Cost-Benefit Analysis of Drip Irrigation in Cotton Production in Northwestern China

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ABSTRACT

The extremely arid climate of the Tarim Basin in Northwestern China offers ideal production conditions for cotton, making the region one of the nation's major cotton production bases. However, in the last decades the overuse of water resources for agricultural production led to severe ecological degradation and increasing competition for water among farmers. Still the majority of farmers in the region use flood irrigation to provide water to their crops. Drip irrigation under plastic mulch constitutes a new technology that generally features increased water use efficiency, however at higher production costs. The present study assesses the costs and benefits of applying drip irrigation based on a primary household dataset collected in the region. The results show, that application of drip irrigation is only beneficial in economic terms, if farmers manage to increase their yield levels at the same time. Therefore it is recommended to improve the agricultural extension service, and cover a substantial share of the additional cost for the farmer through providing subsidy for advanced irrigation technology.

Keywords: Irrigation agriculture, Cotton, Cost-benefit analysis, China

1. INTRODUCTION

1.1 Study Region

With an average precipitation below 50 mm per year the Tarim Region in Northwestern China is one of the country's dryest agricultural production regions. Surounded by the Tianshan and Kunlun mountain ranges the desert region receives most of its fresh water resources by the Tarim River and its tributaries; the water mainly originates from snow and glaciermelt in the mountains (de la Paix et al., 2012). Strong population increase along with positive price developments for agricultural products has led to a massive expansion of agricultural land use area and consecutive irrigation water demand over the last two decades (Feike et al., 2014). The overexploitation of water resources led to decreasing water flow of the river and frequent drying up of the river bed in the lower reaches of the river (Aishan et al., 2013). Severe ecological degradation is the consequence expressing in deterioration of the unique riparian vegetation along the river (Thevs, 2012; Xu et al., 2012). Additionally to the ecological consequences the overuse of water resources also worsens the competition for limited water among farmers, resulting in increasing yield losses caused by water shortage and soil salinity problems (Thevs, 2012). The government is aware of the situation (Aishan et al., 2013); however finds itself in the dilemma of short term

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yield and income increases versus long-term sustainable development. It is terefore vital to support a more sustainable and at the same time economically profitable way of production.

1.2 Irrigated Cotton Production

The major crop of the Tarim Region is cotton, which constitutes a key crop on national level; its constant supply at affordable price is decisive for the functioning and success of China's textile industry. The climatic conditions in the Tarim region are ideal for the cultivation of cotton featuring high light interception and neglectable precipitation. Furthermore cotton is comparatively tolerant to soil salinity and irrigation water salinity (Tanji and Kielen, 2002).
In 2012 more than 50 % of total sown area of the Tarim Region was sown with cotton. Even though an increasing share of this cotton is irrigated using advanced irrigation technology, namely drip irrigation under plastic mulch, still the major share of cotton is irrigated using simple flood irrigation technology (NBSC, 2013). Mamitimin et al. (2014) found out that the vast majority of farmers in the region are actually aware of the benefits of advanced irrigation technology regarding water use efficiency in cotton. There is strong indication that the higher cost of drip irrigation over flood irrigation is hindering a further application of this promising technology.
Therefore the current paper aims at determining the costs and benefits related to the application of drip irrigation over flood irrigation in cotton production in the Tarim region. Building on a primary dataset obtained through farm household survey the costs and revenues of irrigation of four representative farm types are investigated; additionally their natural and monetary crop water productivity are determined.

2. MATERIALS AND METHODS

2.1 Field Survey

To assess agricultural production conditions and farm productivity in the Tarim region a field survey was conducted in 2012. Following two rounds of pre-testing and questionnaire adjustment the actual survey campaign was undertaken in July and August 2012. The farm interviews were conducted by local Han-Chinese and Uighur university students in the respective regions dominated by either ethnic group. The forty page questionnaire focused on farm household characteristics, as well as timing, labor demand, costs and revenues of various crop management steps of the 2011 production year. Four regions along upper and middle reaches of the Tarim River (Aksu-Awat, Division 1 of XPCC, Xayar, and Luntai) were selected purposefully based on their distinct location in the direct vicinity of the river (Fig. 1). In that way it was ensured that the randomly selected farmers retrieve all their irrigation water from the Tarim River, its main tributary the Aksu River, or the connected groundwater system. Among the 257 interviewed farmers 229 produced cotton in their farm. Only those farmers were subject of investigation in the present study.

