Soil & Tillage Research 169 (2017) 35–43

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Comparison of conventional and conservation rice-wheat systems in Punjab, Pakistan

Ahmad Nawaz[a], Muhammad Farooq[a,b,*], Rattan Lal[c], Abdul Rehman[a], Hafeez-ur-Rehman[a]

[a] Department of Agronomy, University of Agriculture, Faisalabad, 38040, Pakistan
[b] The UWA Institute of Agriculture, The University of Western Australia, 35 Stirling Highway, Perth WA 6001, Australia
[c] Carbon Management and Sequestration Center, School of Environment and Natural Resources, 414 B Kottman Hall, 2021 Coffey Road, The Ohio State University, Columbus, OH 43210, USA

ARTICLE INFO

Article history:
Received 5 April 2016
Received in revised form 23 December 2016
Accepted 20 January 2017
Available online xxx

Keywords:
Rice-wheat cropping system
Water use
Resource conservation technologies
Soil properties
System productivity

ABSTRACT

Adoption of resource conservation technologies such as direct seeded aerobic rice (DSAR) and no-till wheat (NTW) seems to be a farmer and ecofriendly option to sustain the productivity of rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.) cropping systems (RWCS) on long term basis. This study was conducted to evaluate the impact of conventional and conservation rice-wheat cropping systems on soil properties, grain yield, and water/system productivities established at two experimental sites (Nankana Sahib and Sheikhupura). There were two rice production systems *viz.* DSAR, and puddled transplanted flooded rice (PudTR). After rice harvest, wheat was planted after plough tillage (PTW) or through no-till. The study was repeated over time and space. At both sites, higher total nitrogen (N), soil organic carbon (SOC), soil microbial biomass carbon (MBC) and soil microbial biomass nitrogen (MBN) were recorded in DSAR than PudTR. The DSAR yielded 3.8 Mg ha^{-1}, against 3.6 Mg ha^{-1} in PudTR at Sheikhupura, while the similar paddy yield of 4.2 Mg ha^{-1} was harvested in DSAR and PudTR at Nankana Sahib. Overall, the adoption of DSAR saved 19% water compared with PudTR. Net benefits of US $729 and 601 ha^{-1} were obtained from DSAR, against US $604 and 403 ha^{-1} in PudTR, at Nankana Sahib and Sheikhupura, respectively. The highest water productivity of 3.01 and 3.43 kg ha^{-1} mm^{-1} was recorded in DSAR compared to 2.41 and 2.50 kg ha^{-1} mm^{-1} in PudTR at Nankana Sahib and Sheikhupura, respectively. The performance of wheat was better when grown after DSAR than PudTR for both experimental sites during both years. The higher total N (0.32 g kg^{-1}), SOC (3.75 g kg^{-1}), soil MBC (165 μg g^{-1}) and soil MBN (611.4 μg g^{-1}) were recorded for DSAR-NTW at both sites. The system productivity (output: input ratio) was 1.89 for DSAR-PTW at Nankana Sahib, and 1.87 for DSAR-NTW at Sheikhupura. In conclusion, DSAR followed by NTW was the best resource conservation technology to sustain the productivity of RWCS, and improve the net profit and the soil properties.

1. Introduction

A rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) cropping system (RWCS) is practiced on about 24 million hectare (Mha) in Asia with 13.5 Mha area in South Asia, principally in the Indo-Gangetic plains (IGP) (Saharawat et al., 2012). The IGP is a fertile area of 255 Mha, which includes most of eastern and northern India, whole of Bangladesh and the north-eastern parts of Pakistan (Taneja et al., 2014). In Bangladesh, India, Nepal and Pakistan, the RWCS occupies 32 and 42% of the total rice and wheat area, respectively (Saharawat et al., 2012). In Pakistan, the RWCS system is being practiced on an area of 2.2 Mha (Ahmad and Iram, 2006; Nawaz and Farooq, 2016).

