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Effect of water-saving irrigation, tillage and residue management on yield and water productivity of rice in Khorezm, Uzbekistan

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1. Introduction

Rice is the second major food crop in terms of area (55,000 ha), and the third in terms of production (197,700 t) in Uzbekistan (FAOSTAT, 2007). Given the aridity of the region and the paddy cultivation method, rice production demands more than 30,000 m^3 ha^{-1} of irrigation water on field level alone (FAO, 1997). Despite rice being one of the most remunerative crops in the dryland zones of Uzbekistan, its area is decreasing due to a diminishing supply and mismanagement of irrigation water. Increasing water shortage is compelling rice growing farmers to develop and adopt water saving technologies.

Bed planting (BP) and zero tillage (ZT) combined with residue retention has the potential to improve soil health, reduce production cost, and increase productivity in maize and wheat under rainfed conditions (Govaerts et al., 2007), and can reduce evaporation losses from the soil surface, salinization, and further improve crop productivity in saline environments (Hobbs and Gupta, 2004). Direct seeded rice planted on raised beds and on the flat avoids the deleterious effects of puddling on soil structure and fertility, improve water- and nutrient-use efficiency and reduce production costs (Timsina and Conner, 2001). Frequent Intermittent Wet and Dry (WAD) irrigated rice combined with conservation agriculture (CA) principles such as residue retention, reduced tillage, and dry-direct seeding, offer potential to reduce water use in rice. This paper presents the results of a field study to investigate the effects of WAD irrigation method, residue retention and reduced tillage on rice grain yield and water productivity in the Khorezm region.

2. Materials and methods

A field experiment was conducted in the growing seasons 2008 and 2009. Six frequent intermittent WAD irrigated rice treatments from the combination of BP and ZT with three levels of residue retention (all residue harvested (RH), 50% residue retention (R50) and 100% residue retention (R100)). These treatments were compared with the farmers' practice of conventional tillage flood irrigation (CT-FI) and a conventional tillage intermittent irrigation (CT-II). The six treatments of WAD irrigated rice and CT-II were irrigated intermittently when soil metric potential dropped below -10 to -20 kPa, while CT-FI was irrigated continuously to maintain a 5-20 cm standing water collar on top of the soil surface. The experiment was conducted in a randomized complete block design (RCBD) with 4 replications. Each plot sized 480 m^2 in WAD rice and CT-II, and 2000 m^2 in CT-FI.

Grain yield was determined by harvesting plants from 6.75 m^2 from a plot and is expressed on oven-dried basis. Spikelets m^{-2} was calculated by multiplying the number of panicles m^{-2} by the number of filled spikelets per panicle. Spikelets per panicle were estimated by counting number of filled spikelets in 20 randomly selected panicles and 1000-seed weight by oven-drying those spikelets. Harvest index (HI) was calculated as the ratio of oven-dry grain yield to the total aboveground biomass. Irrigation water input in treatments of WAD and CT-FI rice was measured separately by installing three Standard Trapezoidal Cipolletti weirs (0.5 m crest width) and automated data logger (Divers) for level measurement. The amount of water discharged (m^3 s^{-1}) from the respective weirs was calculated based on the following equation (Kraatz and Mahajan, 1975):

$$Q = 1.86\, L\, H^{\frac{3}{2}}$$

Where, Q = discharge (m^3 s^{-1}), L = crest width (m), H = height of water above the crest width (m)

Soil samples for mineral N content were collected at major growth stages from three different points of each plot from 0-10, 10-20, 20-30, 30-50 and 50-80 cm soil depths and the samples were composited and dried under plastic house. NO_3- and NH_4-N content determined by using Granvald-Ljashu and Colorimetric analysis, respectively (Protasov, 1977).

3. Results

3.1. Rice grain yield

The averaged grain yield of rice was lower (p<0.001) in 2009 than in 2008 (3293 vs. 4916 kg ha^{-1}, 33%). Yield reduction in 2009 in all treatments of WAD rice was significant while was non-significant in CT-FI (Fig. 1). Disregarding reside and tillage, treatments of WAD rice yielded less (p<0.001) than CT-FI treatment and had yield reduction of 30% (4630 vs. 6633 kg ha^{-1}) in 2008 and 54% (2879 vs. 6197 kg ha^{-1}) in 2009. No significant interactions were observed between BP and ZT with three levels of residue retention. Disregarding residue levels, rice yield was not different (p>0.21) between BP and ZT in both years. Despite non-significant, BP had greater yield by 7% in 2008 and 5% in 2009 than ZT.

