Water productivity of rice crop in irrigated areas

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Abstract

The sustainable productivity of rice wheat system is under threat due to growing water scarcity. More and more groundwater resources are being exploited. One of the major future challenges for agriculture is to produce more food with less water. Therefore, system performance should be evaluated in terms of water use efficiency and water productivity along with the land productivity. This paper studied the water use efficiency and productivity in rice-wheat zone of Punjab, Pakistan. The performances of different rice establishment techniques were evaluated. The results show that canal water shortages were acute; therefore, about 3/4 of the crop demand is met through groundwater exploitation. The water use efficiency of the system was low as the water productivity of gross inflow for rice was only 0.27 kg/m^3. The irrigation water productivity for direct seeding method for rice on flat field was estimated as 0.41 kg/m^3 and the corresponding value for conventional method was 0.34 kg/m^3. The irrigation water productivity for wheat was estimated as, 2.0 kg/m^3 and could be improved further by meeting the full crop demand through better irrigation and groundwater pumpage strategies. The adoption of innovations in the fields of crop physiology, agricultural practices, agricultural engineering and resource conservation technologies could play a leading role in sustaining and enhancing the productivity of rice-wheat systems.

Key words

rice-wheat systems, water productivity, crop establishment, resource conservation and water management,

Introduction

The rice-wheat cropping system has higher water demand, as rice needs more water compared to other crops. New technologies for water saving, e.g., alternate drying and wetting, raised beds and direct seeding are being tested for rice cultivation in South Asia (Bhuiyan and Tuong, 1995; Guerra *et al.,* 1998; Van der hoek *et al*., 2001). Similarly, laser land leveling and zero till wheat sowing are seen as interventions to improve efficiency of water resources for wheat (Hobbs, 2001). Most of the studies compared the traditional practices and the new approaches for mass produced per unit area. In addition, studies conducted in a system perspective are also lacking. It is therefore, essential to determine crop yield and water saving from a system perspective. The question how efficiently water is being used in an agro-ecological context is also extremely important. Therefore, the system performance should be evaluated considering the crop water productivity (production per unit of water) along with the yield per unit of land. Water use efficiency and productivity in rice-wheat zone of Punjab was studied at watercourse and field levels. In addition, different interventions for rice and wheat stand establishment were compared.

Methodology

Study Area

Rice-Wheat zone in Pakistan is sub-tropical semi-arid and represents a low-lying interior of the Indo-Pakistan sub-continent. Rainfall and temperature shows large seasonal fluctuations in the area. The soils are developed in alluvium of the Indus River System and are calcareous and weakly structured. The study area was located in the command areas of Ghour Dhour and Gujjiana distributaries and Kakar Gill

Sub-Minor. Both the distributaries off-take from Upper Gugera canal of Lower Chenab Canal system and comes under the administrative boundary of Sheikupura district. The Kakar Gill subminor emerges from Noshero distributary of Upper Chenab Canal and fall in the administrative boundaries of the district Hafizabad. Two watercourses (WC 28915-L and WC 32326-L) were selected from Ghour Dour distributary and one each on Gujjiana distributary (WC 74634-R) and Kakar Gill sub minor (WC 21900-TF). General characteristics of the watercourses are given in Table 1.

Experimental set up and data collection

Irrigation applied to each plot was measured by using cutthroat flume and daily rainfall was recorded by rain gauges installed in each watercourse command. Seepage and percolation losses were estimated from daily ponding depth measured by scales installed in the rice fields. Temperature, evaporation and rainfall were obtained from WAPDA's meteorological station at Farooqabad for the estimation of evapotranspiration by Hargreeve's method and crop coefficients for the area (Allen *et al*, 1998; Ullah, 2001). The quantity of canal water entering into the watercourse command area was measured daily after the calibration of the outlets. The groundwater pumpage was estimated by recording the daily operation hours and measuring discharge using X-Y method of every tubewell in the study area. A network of piezometers was installed in each watercourse to determine the changes in groundwater level on weekly basis using electrical water table recorder. The groundwater EC was measured monthly by an EC meter.

At three of the seven farms crop stand establishment technology where tested through a replicated field trial. Tillage, fertilizer, and weedicide/pesticides were applied as recommended. The crop yield data for two seasons (Kharif 2001 and Rabi 2001-02) were used to determine Water Use Efficiency and Productivity by water accounting methodology developed by IWMI (Molden 1997; Molden and Sakthivadivel, 1999 and Molden *et al* 2001): Water productivity in term of gross inflow was calculated as yield (kg/ha) / gross inflow (m^3/ha) and water productivity in terms of irrigation as yield (kg/ha) / irrigation inflow (m^3/ha).

Results and discussion

Evapotranspiration and Irrigation Requirement

Average annual crop water requirement for rice in the area is 640 mm and for wheat 330 mm. Variability in crop water requirement by the canal commands was not significant (Ullah, 2001). By combining, the total annual crop water requirement of rice-wheat rotation was 967 mm. Further, the continuous flooding maintained at a depth of 50-75 mm during most of the rice growing season increased irrigation higher than the potential crop demand. Thus the seasonal water requirement ranges from 1200 mm to 1600 mm for a growing period of about 100-150 days. In addition, puddling operation requires approximately 100-200 mm water.

Majority of the farmers have been applying 5-6 irrigations to wheat each with 25-30 days interval and average 75 mm water per irrigation. The recent water shortage, however, forced 3-4 irrigations, yet, achieving the same wheat yield. It was obvious that the farmers have maximized the benefits by strategic irrigation at critical growth periods, which are tillering, flowering and grain filling (Timsina and conner, 2001).