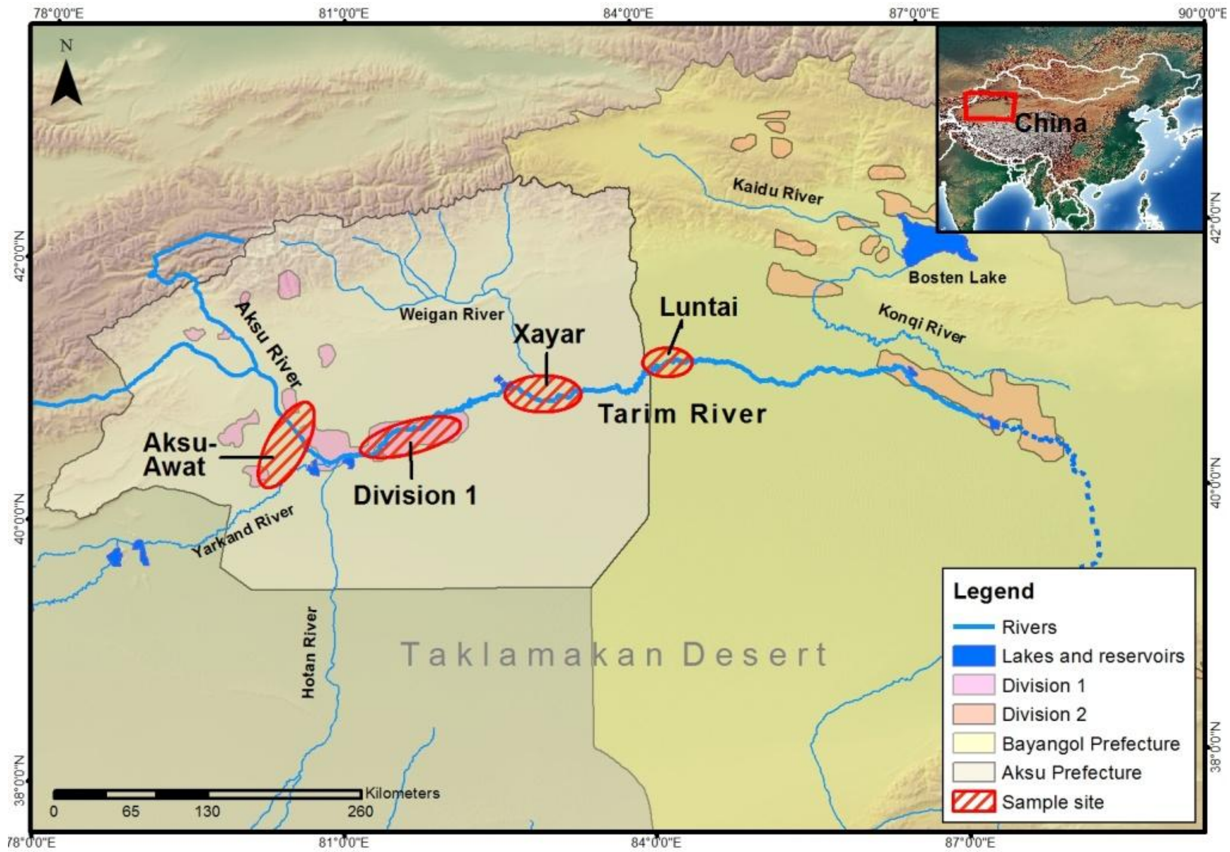

Figure 1. Location of the study region within China and the field survey sites along Tarim River

2.2 Construction of Four Farm Types

Among the 229 cotton producing farmers in the sample 115 farmers irrigated cotton using drip irrigation technology, while 114 farmers used flood irrigation. Accordingly the sample was divided into two groups "drip" and "flood" farmers. To investigate the effect of agronomic yield level on farm economic situation the two subgroups were furthermore subdivided according to their yield level. Using the median seed cotton yield level of each group (250 kg ha^{-1} in flood irrigation; 390 kg ha^{-1} in drip irrigation) as threshold, both groups were further subdivided into a "high yield" and "low yield" group. If the yield level of the respective farm was smaller or equal to the median yield, it belonged to the "low yield" group; if it was larger than the median yield it belonged to the "high yield" group (see Table 1).