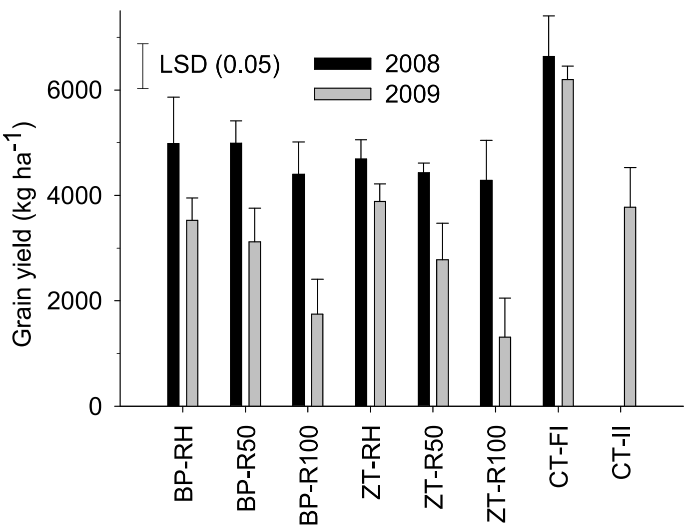

Fig. 1. Grain yield of rice (kg ha^{-1}) as impacted by irrigation, tillage and residue management in 2008 and 2009 in the Khorezm region, Uzbekistan. LSD is the difference between treatments and year at *P*=0.05. Legends: BP-RH-bed planting residue harvested, BP-R50-bed planting 50% residue retention, BP-R100-bed planting 100% residue retention, ZT-RH-zero tillage residue harvested, ZT-R50- zero tillage 50% residue retention, ZT-R100-zero tillage 100% residue retention, CT-FI- conventional tillage continuous flood irrigation, CT-II conventional tillage intermittent irrigation.

While no differences in yield were observed between the WAD treatments in 2008, the differences in 2009 were significant. Yield reduction in WAD rice treatments increased with increasing residue level. Under full residue retention (R100), rice yield was reduced by 10% in

2008 and 59% in 2009 compared to R50. The CT-II treatment in 2009 had a yield reduction of 39% compared to the paddy rice (CT-FI). The lowest yield of rice was observed in ZT-R100 in both years followed by BP-R100, ZT-R50 and BP-R50.

All major yield components were consistently lower ($p<0.05$) in WAD rice compared to CT-FI in both years. The interaction between BP and ZT with the three levels of residue retention was not significant for all yield components examined. But WAD rice had lower spikelets m^{-2} (26% in 2008 and 50% in 2009), spikelets per panicle (26% in 2008 and 47% in 2009), 1000-seed weight (5% in 2008 and 4% in 2009), and HI (5% in 2008 and 31% in 2009) than CT-FI. Treatments of WAD rice had a greater number of sterile panicles and unfilled spikelets percentage. All yield components were further reduced with increasing level of residue retention.

3.2. Water use and productivity

The total water applied to rice under conventional paddy cultivation (CT-FI) was 71,000 and 59,000 m^3 ha^{-1} in 2008 and 2009, respectively. However, when the irrigation method was changed to WAD, water applied to rice was on average reduced by 73% in 2008 and 67% in 2009. The amount of water applied in ZT was greater than in BP by 19% in 2008 and 18% in 2009. The water productivity of rice was significantly affected by irrigation, tillage, and residue levels in both years. It was greater in treatments of WAD rice than in CT-FI (224-310 vs. 101 g m^{-3} in 2008 and 70-224 vs. 117 g m^{-3} in 2009, respectively). RH had greater water productivity than the residue retained treatments. Water productivity in CT-II was equal with RH treatments of WAD rice.

3.3. Soil mineral nitrogen

Total available mineral nitrogen (N) content in 0-80 cm soil profile was generally greater in CT-FI than in WAD rice during the major phonological stages, which was (104 vs. 98 kg ha^{-1}, 7%, $p=0.22$) at panicle initiation and (83 vs. 76 kg ha^{-1}, 7%, $p=0.15$) at flowering stage in 2008; and (111 vs. 78 kg ha^{-1}, 42%, $p<0.001$) at panicle initiation, (99 vs. 82 kg ha^{-1}, 20%, $p=0.01$) at flowering stage in 2009, respectively (Fig. 2).

