The Bioscan 12(1): 521-527, 2017 (Supplement on Agronomy)
AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES
www.thebioscan.com

FERTIGATION EFFECTS ON YIELD, WATER PRODUCTIVITY AND NITROGEN USE EFFICIENCY OF AEROBIC RICE (*ORYZA SATIVA* L.) - ZERO TILL MAIZE (*ZEA MAYS* L.) CROPPING SYSTEM

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KEYWORDS
Aerobic rice- zero till maize cropping system
drip-fertigation
water productivity
yield

Received on :
08.08.2016

Accepted on :
23.01.2017

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ABSTRACT

Effect of drip and N fertigation was studied on aerobic rice (AR) – zero till maize (ZTM) cropping system during 2011-2013 on sandy loam soils of Warangal, Telangana State, India, in a split-plot design with three irrigation schedules and N levels as main and sub-plots, respectively for each crop with four replications. The grain yield of AR increased significantly with increasing water input and N levels with the highest at 200% PE (Pan evaporation) (4211 kg ha^{-1}) and 150 Kg N ha^{-1} (3828 kg ha^{-1}). The yield of ZTM increased up to 100% PE (10347 kg ha^{-1}) and 160 kg N ha^{-1} (10325 kg ha^{-1}) only. The rice equivalent yield (REY) of the cropping system was the highest at 200% PE - 125% PE (16993 kg ha^{-1}) and 150 - 200 kg N ha^{-1} (15943 kg ha^{-1}) applied for AR and ZTM, respectively. However, water productivity was higher with 100% PE - 75% PE schedule to the respective crops (1.78 g grain kg^{-1} of water). The results suggested that drip-fertigation at 200% PE - 125% PE with 150 - 200 kg N ha^{-1} to rice and maize crops, respectively is the best option for better productivity of AR – ZTM cropping system.

INTRODUCTION

Efficient use of water has become imperative in agriculture particularly in arid and semi-arid regions where water is a scarce commodity. This water scarcity also calls for diversification of rice-based cropping systems (Jat *et al*., 2012 and Prasad *et al*., 2013) and shift for production system of rice. In this perspective, Rice-Maize (R-M) cropping system has emerged as the highly productive alternate cropping system to Rice-Rice (R-R) and Rice-Wheat (R-W) during the first decade of this century in South Asia. In particular, it developed rapidly in South India (Andhra Pradesh, Telangana, Tamil Nadu and Karnataka), North India (Bihar and West Bengal) and Bangladesh. Among the competitive crops in sequence to rice, maize has the clear superiority in terms of productivity and profitability that makes it as a favorable option. Maize also requires far less water *i.e*., around 850 liters of water per kg grain production compared to 1000 litres kg^{-1} wheat grain and over 3000 litres kg^{-1} rice grain (Viswanatha *et al*., 2002). The high financial and environmental costs of irrigating rice from electric or diesel pumps is an increasing concern. In India, the undivided Andhra Pradesh State had the highest acreage under R-M system in India (0.25 M ha out of 0.53 M ha in India) (Timsina *et al*., 2010), where this system rapidly increased under resource-conserving technologies, mostly zero tillage. Zero-till maize replaced the rice-fallow pulse crops also due to pest problems and low productivity encountered in the pulse crops.

Much is known about conventional production systems of rice and maize separately in South Asia. Traditional rice production involves submerged conditions with approximately 5 to 10 cm deep standing water throughout the crop growth period. However, the increasing scarcity of fresh water for agriculture and the competing demand from the non-agricultural sector threaten the sustainability of the irrigated rice ecosystem. To cope up with scarcity, several water saving technologies have been developed for rice *viz*. saturated soil culture, alternate wetting and drying, system of rice intensification and raised bed system to lower the water requirements of the rice crop. One of such technologies is to grow rice as an upland crop like wheat or maize called as 'aerobic' cultivation. Aerobic rice cultivation reduces water use as much as 50 per cent compared to lowland rice (Tuong and Bouman, 2003). Aerobic rice can be rainfed or irrigated to maintain soil water content in the root zone to field capacity, and seems to be the most feasible alternative to traditional flood irrigated rice. Aerobic rice cultivation saves water input and increases water productivity by reducing water use during land preparation and limiting seepage, percolation and evaporation (Peng *et al*., 2012). Kadiyala *et al*. (2012) reported that aerobic rice resulted in 37 to 45% water saving compared to flooded rice system.

