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Determinants of cotton farmers' irrigation water management in arid Northwestern China

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ABSTRACT

To combat China's water crisis tremendous research efforts are undertaken aiming at the improvement of water management in cotton production, which is the major consumer of the scarce water resources in arid Northwestern China. In recent years extensive field experiment based research strongly enhanced the theoretical knowledge of optimal water management in cotton production. However, farmers' actual irrigation water productivity remains low. To fill the critical void the present study aims at increasing the understanding of Chinese cotton farmers' actual irrigation water management. The northwestern Chinese Aksu-Tarim Region was selected as a hot-spot of water scarcity in China, where around 60% of total sown crop land are cultivated with cotton. The increasing overuse of scarce surface water resources for irrigation not only leads to severe ecological degradation, but also increases competition among water users triggering the expansion of groundwater exploitation. Based on primary survey data of 228 cotton producing farm households we firstly analyze the production factors determining farmers' yield and irrigation water productivity (IWP). Apart from soil salinity and unbalanced fertilization, which negatively affect yield and IWP, especially the applied irrigation method (drip vs. flood irrigation) and installation of a groundwater well were identified as major determinants. Secondly, we apply logistic regression to evaluate which household and farm characteristics determine the irrigation method and installation of groundwater well. We find that farm size, crop types and cropping intensity determine the use of drip irrigation. We furthermore find that the installation of well is largely related to marginalization, with farm families of ethnic minorities, remote farms and lower educated families being more likely to install wells. The findings of our study can help policymakers in devising strategies for improving irrigation water productivity, while reducing groundwater degradation in the study region and similar arid production regions in the world.

1. Introduction

Water is becoming the most limiting resource for future global agricultural development (UN-Water, 2012). It is expected that under the conditions of climate change, increasing global food demand and increasing water demand from other sectors global water scarcity is going to intensify in the coming decades (Fader et al., 2016). Especially in arid regions of the world severe water scarcity is going to affect a growing share of the population (Mancosu et al., 2015). In many arid and semiarid regions irrigated agriculture is an important economic activity. It generates substantial shares of regional domestic products and constitutes an essential source of rural employment and income. Not only agricultural production but also overall economic development is going to be negatively affected under aggravating water scarcity (UN-Water, 2016).

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Cotton (*Gossypium hirsutum* L.) is globally by far the most important fiber crop and number one agricultural trade commodity (Agbenyegah, 2012). Due to its high temperature and radiation requirements (Constable and Bange, 2015), and the potential negative impacts of rainfall during flowering and bolting stage (Cetin and Basbag, 2010), the cultivation of cotton is predominantly conducted in arid and semi-arid regions of the world under irrigated conditions (Roth et al., 2013). Despite its contribution as lucrative cash crop to rural economic development (Sankar et al., 2014), irrigated cotton naturally competes for scarce water resources with food production and other uses in its arid production regions (Demirdöğen et al., 2016). Hence, cotton production is significantly aggravating the water issue in regions already facing water problems (Chapagain et al., 2006).

China, as the world's number one cotton producer and consumer, produced more than 12 million tons of seed cotton and more than 6 million tons of cotton lint in 2014 (FAOSTAT, 2016). This corresponds to more than one fourth of global cotton production both in seed cotton and cotton lint. Within China the continental Northwestern Xinjiang Province produced 60% of China's cotton in 2014 (NBSC, 2015b). Xinjiang provides ideal climatic conditions for cotton production with abundant radiation and heat resources (Xu et al., 2011). As such, the region is renowned for its high quality and high yielding cotton production, reporting the highest fiber yields in the world (Constable and Bange, 2015), which were obtained under experimental conditions (Tuerxun et al., 2014; Xinhuanet, 2014). Over the last two decades the area of irrigated cotton production expanded very rapidly (Feike et al., 2015), which exacerbated the negative consequences of over-abstraction of water resources in this water scarce arid region. Intensified competition among water users fosters the increasing exploitation of limited groundwater resources (Thevs et al., 2015). This has devastating effects on the region's groundwater dependent natural riparian ecosystems and their ecological functions, increasing the risk of further desertification (Chen et al., 2016). In the future increasing water demand for industrial and domestic purposes (Cai, 2008) as well as a continuously widening water supply/demand gap induced by climate change (Guo and Shen, 2016) is likely to aggravate the acute water situation in Northwestern China.

