Study on Grain and Water Productivity of Rice-Zero-Till Maize Cropping System

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Abstract

The effect of two rice crop establishment methods (transplanted and aerobic), two irrigation (IW: CPE ratio of 0.8 and 1.0) and four phosphorus levels (0, 30, 60 and 90 kg P_2O_5 ha^{-1}) on rice-zero-tillage maize cropping system is studied during 2007-08 and 2008-09 at a field experiment station at Hyderabad. Transplanted rice on an average gave 1.02 t ha^{-1} higher yield than aerobic rice (4.49 t ha^{-1}). However, succeeding maize grown as zero-tilled crop after aerobic rice has 0.34 t ha^{-1} more yields than that after transplanted rice (6.34 t ha^{-1}). The higher water productivity of aerobic rice (0.395 kg m^{-3}) and succeeding zero-tilled maize (1.17) as compared to transplanted rice and succeeding maize (0.37 and 1.095 kg m^{-3}) together brought higher water productivity (0.64 kg m^{-3}) in aerobic rice-maize system in comparison to transplanted rice-maize (0.54 kg m^{-3}). With increase in level of irrigation from 0.8 to 1.0 IW: CPE ratio and increase in P dose, the consumptive use of water by maize increased during both the years of study.

Key words: Rice, zero-till maize, grain yield, consumptive use, water productivity

Rice (*Oryza sativa* L.)-Maize (*Zea mays* L.) is one of the pre-dominant cropping system of both command and non-command areas of Andhra Pradesh. Shortage of irrigation water and increased cost of transplanting in rice made several researchers to study the possibility of rice cultivation under irrigated dry conditions (aerobic). The early crop maturity (7-10 days) and ease of establishment of succeeding crop after aerobic rice cultivation are additional benefits. The concept of zero-tillage is gaining momentum in traditional areas under rice-maize sequence. This technique aids in overcoming planting difficulties in rice fallow, reduces weeds and improves fertilizers and water use efficiency and reduce cost of cultivation (DMR Technical Bulletin, 2009).

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Irrigation as well as nutritional requirements, particularly, the phosphorus (P) of zero-till maize is different from conventionally sown maize because of alteration of physico-chemical properties of soil under rice-based situations. Maize uses water efficiently in terms of total dry matter production among the cereals. Frequency and depth of irrigation has pronounced effect on grain yield of maize. Positive relationship between irrigation and 'P' response in many field crops particularly in maize have been indicated mainly due to the fact that 'P' availability of both soil and applied increases due to adequacy of soil water. Keeping above aspects in view, a study was under taken to assess zero-tillage maize performance under different irrigation and P fertilization following a aerobic and transplanted crop.

Material and Methods

The field study was conducted during rainy and winter seasons of 2007-08 and 2008-09 at Water Technology Centre, Agricultural College Farm, Rajendranagar ($78^0$23 E and $17^0$1 N and 524.6 m above MSL), Hyderabad, Andhra Pradesh. The location with semi arid tropical climate is characterized by hot summer and cold winters. The mean maximum and minimum temperatures ranges from 31.2^0C and 15.6^0C in 2007-08 and 32.1^0C and17.0^0C in 2008-09 had annual rainfall of 398.5 mm and 1095.6 in 2007-08 and 2008-09 which was received in 38 and 39 rainy days. The experimental soil was sandy clay loam with pH 7.4, low in organic carbon (0.51%) and available nitrogen (240.6 kg ha^{-1}), medium in available phosphorus (15.39 kg ha^{-1}) and high in available potassium (631.6 kg ha^{-1}). The experiment was conducted in split-plot design with four replications. During rainy season, two methods of rice crop establishment (transplanted and aerobic) were evaluated whereas in winter season zero-tilled maize was grown in sequence to rice while considering the two previous rice crop establishment methods as main-plot and combination of two levels of irrigation (1.0 and 0.8 Irrigation Water (IW): Cumulative Pan Evaporation (CPE) and four levels of phosphorus (0, 30, 60 and 90 kg P_2O_5 ha^{-1}) as sub-plot treatments. During rainy season semi dwarf rice variety (MTU 1010) was transplanted at a spacing of 20 x 15 cm in a puddled field. Whereas under aerobic method, direct seeding of dry seed was done in solid rows at row spacing of 20 cm. Nursery sowing was done for transplanted rice on the same day as of Aerobic Rice (AR) sowing. A fertilizer dose of 120-60-40 kg, N-P_2O_{5-} K_2O ha^{-1} in the form of urea, Single Super Phosphate (SSP) and Muriate Of Potash (MOP) was applied. In AR, weeds were controlled by spraying pendimethalin 35 EC @ 1.0 kg ha^{-1} in 500 l of water after 24 hours of seeding followed by push hoeing at 25 and 45 days after sowing. In transplanted rice, butachlor 50 EC @1.25 kg ha^{-1} mixed with sand was applied at 2 Days After Transplanting (DAT) maintaining thin film of water followed by one hand weeding at 30 DAT. Two sprays of 0.2% ferrous ammonium sulphate solution were also given at weekly interval for AR to correct the iron deficiency.