Nutrient demand for R-M system is high as they extract large amounts of nutrients especially nitrogen form the soil. Proper nutrient management of exhaustive systems like R-M should aim to supply fertilizers adequate for the demand of the component crops, and apply those in ways that minimize loss and maximize the efficiency of nutrients. Nitrogen management in the R-M system requires special attention so that potentially large losses can be minimized and efficiency can be maximized. Drip-fertigation has been proved as the most efficient method for applying water and nutrients in various crops (Singh *et al*., 2013; Sharma *et al*., 2013; Yanglem and Tumbare, 2014). The nutrient use efficiency in fertigation could be as high as 90 per cent as compared to 40 per cent in conventional methods (Solaimalai *et al*., 2005). Sampathkumar *et al*. (2012) reported higher yields of cotton-maize cropping system with drip-fertigation at 100% ETc replenishment. However, insights into the effects of fertigation in cropping system especially rice-maize cropping system are scarce. Hence the objective of the present study was to evaluate the effects of drip-fertigation on the yield, water productivity and nitrogen use efficiency in aerobic rice-zero till maize system.

MATERIALS AND METHODS

The field experiment was conducted during 2011-12 and 2012-13 at Regional Agricultural Research Station, Warangal (18º00'53.2" N, 79º36'17.2" E and 275 m above mean sea level), Telangana State, India. Climate of the study site is sub-tropical and semi-arid type with mean annual rainfall of 885 mm and a mean annual evaporation of 1621 mm. Soil of the experimental field was sandy loam in texture with pH of 7.9, Electrical conductivity (EC) of 0.17 dS m^{-1} (Jackson, 1973), organic C of 0.40% (Walkley and Black, 1934), available N (227 kg ha^{-1}) (Subbiah and Asija, 1956), available P (11 kg ha^{-1}) (Olsen *et al*., 1954) and available K (65 kg ha^{-1}) (Jackson, 1973). The bulk density of the top 0-30 cm layer was 1.69 g cc^{-1} (Miller and Donahue, 1990). The moisture content at field capacity and permanent wilting point (Dane and Toppe, 2002) was 15.75 and 8.04 per cent, respectively.

The experiment was laid out in split-plot design and replicated four times as suggested by Panse and Sukhatme (1985). Treatments consisted of three irrigation schedules *viz*. drip irrigation at 100% Pan Evaporation (PE), 150% PE and 200% PE for aerobic rice and 75% PE, 100% PE and 125% PE for zero-till maize in main plots and three nitrogen levels through fertigation *i.e*., 90, 120 and 150 kg ha^{-1} for aerobic rice and 120, 160 and 200 kg ha^{-1} to zero- till maize in subplots.

