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RESEARCH PAPER

Effects on yield and yield components and water productivity as influenced by drip fertigation of aerobic rice

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Abstract : Knowledge on the association of yield components with yield and among themselves will be vital in formulating effective technology development for adoption by the farmers with ease. Drip irrigation at 125% PE with 100% recommended dose of fertilizer treatment recorded significantly higher grain yield of 5643 kg ha^{-1} which was 16 per cent increase over conventional aerobic rice / control. Accordingly, same treatment recorded higher water productivity of 1.051 g grain kg $water^{-1}$ with total water applied was 537 mm. Besides this yield components *viz*., number of panicles, number of grains, spikelet fertility, grain filling rate, panicle harvest index and grain harvest index which could be improved substantially with the fertigation practice thus ultimately resulting in significant improvement in grain yield with adequate water supply.

Key Words : Drip fertigation, Panicle harvest index, Grain harvest index, Grain yield, Aerobic rice

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INTRODUCTION

In Asia, rice is the most important staple food, providing 35-80 per cent of total calorie uptake. Thus, the present and future food security of Asia depends largely on the irrigated rice production system. This ecosystem is, however, threatened by water shortage. Therefore, there is a pressure to find ways to reduce water use and increase water productivity in rice production, while maintaining higher yields. A new water saving technology is to grow rice aerobically, that is, in non-puddled and non-flooded aerobic soil with supplementary irrigation (Bouman, 2001).

In the aerobic rice culture, the amount of irrigation water applied should match evaporation from the soil and also transpiration by the plant. Since, it is not possible to apply irrigation water to the root zone only as in the case of surface irrigation, some of it is lost by deep percolation and thus is unavailable for uptake by the crop. Recent studies also indicated that rice could be successfully grown completely under aerobic conditions thereby continuous submergence and seepage and percolation losses are eliminated (Bouman, 2001). This could be easily achieved using sprinkler / drip irrigation with their field application efficiencies of more than 90 per cent in comparison with only 60-70 per cent in the case of surface irrigation (Bouman and Tuong, 2001). Besides cutting down the seepage and percolation losses, evaporation from water surface in the rice fields can also be reduced significantly with the drip system, since there is no continuous standing water layer.

In this paper, attempts have been made to illustrate the relationship between grain yield and yield attributes of aerobic rice crop and the possible role of water saving irrigation and fertilizer supplying system strategies for providing broad perspective necessary to the present study.

MATERIAL AND METHODS

Field experiment was conducted in Wetland, Tamil Nadu Agricultural University, Coimbatore, India during dry season (2007) (11^0 N, 77^0 E). The experimental plots were dry-

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ploughed and harrowed. Raised flat beds were formed and laid out with double channels around all the plots. Before sowing, the wet seeds were treated with the *Azophosmet* biofertilizer at the rate of 200 g 10 kg^{-1} of seeds and sprouted, biofertilizer treated seeds were dry-sown by hand dibbling at 3 cm depth in rows 20 cm apart and covered with soil, in the field for all the treatments except the conventional practice (T_1) at seeding rates of 30 kg ha^{-1}. A pre-emergence herbicide of pendimethalin @ 1.25 kg a.i. ha^{-1} was applied 3 days after the first irrigation and hand weeding taken at 35 days after sowing for maintaining weed free environment.

The fertigation schedule indicating the nutrient requirement at different pheonological stages and quantity of nutrients to be applied for 75, 100 and 125 per cent recommended dose of NPK (150:50:50 kg ha^{-1}), respectively. All the three fertilizers *viz*., nitrogen, phosphorus and potassium were supplied through fertigation in the form of water soluble fertilizers as per the drip fertigation treatments once in a week. In the case of conventional method (T_1), entire dose of P was applied basally before sowing. In the case of N, the recommended dose was given in four equal splits at basal, tillering, panicle initiation and first flowering; while, K was given in two equal splits at basal and panicle initiation stages. Recommended doses of $FeSO_4$ (50 kg ha^{-1}) and $ZnSO_4$ (25 kg ha^{-1}) were applied as the basal dressings before sowing in all the ten treatments. Grain yield adjusted to 14% moisture content was obtained from the whole area of the plot.