Traditionally, the seedbed for rice is prepared by puddling (intensive tillage of a flooded field) followed by transplanting of rice seedlings, and wheat is sown in a field plowed after the rice harvest (Farooq et al., 2008). Puddling is practiced for suppressing weeds, improving nutrient availability and harvesting better yields (Naklang et al., 1996; Surendra et al., 2001; Fageria et al., 2011).

* Corresponding author at: Department of Agronomy, University of Agriculture, Faisalabad, 38040, Pakistan.
E-mail address: farooqcp@gmail.com (M. Farooq).

http://dx.doi.org/10.1016/j.still.2017.01.012
0167-1987/

Unfortunately, puddling also has negative effects on soil properties, the environment and the following upland crops (Sharma et al., 2004).

Puddling increases soil bulk density and reduces porosity (Farooq and Nawaz, 2014), which affect the stand establishment (Nawaz et al., 2016a), and root growth of post-rice crops (Kukal and Aggarwal, 2003). In Indian Punjab, root biomass decreased by 50–68% in highly puddled soil (Kukal and Aggarwal, 2003). Losses of soil N can also be large in saturated soil because of leaching of nitrate-N (Johnston, 2001). Reduced microbial activity and chemical transformation in saturated soils lessen phosphorus (P) release from the organic and mineral complexes (Johnston, 2001). Ishaq et al. (2001) reported that N uptake decreased by 12–35% in wheat following puddled transplanted flooded rice (PudTR) due to sub-soil compaction. Flooded paddy soils are also a source of methane (CH_4) which escapes into the atmosphere through leaves and stem and is a cause of the global warming (Neue et al., 1990; Maclean et al., 2002). Global rates of CH_4 emission from paddy fields are estimated to be 6–112 Tg (Sass et al., 2002; Yan et al., 2003, 2009; Kirk, 2004).

Profit margins in PudTR are low due to high requirements of water, and high costs of labor compared with DSAR (Pandey and Velasco, 1999; Nawaz et al., 2016b). Some 15–20 Mha under PudTR globally will face shortage of water by 2025 (Tuong and Bouman, 2003). In conventional RWCS, soil is plowed after the harvest of PudTR to create a desired tilth for the following wheat crop. Multiple cultivations needed to disrupt the hardpan increase fuel consumption (Rautaray, 2005; Erenstein et al., 2008), and greenhouse gases (GHGs) emissions (Reicosky et al., 2000).

The use of resource conservation technologies (RCTs) in RWCS may be an eco-friendly, and a pragmatic option to sustain the productivity and economic viability of this important cropping system (Hobbs et al., 2007), with substantial improvement in soil properties and decrease in GHGs emissions. Growing direct seeded rice in aerobic environment and wheat by no tillage (NT) is among potential RCTs (Nawaz and Farooq, 2016). In direct seeded aerobic rice (DSAR), seed is sown directly in non-puddled, non-saturated and well drained soil in the absence of ponded water (Bouman et al., 2007). Rice produced by this system matures earlier than PudTR, requires less labor and water input (Farooq et al., 2011a; Bhushan et al., 2007), and has low CH_4 emission (Liu et al., 2014). Due to earlier maturity, DSAR allows timely sowing of the following wheat and other crops (Farooq et al., 2009, 2011a), thus improving post-rice crop performance and yields (Farooq and Nawaz, 2014). Likewise, DSAR improves soil properties for the post-rice winter cereals by reducing soil bulk density and enhancing soil porosity (Farooq and Nawaz, 2014), which results in deeper root penetration and more uptake of water and nutrients.

Wheat sown by NT saves the input cost involved in land preparation (Erenstein and Laxmi, 2008), and improves the soil's structure, fertility and biological properties (Chauhan et al., 2002; Mohanty et al., 2007). Several studies have reported higher soil microbial biomass carbon (MBC; Liu et al., 2010), more soil respiration (Sharma et al., 2011) and higher soil enzymes activities (Lupwayi et al., 2007) under NT than those under plow tillage (PT). A reduction in the time between rice harvest and wheat sowing (Laxmi et al., 2007), and savings of fuel (Singh and Sharma, 2005) and water resources (Mehla et al., 2000) have been widely reported for NT compared with a PT system. Moreover, PT degrades soil and water quality (Rahman et al., 2005), increases the cost of production, exacerbates oxidation of soil organic matter (Qureshi et al., 2003); and negatively impacts soil properties (Nawaz et al., 2016c).