To grow aerobic rice, the selected field was dry-ploughed and harrowed on the onset of monsoon rains but not puddled during land preparation. Rice seed of 'WGL 20471' (Erramallelu) variety, with medium duration (120 days), fine grain and drought tolerant @ 40 kg ha^{-1} were sown in solid rows at a spacing of 30 cm between the rows in favourable soil moisture condition for germination. The gross plot size was 9.6 x 6.0 m. Drip lateral lines were spread as per the layout at one week after sowing. Thinning and gap filling was done at 10 days after sowing. Weeds were controlled by pre-emergence application of pendimethalin@ 1.2 kg a.i ha^{-1} followed by pyrazosufuron ethyl@ 30 g a.i ha^{-1} at 20 days after sowing. Nitrogen was applied as per the treatments in the form of urea as fertigation through ventury fitted to the drip system. The entire dose was split into ten equal parts and applied through drip at weekly interval starting from ten days after sowing. Phosphorus @ 60 kg ha^{-1} P_2O_5 as single super phosphate and potassium@ 50 kg K_2O ha^{-1} as muriate of potash was applied to all the treatments at the time of sowing as basal dose. To correct the 'Fe' deficiency which occurred at 20-30 DAS, ferrous sulphate was applied @5g lt^{-1} for three times at weekly interval. To control yellow mite, dicofol @ 3g lt^{-1} was sprayed at 50 DAS and to control blast, tricyclozole @0.6 g lt^{-1} was sprayed at 90 DAS.

Rainy season rice was harvested manually leaving the stubbles at 5-10 cm height from soil surface. A light irrigation was given and at 5 days after harvest of rice, seed of maize hybrid, 'Pinnacle' a high yielding, 120-130 days duration during *rabi* season, developed by Monsanto India Limited, was dibbled manually under no till condition by the side of rice stubbles at a depth of 5 cm @ one seed $hill^{-1}$ with a spacing of 60 x 20 cm. Tank mixture of atrazine @ 2.5 kg ha^{-1} + glyphosate @ 5 lt ha^{-1} was sprayed immediately after sowing using 500 litres of water per hectare with flood jet nozzle, to control the weeds as well as to prevent ratooning from the harvested rice stubbles. Thinning and gap filling were done at 10 days after sowing. Similar to rice crop, nitrogen was applied as per the treatments in the form of urea as fertigation through ventury fitted to the drip system in ten equal splits starting from ten DAS. Recommended phosphorus and potassium *i.e*., 60 and 50 kg ha^{-1}, respectively were applied at 15 DAS as pocketing. No severe incidence of pests or diseases was noticed during the crop period. As a precautionary measure, however, whorl application of carbofuron granules was done at 15 DAS against stem borer.

Drip irrigation was given every alternate day as per the schedules for both the crops based on the evaporation from open pan evaporimeter (USWB class A) situated at Regional Agricultural Research Station, Warangal. The laterals of 16 mm diameter were laid out at 60 cm apart with a spacing of 50 cm distance between two inline emitters. The emitter discharge was 4.0 lt hr^{-1} and application rate was 13.33 mm hr^{-1}. Control valves were fixed in all the plots to facilitate controlling the water flow as per the treatments. The operation time of the system (T) was calculated by using the following formula:

$$T = \frac{V}{qxNe}$$

Where,

T = operation time of the system (hrs)

V = total volume of water (litres)

q = Emitter discharge (Lph)

Ne = Number of emitters $plot^{-1}$

Data on yield attributes and yield of individual crops was collected and analysed by following the analysis of variance technique described by Panse and Sukhatme (1985) for split-plot design. The treatments means were compared at 5% level of significance. N uptake (kg ha^{-1}) was calculated by multiplying the N concentration (%) with dry matter produced in grain/kernel and straw/stover (Chowdhury *et al*., 2014). Rice equivalent yield (REY) of the cropping system was calculated by converting the maize yield to rice using the prevalent minimum support price of the rice and maize crops for the year and added to the rice yield . Water productivity (WP) of the cropping system was calculated by dividing the rice equivalent yield (REY) by total water received from rainfall and irrigation given to the crops grown in sequence and expressed as: WP = Y/R+I (g grain kg^{-1} water) (Kadiyala *et al.*, 2012). Agronomic Nitrogen-use efficiency (ANUE) (kg grain kg^{-1} applied N) was calculated using the equation: NUE = Y/N; where Y is the REY (kg ha^{-1}); R is the amount of effective rainfall (mm); I is the amount of irrigation water applied (mm) and N is the quantity of N applied (kg).