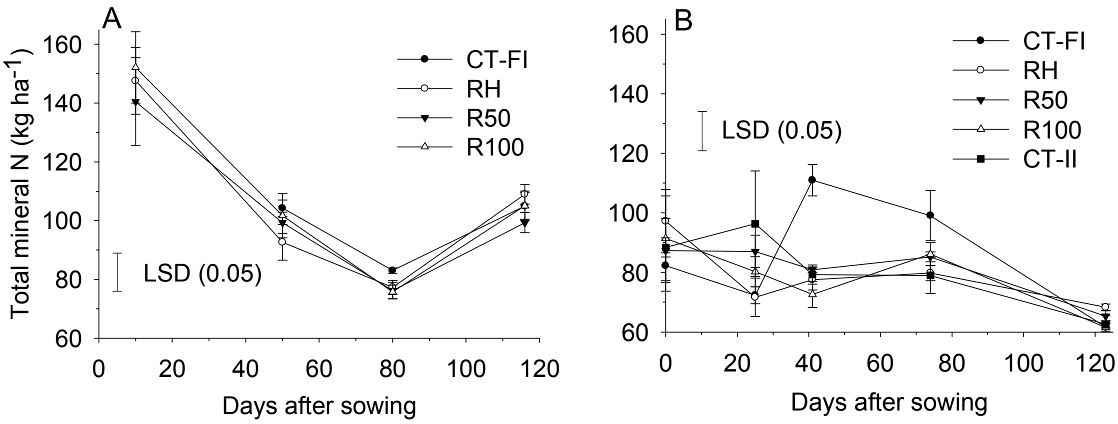

Fig. 2. Total mineral N (kg ha^{-1}) in 0-80 cm soil profile in rice grown under different irrigation and residue levels 2008 (A) and 2009 (B) in Khorezm, Uzbekistan. LSD (0.05) is the difference between treatments in different sampling dates. Legends: CT-FI-Conventional tillage flood irrigation, RH- residue harvested, R50-50% residue retention, R100-100% residue retention, and CT-II-conventional tillage intermittent irrigation.

4. Discussion

Rice yield reduced under frequent intermittent WAD irrigated condition by 30% in 2008 and 54% in 2009 while had water saving potentiality of 67-73% compared to CT-FI rice. Rice yield reduction was due to water stress affecting growth, phenological development, and yield components. Rice yield was also reduced in the treatment with greater amount of residue retention due to shading effect and decreasing soil temperature. Reduced number of spikelets m^{-2} followed by greater number of sterile panicles and spikelets were the main yield limiting factors in rice grown under WAD irrigated condition and presence of greater amount residue. The lower soil mineral N content during the major growth stages especially in 2009 indicated that, in addition to water stress, rice growth, development, and yield in WAD treatments was limited due to N stress. In frequent aerobic-anaerobic cycles, redox potential changes rapidly which accelerated the rapid loss of nitrogen (Reddy and Patrick, 1976).

Compared to the averaged yield of rice in Central Asia (3.1 t ha^{-1}), Uzbekistan (3.6 t ha^{-1}) and Khorezm (4.3 t ha^{-1}) (FAOSTAT, 2009), RH treatments (4.15 t ha^{-1} at 12% moisture) of WAD rice in 2009 yielded 34%, 15% and -3% greater yield than their average yield, respectively. The difference was even greater in 2008. Water application for the 110 days maturity rice variety in wet-direct seeded condition in arid region fairly exceeds 40,000 m^3 ha^{-1} (personal communication with extension agronomist in Khorezm region) and 30,000 m^3 ha^{-1} under transplanted condition (FAO, 1997). Thus, it is possible to achieve 35-55% water saving in regional and national level through the cultivation of rice under residue harvested WAD irrigated condition sustaining the average productivity.

5. Conclusions and outlook

Similar to previous studies, paddy cultivation of rice resulted in significantly higher yield than under water saving irrigation. The yield loss of rice in the WAD treatments was on average 42%. Reduction in the number of spikelets appeared to be the key cause of rice yield decline under water saving irrigation. This was largely due to soil water and nitrogen stresses observed during the rice grain setting phase. Low soil mineral N content together with poor crop performance in WAD rice indicates (i) water stress reduced crop N demand or, (ii) soil conditions led to increased N losses via. nitrification-denitrification and/or ammonia volatilization and/or leaching resulting to poor crop demand and uptake. Both intensive tillage and greater amount of residue retention did not have any beneficial effect on rice yield. Despite the lower yield, the concept of WAD rice combined with CA technologies can have enormous water saving potential. Improvement in agronomic practices to increase N and water use efficiency and the use of improved aerobic rice varieties can reduce the yield gap between WAD and paddy rice.

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