However, the RCTs are site specific, and the soil texture and agro-climatic conditions must be considered prior to recommendation of any specific RCTs for a specific region (Bhatt et al., 2016). Indeed, the soil texture may impact the ion exchange, water retention, nutrient cycling nutrient (Parton et al., 1987; Carnol et al., 1997; Chaudhari et al., 2008) and workability of a specific RCT implement, thus impacting the crop productivity. For example, He et al. (2014) reported that the growth of wheat in a silt loam soil was the most sensitive to water use than that of same wheat grown on clay soil.

To promote a wider adoption, the impacts of RCTs on soil quality, grain yield, system and water productivities of wheat and rice grown in soils of different textures need to be evaluated. This study was, therefore, conducted to test the hypothesis that adaptation of RCTs in RWCS in Punjab, Pakistan can sustain grain yield and increase the profitability of RWCS by improving soil properties, and reducing the production cost. The specific objective of this study was to compare crop performance, system and water productivity of rice and wheat grown under conventional (PudTR, PTW) and conservation (DSAR, ZTW) RWCSs, at two experimental sites (Nankana Sahib and Sheikhupura).

2. Materials and methods

2.1. Site and soil

This study was conducted at Nankana Sahib (longitude 73.7 E, latitude 31.4 N, and altitude 187 masl), and Sheikhupura (longitude 73.98 E, latitude 31.7 N, and altitude 236 masl), Punjab, Pakistan. The study was undertaken in 2012 and again in 2013. The soils were a sandy loam of the Lyallpur series at the Nankana Sahib, and a loam of the Bahalike series at the Sheikhupura site. Both soils were classified as Haplic Yermosols in FAO classification system (FAO, 2014). Additionally, the soil at Nankana Sahib is classified as aridisol-fine-silty, mixed, hyperthermic Ustalfic, Haplargid, and that at Sheikhupura as a coarse loam mixed, hyperthermic Ustalfic, Haplargid in USDA classification system (USDA, 2014).

Before initiating the experiment, soil samples (0–20 cm) were collected from both experimental sites. Different soil parameters were assessed for samples sieved through a 2-mm sieve after gently mixing, drying, and grinding. The initial soil analysis showed that the experimental soils at Sheikhupura and Nankana Sahib had a pH of 7.2–7.5, SOM concentration of 0.48–0.55%, total N concentration of 0.24–0.27 g kg^{-1}, electrical conductivity (EC) of 3.68–4.24 dS m^{-1}, available P of 4.99–5.38 mg kg^{-1}, and exchangeable potassium (K) of 108–115 mg kg^{-1}, respectively. The methodology for the estimation of these soil properties is given in section 2.5.

2.2. Climate

The climate of Nankana Sahib is generally hot, with the maximum temperatures of 45–47 °C during summer, and the minimum of 5–8 °C during winter. The climate of Sheikhupura is also generally hot, with the maximum temperature of 40–45 °C during summer, and the minimum of 4–6 °C during winter. The annual rainfalls of Sheikhupura and Nankana Sahib are 635 and 367 mm, respectively. Rice is grown in summer (*Kharif*), and wheat in winter (*Rabi*) season. The *Kharif* season spans from May/June to September/October, and the *Rabi* from October/November to April/May. The average monthly temperature during *Rabi* season varies from a low of 10 °C in January to a high of 32 °C in May. The monthly temperature in *Kharif* season is high during the May/June (35 °C), starts to decline with the onset of moonsoon and is 30° C in September. The relative humidity varies from 35% in May to 70% in September. The annual sunshine hours vary from 5.1 h in January to 10.4 h in May, while the reference evapotranspiration (ET_0) varies from daily minimum of 1.1 mm in December to 6.4 mm in May.