RESULTS AND DISCUSSION

Effect on aerobic rice

Yield attributes

The data obtained for two consecutive years presented in Table 1 revealed that yield attributes of aerobic rice like number of panicles m^{-2}, number of filled spikelets $panicle^{-1}$, percentage of sterile spikelets, were influenced by irrigation schedules and nitrogen levels in drip fertigation. Number of panicles m^{-2} were significantly higher at 200% PE compared to that of 100% PE but on par with that of 150% PE. Grain yield in rice was highly dependent upon the number of productive tillers produced by each plant, constituting important morpho-physiological trait (Tao *et al.*, 2006). Higher number of panicles at 200% PE drip irrigation schedule might be due to favourable moisture conditions during panicle initiation stage which was beneficial in maintaining normal cell integrity, cell division and elongation apart from enhancing nutrient uptake (Singh, 2004) and finally led to increased sink size. The number of filled spikelets $panicle^{-1}$ increased up to 150% PE during 2011 and up to 200% PE during 2012. On the other hand, the percentage of sterile spikelets was higher in 100% PE schedule. Panicle length and test weight did not differ due to irrigation schedules. With respect to nitrogen levels, the panicles m^{-2}, panicle length and spikelets $panicle^{-1}$ increased from 90 to 120 kg N ha^{-1} applied in fertigation but comparable between 120 and 150 kg N ha^{-1} while sterility of spikelets was more with 90 kg N ha^{-1}. Test weight was found significantly reduced under 150 kg N ha^{-1} compared to the lower doses during 2011 but remained same with all the N levels during the second year of study. Higher yield attributes with the increased nitrogen

Table 1: Yield attributes of aerobic rice as influenced by irrigation schedules and N levels through fertigation

Treatment	Panicles m^{-2}		Panicle length (cm)		Filled spikelets $panicle^{-1}$		Sterility(%)		Test weight (g)	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Irrigation schedule										
100% PE	221	233	21.3	22.3	146	122	15.5	12.4	16.8	16.9
150% PE	249	263	23.1	22	197	167	10.6	11.3	17.1	17.6
200% PE	290	306	23.8	23.6	215	209	11	9.1	17.1	17.2
SEm±	11.8	12.4	0.7	0.51	9.3	10.8	0.99	0.49	0.11	0.2
CD (p=0.05)	41	43	NS	NS	32	37	3.4	1.7	NS	NS
N level (kg ha^{-1})										
90	224	236	20.9	20.8	166	147	14	12.4	12.4	17.1
120	253	267	23	23	185	168	11.9	10.6	10.6	17.4
150	283	298	24.3	24.1	207	182	11.2	9.8	9.8	17.2
SEm±	10.5	11.1	0.26	0.75	7	6.9	0.72	0.39	0.39	0.2
CD (p=0.05)	31	33	0.8	2.2	21	21	2.1	1.2	1.2	NS
Interaction										
SEm±	20.4	21.5	1.2	0.88	16.1	18.6	1.72	0.85	0.19	0.35
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 2: Yield, harvest index and N uptake of aerobic rice as influenced by irrigation schedules and N levels through fertigation

