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Constraints and opportunities for water savings and increasing productivity through Resource Conservation Technologies in Pakistan

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ABSTRACT

Increasing the productivity of rice–wheat cropping systems is critical for meeting food demand in rapidly growing South Asia. But this must be done with increasingly scarce water resources, bringing greater attention to Resource Conservation Technologies (RCTs) such as zero tillage, laser land leveling and furrow bed planting. While the impacts of RCTs on yields are easy to measure and explain, impacts on water savings are not well understood beyond the field scale because of the complex movement of water. This paper uses both physical measurements and farmer survey data from the rice–wheat cropping system of Punjab, Pakistan to explain the main drivers of RCT adoption and their impacts on land and water productivity and water savings across scales. The primary drivers for RCT adoption (zero tillage wheat and laser land leveling) were reduced costs of production and labor requirements, reduced field scale irrigation water application, and higher yield. While the large proportion of farmers benefitting from RCTs explains overall increases in RCT adoption, a considerable proportion (30% of zero tillage adopters for wheat cultivation) reported yield loss, highlighting the need for further technological refinement and enhancing farmers' ability to implement RCT. The study also indicates that the field scale reduction in irrigation application did not always translate into real water savings or reductions in water use at farm, cropping system and catchment scales, especially in areas where deep percolation from the root zone could be reused as groundwater irrigation. Finally, the evidence shows that medium and large farmers tended to use the field scale irrigation savings to increase their cropped area. This finding suggests that without regulations and policies to regulate the use of "saved" water, adoption of RCTs can result in overall increased water use with implications for the long-term sustainability of irrigated agriculture.

1. Introduction

Pakistan has a population of around 185 million, making it the world's sixth most populous state. In just the last 10 years, its population has increased by over 25%, and is expected to reach more than 230 million by 2030. This poses serious food security concerns as more than half the country is already categorized as food insecure (with less than 2000 calories/person/day) and 28% as severely food insecure (less than 1700 calories/person/day) (IFPRI's Food Security Portal at http://www.foodsecurityportal.org/pakistan). A key issue in efforts to keep food production rising at least as fast as population growth is the lack of additional sources of fresh water for agricultural use. Partially in response to the water challenge, various Resource Conservation Technologies (RCTs) are being developed and promoted, in particular for rice and wheat which together make up 90% of the country's total food grain production (PARC-RWC, 2003). These technologies include zero tillage wheat (referred to hereafter as zero tillage), direct seeded rice, bed planting of rice and wheat, laser land leveling and crop residue retention (PARC-RWC, 2003; Mujeeb-ur-Rehman et al., 2011). Among the technologies, zero tillage and laser land leveling are the most widely adopted technologies. Recent published estimates indicate the area under laser land leveling and zero tillage wheat in Pakistan is around 0.9 and 0.5 million hectares, respectively (Gill et al., 2013).

The use of RCTs has been said to bring many possible benefits including reduced water and energy use (fossil fuels and electricity), reduced greenhouse gas emissions, soil erosion and degradation of the natural resource base, increased yields and farm incomes, and reduced labor shortages (e.g. Hobbs and Gupta, 2003; Holland, 2004; Farooq et al., 2007; Erenstein et al., 2008; Jat et al., 2009; Nangia et al., 2010; Mujeeb-ur-Rehman et al., 2011; ADMIT, 2012; Pandey et al., 2012; Saharawat et al., 2012). Several

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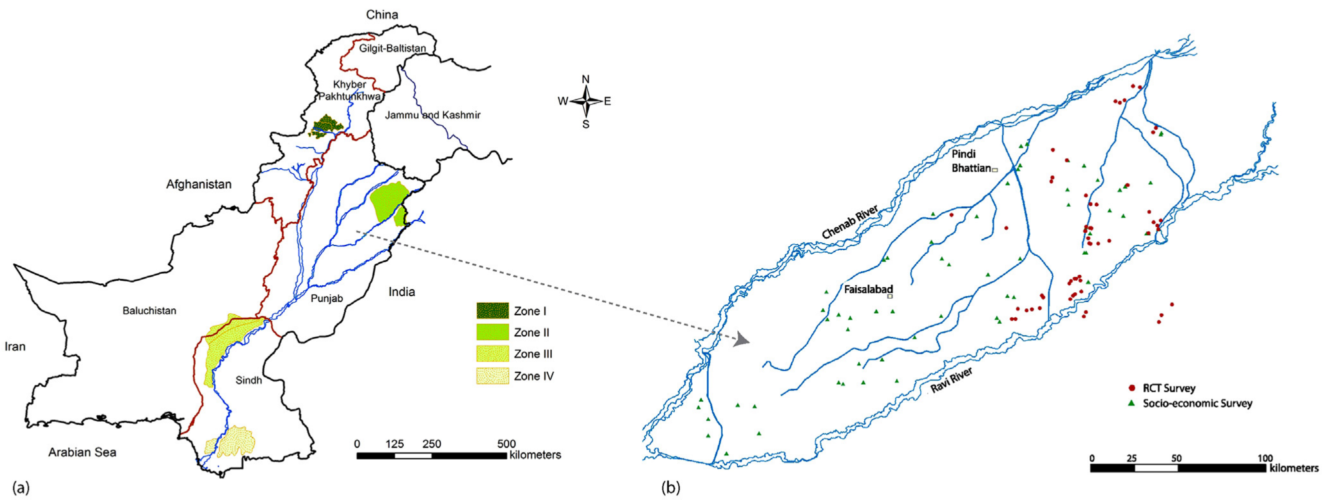

