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Economic sustainability of irrigation practices in arid cotton production☆

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ABSTRACT

Drip irrigation has been widely touted as a potential mean to promote ecological sustainability in arid crop production. However, the long-term viability of this practice also depends on its economic sustainability. Despite the potential increase in water use efficiency and yield, the system also needs to generate higher income to be popular among farmers. In view of this, we examine how the use of drip irrigation instead of traditional flood irrigation affects both the yield and gross margin of cotton production in arid northwestern China. Results from propensity score matching of production data from 228 cotton producers show that even though the use of drip irrigation increases farmers' yield, its impact on gross margin is statistically insignificant. We furthermore find through regression analysis that the effect of drip irrigation on gross margin is significantly positive only for the farmers with less water availability constraint, as measured by their water use. With water scarcity in the region expected to increase in the future, the adoption of drip irrigation is likely to become less profitable and hence less viable from farmers' perspective. Therefore, we conclude that especially in regions with water shortage, the promotion of drip irrigation technology inevitably needs to be supported by the simultaneous improvement of water infrastructure to ensure water access at all times. Only then the full potential of drip irrigation to support ecological sustainability of arid crop production can be tapped.

1. Introduction

Water use for crop production has globally been increasing twice as fast as population growth over the last hundred years [14]. According to a report by the United Nations Water Scarcity Initiative, two-thirds of the world population could be living in regions facing water stress by 2025 with 1800 million people facing severe water scarcity. These regions cover vast areas of the world including countries such as Mexico, Pakistan, South Africa, large parts of China and India, and most countries in the Near East and North Africa [58]. Irrigated agriculture and hence household income in these areas will be severely affected due to the water shortage problem

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[45,47,52,62,65].

Drip irrigation is a method used in the face of water scarcity. As it transports water directly to the root zone of the plants and not necessarily to the whole field, it generally realizes increased water use efficiency compared to the traditional irrigation technologies, such as flood irrigation [1,44,61]. Additionally it allows an optimized timing of irrigation events in accordance with the actual crop water demand [54,55]. The technology has been introduced in developing countries of various regions with promising results [4,12,28,43,46]. Especially in water scarce regions with water competition between agriculture and natural ecosystems, drip irrigation can support the ecological sustainability of crop production through increased water use efficiency and thus decreased water consumption. However, ecological sustainability is only one dimension of sustainable development [59]. To ensure the ecological sustainability of irrigation practices in the long-run, it is crucial to also ensure their economic sustainability. Therefore, we carry out a quantitative analysis on how the adoption of drip irrigation affects the yield and the gross margin of farmers in order to examine whether the practice is economically sustainable. Our study area is located in the Aksu-Tarim Region in the southern part of the Xinjiang Uighur Autonomous Region in northwestern China. Despite its extreme aridity with annual precipitation below 50 mm and potential evapotranspiration above 2100 mm [22], the region is an important crop production base of China. Agriculture constitutes an important economic factor and major source of income for the majority of the rural population in the region [17]. In order to allow for consistent comparison of farmers' water use patterns, we choose to focus on one crop, cotton (*Gossypium hirsutum* L.). It is the main agricultural production in the region covering more than 60% of sown cropping area [40,42]. In 2012 the region contributed around 50% of the Chinese national cotton production, which corresponded to about 15% of world cotton production [41].

The long-term viability of adopting drip irrigation depends on the gross margin from running and maintaining the system. Therefore, we compare the effect of drip irrigation on yield and gross margin. Another potential benefit of drip irrigation is it allows fertilizer to be delivered to the plants together with water, which could improve the efficiency of fertilizer use [1,23,32], so we examine also how the use of drip irrigation affects fertilizer productivity.

2. Study region and dataset

Under the arid conditions of the Aksu-Tarim Region, irrigation is indispensable for crop production. The required water mainly stems from rainfall, snow- and glacier-melt from the surrounding mountain ranges. The water is provided through the Tarim River and its main tributary the Aksu River with the peak of river run-off generally occurring in early summer [51]. The water is partly stored in large reservoirs and distributed via vast channel systems to the farmers' fields. Depending on the location the water storage and allocation systems differ in their extent and degree of sophistication. Additionally, the use of groundwater plays an increasing role in recent years [17]. Since the early 1990s the crop production area and related water use more than double in the region, which is largely triggered by cotton production [40,42]. The increasing agricultural water demand not only leads to a severe degradation of the natural riparian ecosystems along the regions' rivers, but also causes increasing competition for water among different user groups [57].

For the present study, detailed crop production data including timing, quantities, and costs of various crop management steps and production inputs of the 2011 cotton growing season were collected through farm household survey in July and August 2012 using standardized quantitative questionnaire. During questionnaire development phase a series of in-depth interviews with local agricultural water management experts and respective water authorities were conducted. Additionally, two rounds of questionnaire pre-testing were executed in the field in autumn 2011 and spring 2012 to improve the scope and clarity of specific sections of the questionnaire. The actual survey was then conducted by well-trained and highly-motivated M.Sc.-students of the local Xinjiang University and Tarim University.

A total of 228 cotton producing farm households were interviewed in four distinct regions: Awat-Aksu, Aral, Xayar, and Yingbazha. The counties and respective villages within the regions were selected purposefully based on their location in the direct vicinity to Aksu River and Tarim River. We use the word upstream to refer to some regions in this article, as they are located by the upper section of the river relative to the other regions in the study area. However, all the households in the survey are located in the plain of Tarim basin [51], so steeper land is not an issue for the upstream regions. In addition, the largest city in the study area, Aksu, is located upstream. On village level respondents were selected randomly from village household lists. Before the actual household level interviews in the village, key-informant interviews with local farm input dealers were conducted to generate lists of locally commonly applied fertilizers, pesticides and other crop inputs. These lists then supported smooth and accurate data collection during face-to-face farm household interviews. Additionally local product price ranges could be obtained from local dealers, which were available for plausibility check.

As determined during pre-survey, only two irrigation technologies are of relevance in the region: flood irrigation and drip irrigation. Each technology is applied by around 50% of the surveyed farmers. Compared to other irrigation regions in the world, where some intermediate technologies (e.g., sprinkler, wheel line, etc.) are also applied, only the most traditional flood system and highly advanced drip system are applied in the study region. The major reason is that the technological development in China is very fast, with intermediate technologies often being skipped, and the most advanced technology being implemented directly. However some users still stick with their traditional technology, in our case flood irrigation. While Chinese policy makers have recognized the importance of water saving in agriculture, government efforts for the greatest part focus on investments in research and development of water saving technologies and less on its implementation [60].

A specific challenge in production data collection is the appraisal of irrigation water quantities. While farmers can reliably recall the previous year's exact cotton yield and other crop management information (e.g., fertilizer types and amounts), they cannot provide data on their irrigation water quantities. Water metering on farm level is not practiced in the region and its implementation for data collection in the frame of the present study was logistically and financially infeasible. Hence, farmers were asked about the height of flooding and duration of each drip irrigation event to estimate the applied water quantities for flood and drip irrigation, respectively.