Table 1. Number of farms and average cotton harvest area of the four farm types: "Flood Irrigation Low Yield", "Flood Irrigation High Yield", "Drip Irrigation Low Yield", and "Drip Irrigation High Yield".

Irrigation type	Yield level	Number of farms	Harvest area [ha]
Flood	Low	66	3.94
Flood	High	48	5.12
Drip	Low	58	9.47
Drip	High	57	7.10
Total		229	6.38

2.3 Cost and Benefit Calculation

To compare the performance of the four groups of farms, average values of various parameters were determined from the primary data set. Regarding the cost categories variable costs of all crop production steps were aggregated; this includes material, energy, labor and machine rental costs for seedbed preparation, sowing, irrigation, flushing, mineral and organic fertilization, weeding, pesticide application, cut-out, and crop harvest. Family labor input was excluded from the cost. Revenues were calculated by multiplying the natural cotton seed yield obtained by the farmer by the sale price of seed cotton the respective farmer realized. Finally gross margin was calculated by subtracting the sum of variable costs from the revenues.
To give the study a broader perspective, natural and monetary water productivity were calculated. Natural crop water productivity (NCWP) was calculated by dividing the obtained natural yield by the sum of annually applied irrigation water. Accordingly the monetary crop water productivity (MCWP) was calculated by dividing the gross margin by the sum of annually applied irrigation water. For both parameters natural precipitation was not included due to its insignificant contribution to total precipitation.

3. RESULTS AND DISCUSSION

3.1 Natural Crop Water Productivity

It can be seen that under both irrigation methods the "high yield" farms applied significantly more water than the "low yield" farms, with 9617 m^3 ha^{-1} versus 7635 m^3 ha^{-1} in flood, and 6808 m^3 ha^{-1} versus 4283 m^3 ha^{-1} in drip irrigation. This also reveals that flood irrigation demanded more water than drip irrigation under both low and high yield conditions. The divergence is mainly due to the actual irrigation amount, and not the amount of water applied during the flushing events; flushing was applied in one or two events in the period after harvest until sowing, with the goal of leaching salts in the soil below the rooting zone.
Even though the "flood irrigation, high yield" farmers obtained a higher yield compared to the "drip irrigation, low yield" farmers, their NCWP (0.50 kg m^{-3}) was substantially below the NCWP realized by the drip irrigation group (0.71 kg m^{-3} for low yield and 0.87 kg m^{-3}) for high

yield. The range of NCWP observed in the present study covers a similar range observed for cotton by Zwart and Bastiaanssen (2004) in a global study; they identified an average crop water productivity of 0.65 kg m^{-3} in a range from 0.41 kg m^{-3} to 0.95 kg m^{-3}.

Table 2. Average water consumption of irrigation and flushing, yield level and natural crop water productivity (NCWP) of four farm types plus average over all farms.

Farm type	Water consumption Irrigation	Flushing	Total	Yield	NCWP
	[m^3 ha^{-1}]			[kg ha^{-1}]	[kg m^{-3}]
Flood irrigation, low yield	4835	2800	7635	3209	0.42
Flood irrigation, high yield	6515	3102	9617	4784	0.50
Drip irrigation, low yield	3371	2693	6064	4283	0.71
Drip irrigation, high yield	4894	2889	7783	6806	0.87
Average of all farms	4831	2859	7690	4706	0.61

3.2 Monetary Crop Water Productivity

Considering the ever widening rural-urban income gap in China as a key issue, the monetary crop water productivity may be considered the even more important parameter when determining the sustainability of cotton production in the Tarim Region. The results in Table 3 show that the total production costs are significantly higher under drip irrigation with 5719 US-$ ha^{-1} and 7342 US-$ ha^{-1} compared to flood irrigation with 4218 US-$ ha^{-1} and 4889 US-$ ha^{-1} for the low yield and high yield group, respectively; in both the low yield groups spend less money for production than the high yield groups. The same trend can be observed for the total variable irrigation cost, which includes material cost, hired labor cost, energy cost, and water fees. However, not all the difference in total cost is explained by the difference in spending for irrigation.