Field Scale Evaluation of Traditional Rice Crop

The water balance components indicated average gross inflow 1339 mm against the crop demand of 570 mm (Table 2). The irrigation inflow constituted about 3/4th of the gross inflow, of which about 70% was contributed from groundwater pumpage. The rainfall events were sporadic and concentrated in the month of July. The change in root zone storage was assumed as zero over the whole growing season. The average seepage and percolation (SP) losses in the study area were 769 mm.

The term gross depleted fraction (DF_gross) represents the proportion of the gross inflow used as the evapotranspiration by the rice crop. The overall average value of the DF_gross was 0.43, ranging from 0.38 to 0.46, which showed low efficiency of water use. The large amount of irrigation water and rainfall (57%) was not used beneficially by the rice crop and goes out of the root zone. This stressed the need for better and efficient use of irrigation and rainwater to improve water use efficiency.

The average rice yield (unhusked) in the study area remained 3520 kg/ha. The water productivity values for gross inflow were 0.27 kg/m^3 ranging from 0.20 kg/m^3 to 0.31 kg/m^3. This indicated 3738 L water used to produce one kg of paddy rice. The water productivity calculated based on irrigation inflow was slightly higher than that of the gross inflow (because of less value of denominator) and averaged at 0.34 kg/m^3. The productivity values were low when compared with the other countries of the world. The irrigation water productivity of traditional rice cultivation in Tuanlin China is 1.95 kg/m^3 (Dong B. et al 2001) and 1.4 to 1.6 kg/ha for wet seeded rice in Philippines (Toung and Bouman, 2002).

Table 1. Characteristics of water supply and the soil in the study area.

Description	WC28915-L	WC32326-L	WC74634-R	WC21900-TF
Gross command area (ha)	72.3	109.6	268.4	231.8
Cultivable command area (ha)	71.9	107.5	267.1	199.0
Designed discharge (cfs)	0.25	0.55	1.41	2.39
Tubewells (#)	2	17	38	25
Groundwater EC (dS/m)	1.1	1.2	0.8	0.8
Cropped area (ha), annual	131.8	185.3	479.1	384.7
Kharif 2001	63.4	79.7	224.1	196.5
Rabi 2001-02	68.4	105.6	255.0	188.2
Cropping Intensity (%)	183	172	179	193
Kharif 2001	88	74	84	99
Rabi 2001-02	95	98	95	95
Soil texture	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam

Table 2. Summary of water balance components in conventional Kharif 2001 rice.

Category	WC28915-L	WC32326-L	WC74634-R	WC21900-TF
Field area (m^2)	1720	4049	2111	1804
Inflow (mm)				
Irrigation	1064	852	1192	1133
Rainfall	315	315	241	244
Gross inflow	1379	1167	1433	1377
Outflow (mm)				
ET	631	521	531	597
S&P losses	748	646	902	780
Performance				

Depleted fraction	0.46	0.45	0.38	0.44
Paddy rice yield (kg/ha)	4014	3030	2814	4223
Water productivity (kg/m^3)				
WP_Gross inflow	0.30	0.26	0.20	0.31
WP_Irrigation	0.39	0.36	0.24	0.38

Water Productivity of Rice Establishment Interventions

The different rice establishment technologies were tested at three farms located in rice-wheat zone. The direct seeding on flat needed the least irrigation water (865 mm) followed by direct seeding on beds (924 mm) and transplanting on beds (999 mm) compared to 1130 mm needed in case of conventional rice cultivation. The average irrigation water productivity for direct seeding on flat was 0.41 kg/m^3, 21% higher than that of conventional method with 0.34 kg/m^3. Water productivity for direct seeded rice on bed and for transplanting on bed was 0.37 and 0.30 kg/m^3. The average yield for direct seeded rice on flat was 3404 kg/ha (ranging from 1685 to 5813 kg/ha) and 3690 kg/ha (ranging from 2313 to 5354 kg/ha) for conventional method. Farm wise comparison show that at one farm (21900/TF, Zaidi Farm) direct seeded on flat attained more land productivity (yield/ha) and water productivity (kg/m^3) compared with the conventional method. At the other two farms (28915/L, Malik Farm and 74634/R, Dogar Farm) conventional method gave higher crop yields as compared to DSF.

Water Productivity of Wheat Establishment Interventions

The irrigation applied to wheat planted on three row beds, two row beds, conventional, and zero tillage methods amounted to 203 mm, 215 mm, 221 mm, and 230 mm, respectively. The water productivity for these treatments worked out to be in the range of 1.3 – 2.0 kg/m^3. Similar results have been quoted by Kahlown *et al* (2002), indicating that the irrigation water productivity for conventional was 0.9 and was 1.4 kg/m^3 for zero tillage and laser leveling. The zero tillage method gave equally good results in term of land and water productivity compared with laser leveling and conventional method. This finally, increased the water productivity of the farms where resource conservation technologies were adopted.

Conclusions

The water productivity of rice based on gross inflow was 0.27 kg/m^3 indicating that approximately 3740 L water was used to produce one kg paddy rice during Kharif 2001. The study showed potential to increase land and water productivity by direct seeding rice provided proper agronomic practices are adopted. The wheat crop was under irrigated to maximize the productivity of canal water. The irrigation water productivity for wheat was 2.0 kg/m^3 and could be improved further by meeting the full crop water demand through better irrigation and groundwater pumpage strategies. Improvement in water productivity was vital to increase the water use efficiency and overall productivity of rice-wheat systems.

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