For transplanted rice, 2 cm standing water was maintained upto panicle initiation stage and later 5 cm of level was maintained. In AR a soaking irrigation was given initially later on from 7 days onwards irrigations (5 cm) were given when the soil moisture reached to 28% corresponding to -20 Kpa tension that was measured with theta probe soil moisture sensor ML2. The amount of water applied was measured through water meter and was directly delivered to plot. During winter season, paraquat 50 EC @ 1.25 kg ha^{-1} was sprayed immediately after rice harvest to control the existing weeds as well as to arrest the re growth of rice stubbles. Maize hybrid 'DHM 117' seeds were dibbled at a spacing of 60 x 20 cm under zero-tillage and a day later atrazine @1.0 kg ha^{-1} was sprayed for weed control. A uniform fertilizer dose of120-40 kg N-K_2O ha^{-1} fertilizers along with P fertilizer as per the treatment was applied. The entire P and K was applied as basal in the form of SSP and MOP and N was applied in three equal splits (basal, knee high and tasseling & silking) in the form of urea. Pests and disease control were adopted as per the recommendations for the region. One pre-sowing irrigation followed by one common irrigation each of 2.5 cm immediately after sowing of the crop was given to ensure uniform germination. Subsequent irrigations were scheduled based on IW: CPE ratio. In IW: CPE approach, 5 cm depth of irrigation water was applied uniformly when CPE reached 6.25 and 5.0 cm in order to get a ratio of 0.8 and 1.0. CPE values were obtained from standard USWB Class A pan. The soil moisture depletion method was employed to determine the Consumptive Use (CU). Consumptive use was calculated from change in the soil moisture content in successive samples Sankara Reddi and Yellamanda Reddy, 1995).

$$U = \sum^{n} (Mxi - Mzi)$$

i=1 --------------------- x BDi x Di

100

Where, U = Consumptive use or actual moisture used from the root zone within one irrigation cycle (mm)

n = Number of soil layers sampled in the root zone depth D

Mxi = Soil moisture percentage at the time of first sampling in the i^{th} layer

Mzi = Soil moisture percentage at the time of second sampling in the i^{th}layer

BDi =Bulk density of the soil of i^{th} layer (g cm^{-3})

Di = Depth of ith layer of the soil (mm)

CU = ∑ U

The seasonal CU was obtained by adding CU values for each sampling interval. Soil moisture extraction was worked out for different soil depths for the period of sampling interval during the crop growth. Then, the total moisture extracted (SMDt) from the root zone depth (0-60 cm) was calculated using the expression

SMDt = SMD 1 + SMD2 + SMD3 + SMD4

where, SMDt = Soil moisture depleted from 0-60 cm

$SMD_{1,2,3,4}$ = Soil moisture depleted from 0-15,15-30, 30-45 and 45-60 cm

Moisture depletion from each part of the soil depth was then expressed as percentage of total moisture depletion from the part of soil depth. A comprehensive analysis of water productivity **(**kg m^{-3}**)** was done. Crop water productivity was estimated as ratio of maize yield (kg) to that of CU (m^3) of the crop and field water productivity (kg m^{-3}) was calculated as ratio of yield (kg) to that of water applied to the crop including rainfall (m^3) in the season.