Treatment	*Grain yield (kg ha^{-1})*		*Straw yield (kg ha^{-1})*		*Harvest Index*		*N uptake (kg ha^{-1})*			
							grain		*straw*	
	2011	*2012*	*2011*	*2012*	*2011*	*2012*	*2011*	*2012*	*2011*	*2012*
Irrigation schedule										
100% PE	*2474*	*3048*	*3664*	*5557*	*40.2*	*40.1*	*28.4*	*33.4*	*20.8*	*33.2*
150% PE	*3263*	*3540*	*4837*	*6852*	*40.4*	*41.3*	*41.7*	*45.3*	*27.3*	*42.7*
200% PE	*4073*	*4349*	*5783*	*8979*	*42.6*	*42.3*	*59.5*	*60.6*	*35.4*	*61.2*
SEm±	*158.1*	*142.4*	*218.9*	*374.8*	*0.58*	*0.56*	*2.52*	*2.53*	*0.92*	*4.03*
CD (p=0.05)	*546*	*492*	*756*	*1294*	*2*	*NS*	*8.7*	*8.7*	*3.2*	*13.9*
N level (kg ha^{-1})										
90	*2998*	*3199*	*4508*	*5954*	*39.8*	*39.6*	*37.4*	*37.4*	*24.2*	*38.8*
120	*3385*	*3711*	*4793*	*7301*	*41.3*	*41.5*	*43.3*	*47*	*28.2*	*41.5*
150	*3628*	*4027*	*4984*	*8133*	*42.1*	*42.6*	*48.9*	*55*	*31.1*	*56.8*
SEm±	*72.1*	*85.5*	*156*	*225.1*	*0.63*	*0.58*	*1.71*	*1.86*	*1.19*	*3.16*
CD(p=0.05)	*214*	*254*	*NS*	*669*	*1.9*	*1.7*	*5.1*	*5.5*	*3.6*	*9.4*
Interaction										
SEm±	*273.8*	*246.7*	*379.2*	*649.2*	*1.01*	*0.96*	*4.37*	*4.39*	*1.9*	*6.98*
CD (p=0.05)	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*

Table 3: Yield attributes of zero till maize as influenced by irrigation schedules and N levels through fertigation

Treatment	Barrenness (%)		No. cobs plant^{-1}		Cob length (cm)		No. of kernels cob^{-1}		Test weight (g)	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Irrigation schedule										
75% PE	5.68	5.18	1.3	1.4	17.4	19.8	506	488	29.1	29.9
100% PE	4.71	4.73	1.5	1.5	18	20.9	532	559	28.8	29.7
125% PE	4.84	4.33	1.6	1.5	18.3	22.1	553	611	29.7	30.1
SEm±	0.38	0.26	0.03	0.03	0.31	0.3	8.3	17.5	0.47	0.64
CD (p=0.05)	NS	NS	NS	NS	NS	1	29	60	NS	NS
N level (kg ha^{-1})										
120	5.07	4.8	1.5	1.5	17.1	20.1	510	503	29.3	30.3
160	5.18	4.94	1.4	1.4	18.1	20.8	528	561	28.8	29.6
200	4.98	4.5	1.5	1.5	18.4	21.9	552	593	29.4	29.8
SEm±	0.37	0.31	0.07	0.06	0.23	0.43	10.4	18.2	0.47	0.53
CD (p=0.05)	NS	NS	NS	NS	0.7	1.3	31	54	NS	NS
Interaction										
SEm±	0.67	0.45	0.05	0.05	0.54	0.52	14.3	30.2	0.81	1.1
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4: Yield, harvest index and N uptake of zero till maize as influenced by irrigation schedules and N levels through fertigation

Treatment	Kernel yield (kg ha^{-1})		Stover yield (kg ha^{-1})		Harvest Index		N uptake (kg ha^{-1})			
							Kernel		Stover	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Irrigation schedule										
75% PE	8039	9331	9861	11499	45.0	44.7	67.0	77.9	48.3	55.9
100% PE	10045	10649	12217	12793	45.2	45.5	85.9	93.0	57.2	58.5
125% PE	11345	11716	12933	13566	46.7	46.4	100.9	106.6	75.3	79.0
SEm±	455.1	332.6	617.0	354.9	0.34	0.80	3.76	3.39	2.66	3.07
CD(p=0.05)	1571.0	1148.0	2130.0	1225	1.20	NS	13.0	11.7	9.2	10.6
N level (kg ha^{-1})										
120	9168	9536	11304	11965	44.8	44.3	72.7	74.9	54.4	56.8
160	9801	10849	11565	12812	45.9	45.8	84.8	96.1	56.8	63.1
200	10461	11311	12141	13081	46.2	46.5	96.4	106.6	69.5	73.6
SEm±	171.1	318.2	256.6	543.2	0.43	0.58	1.52	4.06	3.82	3.38
CD(p=0.05)	508.0	946.0	NS	NS	NS	NS	4.50	12.10	11.40	10.00
Interaction										
SEm±	788.3	576.1	1068.7	614.6	0.59	1.38	6.52	5.86	4.61	5.32
CD(p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 5: Rice equivalent yield (kg ha^{-1}), water use (mm), water productivity (g grain kg^{-1} of water) and agronomic nitrogen use efficiency (kg grain kg^{-1} N applied) of aerobic rice - zero till maize cropping system as influenced by irrigation schedules and nitrogen levels through fertigation (mean data of two years)