When looking at the revenues, one can see that under both irrigation regimes the high yield groups receive significantly higher revenues compared to the low yield groups. With 6286 US-$ ha^{-1} the “Flood irrigation, high yield” group obtains a slightly higher revenue compared to the “Drip irrigation, low yield” group. Due to their comparatively high production cost the “Drip irrigation, low yield” group realizes a negative gross margin (GM) of -118 US-$ ha^{-1} in the 2011 production year. Under low yield the flood irrigation group realized a slightly positive GM of 18 US-$ ha^{-1}. Due to the lower production cost the “Flood irrigation, high yield” group achieved a higher GM compared to the “Drip irrigation, high yield” group with 1398 US-$ ha^{-1} compared to 1234 US-$ ha^{-1}.

Looking at the monetary crop water productivity (MCWP), only the two high yield groups realized significantly positive results. Under drip irrigation one cubic meter of invested irrigation water yielded 0.16 US-$. Under flood irrigation a slightly lower productivity of 0.15 US-$ per invested cubic meter of irrigation water was achieved. This shows that under current production conditions there is actually no advantage for the farmer of applying drip irrigation, as it yields a lower GM both under high and low yield conditions. However, under high yield conditions the MCWP is better under drip irrigation.

Table 3. Average total variable cost, variable irrigation cost, revenue, gross margin and monetary crop water productivity (MCWP) of four farm types plus average over all farms.

Farm type	Total cost	Irrigation cost	Revenue	Gross margin	MCWP
	[US-$ ha^{-1}]				[US-$ m^{-3}]
Flood irrigation, low yield	4218	548	4237	18	0,00
Flood irrigation, high yield	4889	848	6286	1398	0,15
Drip irrigation, low yield	5719	1046	5601	-118	-0,02
Drip irrigation, high yield	7342	2215	8576	1234	0,16
Average of all farms	5523	1152	6102	579	0,08

4. CONCLUSIONS

Based on a primary farm household dataset the costs and benefits of applying drip irrigation instead of the traditional flood irrigation method were investigated in the present study. It was shown that drip irrigation demands less water compared to flood irrigation, and that significantly higher natural crop water productivity can be achieved. However, drip irrigation farmers achieved a slightly lower gross margin compared to flood irrigation farmers, both under low and high yield levels. Even though the monetary crop water productivity was slightly higher in drip irrigation under high yield conditions, it is economically viable to opt for the traditional flood irrigation method instead of drip irrigation. If the government wants to increase natural crop water productivity and at the same time support farmers' incomes, it seems a viable option to support the application of drip irrigation, e.g. via subsidizing the material cost for drip tubes. As the yield levels obviously have a stronger impact on both the natural and monetary crop water productivity compared to irrigation technology, it is important to intensify the efforts of closing the existing yield gaps. Therefore increasing the investments into agricultural extension is an important option for policy makers.

5. REFERENCES

Aishan T., U. Halik, B. Cyffka, M. Kuba, A. Abliz, A. Baidourela. 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.

de la Paix, M.J., L. Li, J. Ge, H.J. de Dieu, N. Theoneste. 2012. Analysis of snowmelt model for flood forecast for water in arid zone: case of Tarim River in Northwest China. *Environmental Earth Sciences* 66(5): 1423–1429.

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

Mamitimin, Y., T. Feike, I. Seifert, R. Doluschitz. 2014. Irrigation in the Tarim Basin, China: farmers' response to changes in water pricing practices. *Environmental Earth Sciences* (in press) doi: 10.1007/s12665-014-3245-2.

NBSC (National Bureau of Statistics of China). 2013. Xinjiang Statistical Yearbook 2012. China Statistical Press, Beijing, China.

Tanji, K.K., N.C. Kielen. 2002. Agricultural Drainage Water Management in Arid and Semi-Arid Areas. FAO Irrigation and Drainage Paper 61; FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. Rome, 2002.

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(3): 113–137.

Xu, J., Y. Chen, W. Li, L. Zhang, Y. Hong, X. Bi, Y. Yang. 2012 Statistical analysis of groundwater chemistry of the Tarim River lower reaches, Northwest China. *Environmental Earth Sciences* 5(6): 1807–1820.

Zwart, S.J., W.G.M. Bastiaanssen. 2004. Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. *Agricultural Water Management* 69(2): 115-133.