Results and Discussion

Crop establishment methods and yield

Transplanted rice rerecorded 1.09 tonne higher yield than aerobic crop (4.63 and 4.35 tonne ha^{-1} in 2007 and 2008). The higher grain yield might be due to efficient utilization of water and nutrients by puddle transplanted rice resulting in yield attributes. The low yields in aerobic rice may be due to excessive vegetative growth and more panicle density that caused tiller mortality and spike let sterility as compared to transplanted rice. Similar results are also reported by Gill *et al*. (2006).

Winter maize productivity grown under zero-tilled conditions after aerobic rice was higher than that after transplanted rice (Table 1) on account of greater values of yield attributes (cob number ha^{-1}, cob weight, cob length, cob girth, number of grains cob^{-1} and shelling percentage). The favorable conditions under AR cultivation might have improved the plant growth and dry matter and also crop with optimum source-sink ratio facilitate proper portioning of photo synthetates and thus resulted in better filling of grains. In case of transplanted method of establishment, due to puddling soil structural changes along with formation of hard pan development in sub-soil might have restricted the root growth which in turn reduced shoot growth. Whereas in, aerobic rice the dry land preparation was done and good pulverized soil condition facilitated for better root development and good crop performance. These results are supported by Gangwar *et al*. (2008). The interaction between methods of crop establishment and irrigation level indicated that maize grain yield with 1.0 IW: CPE ratio irrigation was significantly higher than 0.8 IW:CPE ratio after both the methods of crop establishment. Maximum benefit from irrigation was realized under aerobic method of cultivation in both years (Table 1). The interaction between irrigation and P level also attained level of significance. Application of 30 kg P_2O_5 ha^{-1} at irrigation of 1.0 IW:CPE ratio resulted in comparable grain yield of maize as that of 90 kg P_2O_5 ha^{-1} at irrigation level of 0.8 IW:CPE ratio. The beneficial effect of P application was more pronounced at IW: CPE ratio of 1.0 than 0.8 at all P levels (Table 2).

Crop establishment methods - water use and water productivity

In the present study, transplanted method recorded the highest field water use compared to AR. It was observed that on an average AR recorded a saving of 35.7% and 29.2% of field water compared to transplanted rice in 2007 and 2008 (Table 3). LavBhushan *et al*. (2007) observed 23% saving of irrigation water with direct seeded rice over transplanted rice. The effective rainfall during 2008 (5795 m^3 ha^{-1}) was much higher than that in 2007 (2238 m^3 ha^{-1}) and thus the water applied through irrigation during 2008 was comparatively lower than 2007. Therefore, the total water use was higher during 2008 than 2007. Field water productivity was lower in 2008 irrespective of establishment method because of lower grain yield. In AR the field water use was low as compared to transplanted rice because of dry land preparation which led to reduction in irrigation water and total water requirement. Similar findings were also reported by Cabangon *et al*. (2000) and Tabbal *et al*. (2000). Lower water consumption by AR has resulted in higher water productivity (0.40 and 0.34 kg m^3 in 2007 and 2008) as compared to the transplanted method of cultivation (0.44 and 0.35 kg m^3 in 2007 and 2008 respectively) (Table 3). In AR, seepage and percolation and evaporation losses are greatly reduced and also increased effective utilization of rain water which helped in enhancing the water productivity (Singh and Vishwanathan, 2006; Bouman *et al*., 2005; Gill *et al*., 2006).