Treatment Aerobicrice	Zero till maize	REY (kg ha^{-1})	Total water used (mm)	WP	ANUE
Irrigation schedule					
100% PE	75% PE	12836	718.7	1.78	47.02
150% PE	100% PE	15045	956.0	1.57	55.56
200% PE	125% PE	16993	1195.8	1.42	62.73
Nitrogen level (kg ha^{-1})					
90	120	13798	—	1.46	65.71
120	160	15133	—	1.67	54.04
150	200	15943	—	1.70	45.56

Price	Rice grain	Maize kernel
2011-12	Rs. 13.1 kg^{-1}	Rs. 13.0 kg^{-1}
2012-13	Rs. 10.8 kg^{-1}	Rs. 11.6 kg^{-1}

application under fertigation might be due to availability of N in sufficient quantities required by the crop which encouraged the increased sink formation. Fertigation leads to increased photosynthetic activity, protein synthesis and assimilate translocation resulting in more growth attributes (Ughade *et al*., 2016). Improved yield attributes through fertigation were also reported by Sharma *et al*. (2013) in guava, Vanitha and Mohandass (2014) in aerobic rice and Yanglem and Tumbare (2014) in cauliflower.

Yield and N uptake

Significant increase in grain yield was observed from 100% PE to 150% PE and then to 200% PE during both the years (Table 2). The mean grain yield increased by 24% at 150% PE over 100% PE and similar advantage was noticed at 200% PE (24%) over 150% PE. Grain yield is mostly limited by sink capacity and the ability of grain to accept assimilates (Fukai *et al*., 1991). In the present study, the grain yield increased steadily with the increased water input. Yanglem and Tumbare (2014) reported the maximum and significantly higher photosynthetic rate, stomatal conductance and transpiration rate in cauliflower at 1.2 ETc irrigation schedule compared to lower levels which resulted in higher yield. The results of the present study are also in accordance with those obtained by Mallareddy *et al*. (2013) in aerobic rice and Sharma *et al*. (2013) in guava. Similar trend was noticed in straw yield also. Higher harvest index was obtained with irrigating at 200% PE compared to 100% PE during first year but not during second year. Regarding the nitrogen levels, increasing the nitrogen supply from 90 to 150 kg ha^{-1} increased the rice yield significantly under fertigation. The highest grain yield was recorded at 150 kg ha^{-1} during both the years. It increased by 13 and 16 per cent during 2011 and 2012, respectively with the application of 120 kg N ha^{-1} over 90 kg ha^{-1}. It again increased by 7 and 9 per cent, respectively with 150 kg ha^{-1} compared to 120 kg ha^{-1}. These results are in close conformity with those of Vanitha and Mohandass (2014) and Balaji Naik *et al*. (2015) in aerobic rice. They have attributed that increased nutrient availability and absorption by the crop at the optimum moisture supply coupled with frequent nutrient supply by fertigation and consequent better formation and translocation of assimilates from source to sink might have increased the grain yield under fertigation with high N level. Farooq *et al*. (2009) opined that the shift from puddled to aerobic soil conditions brings profound changes in soil water status, aeration, soil organic matter turnover, nutrient dynamics, carbon impounding, weed flora and greenhouse gas emissions. The differences in soil N dynamics and pathways of nitrogen losses in dry sown rice system may result in different fertilizer nitrogen recoveries. Hence supplying the N matching with the requirement of the rice crop in aerobic condition is essential which is possible through fertigation. It also leads reduced N losses from the soil. N uptake by grain and straw also varied among the irrigation schedules. It was significantly increased with water input increasing from 100% PE to 200% PE during both the years of study. N uptake by grain was significantly increased from 90 to 120 kg N ha^{-1} and from there to 150 kg N ha^{-1} during both the years. In straw, N uptake increased upto 120 kg N ha^{-1} during 2011. Eventhough, it increased with the N doses in 2012, the difference between 120 and 150 kg N ha^{-1} was only significant.

