

Harvest:

Machinery

Chengbao fee (Land lease)

Water fee

Other fees

Transport to tea / fibre producer

Others like fertilizer

9. What is the fiber yield from one kg of Kendir stems ?

10. Which fibre extraction methods are used for Kendir /Qige ?

11. What are the costs and inputs to extract 1 kg of fibers ?

12. What is the selling price for 1 kg of Kendir fibers ?

13. How much tea is produced from 1 kg of Kendir leafs ?

14. What is the selling price for 1 kg of Kendir tea ?

15. What is the gross fibre and tea production of Kendir in Xinjiang / the Tarim Basin ? How did the gross production develop over the past 50 years ?

16. Please explain us the planting and cultivation techniques of Kendir /Qige

17. Which strategy is there regarding the further utilization of Kendir /Qige?

18. Which obstacles or advantages are there regarding the further utilization and propagation of Kendir /Qige?