In zero-tillage maize, both the methods of rice establishment utilized more or less same field water under different irrigation schedules during two years of study (Table 4). Irrigation scheduled at 1.0 IW : CPE ratio has recorded more field water use due to more number of irrigations than 0.8 ratio. The field water productivity was higher in the latter irrigation schedule than that in the former. The CU of maize after transplanted rice was less (343.8 and 362.5 mm) as compared to AR (382.8 and 396.2 mm) in both years and water productivity of maize was found to be more when grown after transplanted rice than after over aerobic rice. In maize grown after puddle rice, the leaching losses are minimum where as after aerobic rice relatively leaching of irrigation water is more due to un-puddled condition.With increase in level of irrigation from 0.8 to 1.0 IW : CPE ratio there was an increase in CU of water by maize during both the years of study. During 2008-09, maximum CU was recorded due to more number of irrigations provided to the maize crop. Similar results of maximum water requirement (58.86 cm) was recorded under IW:CPE of 1.2 and minimum water requirement (44.98 cm) was observed with 0.6 IW:CPE ratio was reported by Bharathi *et al*.(2007).The system water use was lowest in aerobic rice-maize system and thus system water productivity was higher as compared to transplanted rice-maize during the years of study (Table 4).

Increase in level of P application resulted in increase in CU (Table 5). With each level of P increase from 0 to 90 kg P_2O_5 ha^{-1} the CU use increased considerably. The difference in CU between control and 90 kg P_2O_5 ha^{-1} was 68.8 and 74.6 mm during 2007-08 and 2008-09 respectively.

The influence of irrigation frequencies are more pronounced on CU use rather than on water productivity. The luxuriant crop growth at 1.0 IW: CPE which utilized more irrigation water to meet the higher crop demand and realized higher productivity. The water productivity was higher in maize grown after transplanted than aerobic rice. Irrigation at IW:CPE ratio of 0.8 recorded higher water productivity than irrigation at IW : CPE ratio of 1.0.

Increase in the level of P increased the water productivity. The increase in water productivity with increase in level of P was noticed up to 30 kg P_2O_5 ha^{-1} during 2007-08 and upto 60 kg P_2O_5 ha^{-1} during 2008-09.

Soil moisture extraction pattern

Based on the CU of water, soil moisture extraction pattern was maximum from the top 0-15 cm soil and decreased with each successive soil layers irrespective of preceding rice establishment methods, levels of irrigation and phosphorus. Lowest extraction was observed from 45-60 cm soil depth (Table 6). Slightly more soil moisture was extracted from deeper layers (30-45 cm and 45-60 cm) in transplanted rice as compared to aerobic rice during second year. IW:CPE ratio of 1.0 resulted in slightly more soil moisture extraction from 30-45 cm and 45-60 cm soil layers during both the years. Increase in phosphorus level increased the soil moisture extraction from 30-45 cm soil depth compared to control.

From the present study, it can be concluded that in the irrigated command areas the aerobic rice establishment method would be a viable option in terms of water saving and also aerobic rice-maize system will be more productive and profitable and results in higher system water productivity indicating sustainability of aerobic rice-maize system compared to the transplanted rice-maize system.

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Table 1: Interaction effect of rice crop establishment method and irrigation level on maize grain yield (kg ha^{-1})

IW:CPE ratio(I)	**Rice crop establishment method (M)**					
	2007-08			**2008-09**		
	Transplanted	**Aerobic**	**Mean**	**Transplanted**	**Aerobic**	**Mean**
0.8	5798	6462	6130	6258	6536	6396
1.0	6381	6728	6554	6808	7072	6940
Mean	6139	6545		6533	6803	
	SEm ±	CD(P=0.05)		SEm ±	CD(P=0.05)	
I	107	217		89	180	
M	68	156		62	199	
I at same or different M	152	307		126	255	
M at same or different I	114	245		109	262	

Table 2: Interaction effect of Irrigation and Phosphorus level on maize grain yield (kg ha^{-1})

P level(kg P_2O_5 ha^{-1})	**Irrigation levels (IW: CPE ratio)**					
	2007-08			**2008-09**		
	0.8	**1.0**	**Mean**	**0.8**	**1.0**	**Mean**
0	4751	5125	4938	4938	5734	5340
30	5756	6333	6045	6506	6865	6686
60	6934	7350	7142	7058	7478	7268
90	7079	7408	7244	7084	7674	7379
Mean	6130	6554		6396	6940	
	SEm ±	CD(P=0.05)		SEm ±	CD(P=0.05)	
P	132	292		116	225	
I	107	217		89	180	
Pat same or different I	155	311		179	359	
I at same or different P	149	218		179	359	