Effect on zero till maize

Yield attributes

Yield attributes of zero-till maize were also influenced by irrigation schedules and nitrogen levels under drip fertigation. Significantly higher number of cobs $plant^{-1}$ and kernels cob^{-1} were recorded with 100% PE compared to 75% PE but comparable at 125% schedule during both the years of experimentation (Table 3). Cob length during second year and kernel weight cob^{-1} during both years were increased at 125% PE compared to the other two schedules. Similarly, longer cobs with more number of kernels cob^{-1} and kernel weight cob^{-1} were registered with increase in N level from 120 to 160 kg N ha^{-1} but not beyond it. Adequate soil water availability lead to both a better uptake and use of nutrients in the cell metabolic processes, increasing crop biomass, sink size and partitioning of the assimilates (Paolo and Rinaldi, 2008). N also plays an important and direct role in kernel development by regulating the enzymatic activities involved in the translocation of sucrose from stem to the developing ovaries (Below *et al*., 2000). It increases the potential sink capacity and sink growth rate (Melchiori and Caviglia, 2008). Maize yield is mainly related to kernel number per unit area (Andrade *et al*., 1999). Nitrogen levels did not influence the cobs $plant^{-1}$ during both the years. Barrenness and test weight were also not influenced by either the irrigation schedules or nitrogen levels (Table 3).

Yield and N uptake

Data illustrated in Table 4 revealed that irrigation schedules and nitrogen levels in fertigation significantly influenced the kernel yield of zero-till maize. The kernel yield was significantly increased with increase in the quantity of water applied from the irrigation schedule 75% PE to 100% PE during both the years of study. However, 100% PE and 125% PE were at par with each other. Increase in kernel yield under drip irrigation at higher levels of irrigation could be attributed mainly due to improved soil moisture status throughout the crop growth period consequently higher plant relative water content and less negative leaf water potential (Viswanatha *et al*., 2002). Plant water deficit in 75% PE treatment might have affected the final yield through its influence on various physiological processes. The magnitude of the adverse effect of plant water deficit on final yield depends on stage of the growth at which the moisture stress occurs (Salter and Goode, 1967). Among the three nitrogen levels studied, higher kernel yield was recorded at 200 kg N ha^{-1} which was superior to that of two lower doses during first year and 120 kg N ha^{-1} only during second year (Table 4). Application of 160 kg was again superior to 120 kg N ha^{-1} during both the years. Similar findings have also been reported by Ramulu *et al*. (2010), Muthukrishnan fanish. (2011) and Patil *et al*. (2012) in maize. Nitrogen fertigation with more readily available form at more frequent intervals might have resulted in higher availability of nitrogen in the soil solution which led to higher growth, uptake and better translocation of assimilates from source to sink thus in turn increased the yield (Anitta Fanish and Muthukrishnan, 2011).