Furthermore, the Chinese agricultural sector features very low irrigation water productivity (Jiang, 2009). The Chinese government has recognized water scarcity as a crucial issue and started to heavily invest into research on water saving agriculture (Blanke et al., 2007). In consequence numerous field experiment based studies were conducted on cotton production, especially in arid Northwestern China (e.g., Li et al., 2016; Mai et al., 2012; Wang et al., 2014b). As the use of drip irrigation (instead of traditional flood irrigation) is considered a technological advancement (Mamitimin et al., 2015), which enhances irrigation water productivity (Ibragimov et al., 2007), the vast majority of experiments focuses on drip irrigated cotton. Reviewing the published research, the theoretical understanding of how to increase cotton yields and water productivity has greatly advanced in recent years. The scientific findings on improving cotton production comprise management aspects like optimal irrigation water amount (e.g., Wang et al., 2012a; Yang et al., 2015), frequency (e.g., Kang et al., 2012; Liu et al., 2011), and quality (e.g., Min et al., 2014; Zhou et al., 2016), but also optimal technical arrangements (e.g., Wang et al., 2014a, 2012b), crop establishment (e.g., Huang, 2015; Wang et al., 2014c; Yang et al., 2014), and crop nutrition (e.g., Deng et al., 2013; Min et al., 2016).

While the theoretical knowledge of optimal cotton cultivation methods has strongly increased, the understanding of farmers' actual cotton production and related water management in China remains poor. Considering China's low irrigation efficiency (Cheng et al., 2009), severe water scarcity issue (Jiang, 2009), low adoption of water saving technologies among farmers (Lohmar et al., 2003), and at the same time strong potential for improving farmers' actual irrigation water productivity (Zhang and Dong, 2007), the existing empirical research is very small. The few existing literature focuses on the adoption of specific water saving technologies, such as rainwater harvesting (He et al., 2007) and plastic mulching in rice production (Zhou et al., 2008). Other studies assess the adoption of a range of water saving technologies in different regions of China, mainly focusing on the Eastern and Central regions (Blanke et al., 2007; Cremades et al., 2015; Liu et al., 2008; Mushtaq et al., 2009). A single study evaluates the determinants of (wheat) farmers' irrigation water productivity (Wang, 2010). So far no empirical study is available on farmers' irrigation water management in China's Xinjiang Province, which is the most arid Province facing the most severe water shortage situation in all of China (Guo and Shen, 2016). Furthermore, there is a strong lack of knowledge on the factors influencing farmers' adoption of drip irrigation and groundwater use in this ecologically fragile region of China.

Considering the urgency and relevance of improving farm level agricultural water management in arid Northwestern China, an apparent lack of available research needs to be noted. Therefore, to support sustainable irrigation water management and related policies, the current study aims at increasing the understanding of farmers' actual water management in cotton production and the respective influencing factors. The specific objectives of this study are to (i) assess the production factors determining cotton farmers' yield and water productivity, and to (ii) assess the household and farm characteristics determining farmers' decision of using drip irrigation (instead of traditional flood irrigation) and drilling a groundwater well.

2. Materials and methods

2.1. Study region

The Aksu-Tarim Region (ATR) in Northwestern China is selected as study region. The ATR is located in southern Xinjiang stretching along the Northern edge of the Taklimakan desert, which is the second largest sand desert in the world (cf., Fig. 1). The climate is a warm temperate continental desert climate (Zhao et al., 2015). During cotton growing season (May–September) the average daily solar radiation is 225 W m^{-2}, average minimum and maximum temperature are 17 °C and 31 °C, respectively, average relative humidity is 46% and average wind speed is 1.1 m s^{-1} (Zia-Khan et al., 2015). While potential annual evaporation is above 2200 mm (Yang et al., 2016), natural precipitation is extremely scarce with annual precipitation seldom exceeding 50 mm (Rumbaur et al., 2015). Rainfall, snowfall and glacial melt from the Tianshan mountain range are therefore the major water source for the arid region. The precious water is distributed within the region by the 1300 km long Tarim River and its main tributary the Aksu River. Human settlements and agricultural production are limited to the river oases stretching along the region's rivers. Crop production is still the most important source of employment and income for the rural population (Feike et al., 2015). While fruit and grain production are of minor importance, cotton is by far the most important crop covering more than 60% of the region's total sown area. In 2014 the ATR produced more than 20% of China's cotton, which corresponds to 6% of global cotton production (FAOSTAT, 2016; NBSC, 2015a,b,c). The agricultural production systems in the region are quite diverse stretching from traditional small-scale to highly mechanized large-scale farms (Thevs, 2011). Besides, the population of the ATR is ethnically very diverse. Apart from the Han, the ethnic majority of China, a large group of Uighur, as well as Kazak, Hui, Kirgiz, and many others of the 55 officially recognized ethnic minorities of