Table 3: Influence of crop establishment method of rice on field water use (m^3 ha^{-1}) and field water productivity (kg m^{-3})

	2007		2008	
	Transplanted	**Aerobic**	**Transplanted**	**Aerobic**
Number of irrigations	33	24	27	16
Irrigation water applied	12200	8400	10100	6500
Effective rainfall during crop period	2238	2238	5795	5795
Quantity of field water used	14438	10638	15895	12295
Field Water Productivity	0.40	0.44	0.34	0.35

Table 4: Influence of rice crop establishment methods and irrigation levels on field water use (m^3 ha^{-1}) and field water productivity (kg m^{-3} grain) in zero-tillage maize and rice-maize system

	2007-08				2008-09			
	Maize after Transplanted rice		Maize after aerobic rice		Maize after Transplanted rice		Maize after aerobic rice	
	IW: CPE ratio							
	0.8	**1.0**	**0.8**	**1.0**	**0.8**	**1.0**	**0.8**	**1.0**
Maize								
Number of irrigations	8	10	8	10	10	13	10	12
Quantity of irrigation water applied	4500	5500	4500	5500	5500	7000	5500	6500
Effective rainfall	339	339	534	534	365	365	--	--
Total quantity of water used	4839	5839	5034	6034	5865	7865	5500	6500
Field Water Productivity	1.33	1.18	1.31	1.16	1.07	0.80	1.17	1.04
Rice-maize system								
Total quantity of water used	21071		16172		22839		18295	
Water productivity	0.56		0.68		0.52		0.60	

Table 5: Consumptive use and crop water productivity of maize as influenced of rice crop establishment method, irrigation and phosphorus level

Treatments	Consumptive use (mm)		Crop water productivity (kg m^{-3})		
	2007-08	2008-09	2007-08	2008-09	Mean
Crop establishment methods (M)					
Transplanting rice	343.75	362.46	1.83	1.82	1.83
Aerobic rice	382.79	396.20	1.78	1.76	1.77
Irrigation level (IW:CPE ratio)					
0.8	376.95	404.62	1.68	1.62	1.65
1.0	421.10	458.14	1.69	1.53	1.61
Phosphorus levels (kg P_2O_5 ha^{-1})					
0	292.58	327.56	1.67	1.56	1.62
30	320.85	375.90	2.04	1.82	1.93
60	349.72	396.10	2.03	1.87	1.95
90	361.39	405.20	2.01	1.84	1.93

Data not analyzed statistically

Table 6: Soil moisture extraction pattern (mm) in zero-tillage maize as influenced by crop establishment method irrigation and phosphorus level

Treatments	Soil depth (cm)									
	2007-08					2008-09				
	0-15	15-30	30-45	45-60	Total	0-15	15-30	30-45	45-60	Total
Crop establishment method										
Transplanted rice	137.5	103.12	67.24	35.89	343.75	138.98	100.72	80.16	42.60	362.46
Aerobic rice	158.05	118.79	71.52	34.43	382.79	161.86	116.12	76.24	42.08	396.20
Irrigation level (IW:CPE ratio)										
0.8	142.54	108.26	82.76	43.39	376.95	162.85	122.39	78.92	40.46	404.62
1.0	160.44	124.33	84.24	32.09	401.10	174.06	140.04	94.03	50.01	458.14
Phosphorus level (kg P_2O_5 ha^{-1})										
0	121.03	89.7	53.52	28.26	292.58	129.02	95.27	64.12	39.15	327.56
30	131.34	98.26	61.17	30.08	320.85	150.36	106.77	71.18	47.59	375.90
60	137.89	102.92	75.94	32.97	349.72	159.44	120.83	71.22	44.61	396.10
90	141.09	100.16	82.24	37.90	361.39	162.12	122.83	76.24	44.02	405.20