Stover yield (kg ha^{-1}) of no till maize was influenced by irrigation schedules but not by the nitrogen levels (Table 4). During both the years of study, stover yield significantly increased from 75% PE to 100% PE drip schedule. The increase in stover yield at 125% PE was not significant compared to 100% PE. The harvest index of maize was influenced by irrigation schedules during the first year of study only (Table 4). It was significantly increased with 125% PE compared to the other two schedules *i.e*., 75% and 100% PE both of which were found to be at par with each other. Nitrogen uptake by kernels and stover was higher at 125% PE than that of other two schedules (Table 4). It was increased from 120 to 160 kg N ha^{-1} but not beyond it.

Interaction effects between irrigation regimes and N levels in drip fertigation

None of the yield attributes, yield and N uptake of both aerobic rice and zero-till maize were significantly influenced by interaction effects of irrigation schedules and N levels in drip-fertigation.

Effect on Aerobic rice – zero till maize cropping system

Rice equivalent yield

Total cropping system productivity of rice-maize in terms of rice equivalent yield (REY) is presented in Table 5. A perusal of the data revealed that REY (kg ha^{-1}) of rice-maize cropping system was the highest with the irrigation schedule of 200% PE to rice and 125% PE to maize crops followed by 150% PE to rice and 100% PE to maize. The lowest REY was registered with the irrigation schedule of 100% PE to rice and 75% PE to maize crop, during both the years of study. Similarly, higher REY was obtained with the application of 150 and 200 kg N ha^{-1} to rice and maize crops, respectively and the lowest in the nitrogen level of 90 and 120 kg for rice and maize crops, respectively. Similar results were reported by Kadiyala *et al*. (2012). Drip fertigation maintained favourable soil physical properties for the second crop raised without any tillage practices and disturbance to the existing drip system layout and hence increases the yield (Sampathkumar *et al*., 2012).

Water use and water productivity

Data presented in Table 5 revealed that water requirement was higher in the irrigation schedule of 200% PE - 125% PE compared to that of 100% PE - 75% PE to rice and maize crops in the sequence during both the years of experimentation. Water productivity (WP) (g grain kg^{-1} of water) differed due to drip irrigation schedules and nitrogen levels through fertigation in rice-maize cropping system during both the years (Table 5). It decreased with the increased water input but increased with the successive level of nitrogen. The highest water productivity was recorded in the irrigation schedule of 100% PE to rice and 75% PE to maize crops. It was reduced by 6.6 and 1.5 per cent in 150% PE - 100% PE schedule and 12.5 and 25.6 per cent in 200% PE - 125% PE schedule, during first and second year of study, respectively. Among the three nitrogen levels, the highest water productivity was recorded with 150 and 200 kg N ha^{-1} to rice and maize crops in the sequence which was a 7.0, 4.5 and 15.9, 16.9 per cent increase over 120 - 160 and 90 - 120 kg N ha^{-1} levels during 2011 and 2012, respectively. Similar findings were reported by Sampathkumar *et al*. (2012) in cotton-maize cropping system.

Agronomic nitrogen use efficiency

Data on agronomic nitrogen use efficiency (ANUE) (kg grain kg^{-1} N applied) are presented in Table 5. The data indicated that ANUE increased with the increase in water input but decreased with the increase in N level as was observed in the individual crops of rice-maize cropping system. During both the years of study, ANUE was more in the irrigation schedule of 200% PE - 125% PE and 90 - 120 kg N ha^{-1} to rice and maize crops, respectively. Split application of N in fertigation with much of the N applied in-season at the time of high N uptake likely contributed to high NUE (Wortmann *et al*., 2011). The results are in line with those obtained by Satish *et al*. (2010) in rice-maize cropping system and Zhang *et al*. (2010) in green pepper.

Thus in the present study conducted for two consecutive years, drip-fertigation at 200% PE with 150 kg N ha^{-1} to aerobic rice and 100% PE with 160 kg N ha^{-1} to zero till maize crops was found to be beneficial in increasing the productivity of aerobic rice - zero tillage maize cropping system.

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