Fig. 1. Rice–wheat cropping zones in the Indus Basin of Pakistan and location of sample farms surveyed in and near Rechna Doab, the Punjab, Pakistan.

experimental farmers' field studies in Pakistan report various impacts of RCTs on a range of these factors, though with irrigation water application and crop yield as the two main performance indicators.

For instance, Kahlown et al. (2006) showed that the use of RCTs, including zero tillage, laser leveling and bed and furrow planting, reduced irrigation water applications between 23 and 45% while increasing yield. Farooq et al. (2007) indicated that zero tillage adopters in Pakistan's Punjab had reductions in irrigation applications of 5–15% and obtained similar yields compared to the conventional agricultural practices. A review of various studies suggested that laser land leveling in Pakistan resulted in about a 25% reduction in irrigation water application and an increase of about 30% in wheat yield as compared to conventional practices (non-laser leveled fields; Humphreys et al., 2005, 2010). Similar increased yield and reduced irrigation water application in the case of zero tillage wheat and laser land leveling were reported in other countries such as India and China (Gupta and Seth, 2007; Jat et al., 2009; Humphreys et al., 2010; ADMIT, 2012). In the case of rice, however, the use of direct dry seeding on flat and raised beds while resulting in considerable water savings, generally had negative impacts on rice yield (e.g. Bouman et al., 2007; Choudhury et al., 2007; Humphreys et al., 2010).

While the impacts on water inputs seem impressive, the estimated savings reported in these studies are in fact related only to irrigation water application. Whether or not reduced application translates into 'real' water savings and reduced water use depends on many factors such as how a specific RCT changes different components of the water balance in a given setting, what farmers do with water saved through reduced irrigation application, and the hydrologic interactions across scales between the field and farm, the irrigation system and the entire river basin. For example, excess irrigation water application may percolate to the groundwater table from where it is (many times) recycled through pumping by the same or other farmers and therefore not lost or wasted (Keller and Keller, 1995; Keller et al., 1996; Seckler, 1996; Ahmad et al., 2002; Tuong et al., 2005). Economic theory also tells us that the new technologies may induce farmers to use more of the now more productive resource, thereby increasing overall water use (Caswell and Zilberman, 1986). This "rebound effect" has been well-studied in the energy literature (Greening et al., 2000).

How the reduced field scale irrigation water application found in the above studies translates into water savings and overall use levels at larger scales is not well understood or documented. This paper partially fills this knowledge gap by evaluating reasons for RCT adoption, farmer response to reduced irrigation input through RCT use, and how this affects water use by small, medium and large farmers in the Punjab rice–wheat zone of Pakistan's Indus Basin, the center of the country's food grain production system. Based on this analysis, the conditions under which field level water savings translate into larger scale savings in the context of Pakistan's Indus Basin and more generally are discussed.

2. Materials and methods

2.1. Description of the study area

The Indus Basin contains approximately 16 million of Pakistan's 22 million hectares (ha) of cultivated land and the vast majority of the country's irrigated area. Within the basin, rice–wheat combined production systems account for about 14% of the area and forms the core base of the nation's food grain output. As shown in Fig. 1, rice–wheat production areas have been categorized into four main zones (areas) based on climate, land and water use. Rice is cultivated in the summer (kharif season) and is restricted primarily to the rice–wheat zones. Wheat is cultivated in winter (rabi season) after rice in rice–wheat zones but also in combination with a range of other crops across the Indus basin. This study focuses specifically on the Punjab rice–wheat zone because it covers about 65% of the area (1.44 million ha) of overall rice–wheat cropping systems, and it contributes significantly to food grain production and the economy. Furthermore, as explained in more detail later, because of the nature of conjunctive (surface and groundwater) agricultural water use in the system, key concepts and issues in understanding water saving across scales may be examined more comprehensively. Finally, the Punjab rice–wheat is an area where considerable hydrologic and agronomic information is available.

The climate in the Punjab rice–wheat zone is semi-arid and typical of the low-lying interior of the northwest Indian sub-continent. Summers are long and hot, lasting from April through September, with maximum temperature ranging from 21 °C to 49 °C. Winter lasts from December through February, with maximum daytime temperatures of up to 27 °C in December and January, with minimum temperatures falling below zero at night. Average annual rainfall is approximately 400 millimeters (mm), about 75% of which falls during the June to September monsoon season.

The prevailing temperature and rainfall patterns govern two distinct cropping seasons. Water intensive rice is grown during the