Depth or volume of irrigation water was measured using the discharge of the delivery hose connected in the pump, time of irrigation, and surface area of the plot. Calibration of water discharge from the delivery hose was done by measuring the discharged water using graduated cylinder at a certain time. It was done in a series of trials at different sections or length of delivery hose. With the given depth of irrigation, size of plot and average discharge of the delivery hose, the time of irrigation for every plot was computed. Drip fertigation treatments comprised of three water and fertilizer levels as furnished in Table 1 and 2.

For assessing the relationship between yield and its components, the following parameters were recorded at the time of harvest. The details of the method for estimating each character (Yoshida *et al*., 1971) are indicated below.

In each treatment and replication, five plants were selected and labeled and the number of tillers producing panicles was recorded. The panicles harvested from the sample plants were threshed, cleaned and the total number of spikelets was counted manually. The number of grains per panicle was worked out and the number expressed per m^2 basis. After harvest, five plants from each treatment and replication were selected and the number of filled grains per panicle was counted and the number expressed per m^2 basis. The ratio of filled grains to the total number of spikelets in the primary panicles in each hill was expressed as per cent. Ten randomly selected panicles from the main tillers in each treatment and replication were dried and their weight was taken. The values were given in g $panicle^{-1}$. Panicle harvest index (PHI) was calculated by using the following formula as suggested by Lafitte *et al.* (2003) and expressed as percentage. PHI = (Grain weight / Weight of the panicle) x 100.

The grains were dried in oven at 80 ± 12°C for 24 h and 1000 grain weight for each treatment (in five replications) was recorded. The average was arrived and expressed in g. The yield of grain per plot of each treatment and replication was recorded from the net plot and expressed as g $plot^{-1}$. After thrashing the grains, weight of the straw was taken and expressed as g $plot^{-1}$. Grain yield per hectare was calculated from the mean plot yield and expressed in kg ha^{-1}. Grain harvest index (GHI) was calculated from the dry weight of grain and total dry weight $hill^{-1}$ at harvest by using the formula of Yoshida *et al*. (1971) as given below and expressed in percentage. GHI = (Economic yield/ Biological yield) x 100. Water productivity was calculated as the weight of grains produced per unit of water input (irrigation and rainfall) as per the following formula of Yang *et al*. (2005) and expressed as g grain kg^{-1} water. Water productivity = Grain yield / (Irrigation + Rainfall).

The data collected were subjected to statistical analyses in the randomized block design using ANOVA (AGRES version 7.01) following the method of Gomez and Gomez (1984). Correlation coefficient ('r') was worked out wherever by adopting the procedure of Heady and Dillon (1961) using INDOSTAT, Hyderabad package.

RESULTS AND DISCUSSION

Grain yield is the final manifestation of several complex morpho-physiological processes in the plants, which is often influenced by various metabolic processes. Number of panicles per unit land area, the dominant yield component influencing grain yield, linearly decreased with the number of tillers per square meter (Cruz *et al.*, 1986). In the present study, panicle number m^{-2} as influenced by the treatments showed (Table 1) that the drip fertigation treatment at 125 % PE + 100 % RDF registered significantly higher panicles (407), while the least panicles (258) were produced with the drip fertigation scheduled at 100 % PE + 75 % RDF. Similar reduction of productive tillers due to water stress was observed by Ichwantori *et al*. (1999). Nevertheless, lesser tiller number with higher panicle weight was considered as the important character for augmenting the yield (Bhattacharya and Ghosh, 2004).

Nevertheless, this hypothesis was slightly deviated in the present investigation that moderate number of panicles with increased panicle weight did not translate into yield especially in higher moisture regime. Increased panicle weight of 2.92 g was recorded with the drip fertigation treatment at 150 % PE + 125 % RDF (T_{10}) level, but was comparable with T_1 (2.85) and T_9 (2.80). Increase in the number of productive tillers and mean panicle weight with the use of biofertigation was clearly evident especially at 100 % RDF. This could be due to the favourable plant water relations (Mohandass *et al*., 1988) as observed in the present study.

Number of spikelets, an important yield component decided during PI and for determining the grain number during anthesis, was found to be reduced with decreased water supply (Rajkumar, 2001). Increased number of spikelets were produced when drip fertigation was given at 125 % PE + 125 % RDF (34.06), which was comparable with the fertigation treatment scheduled at 125 % PE + 100 % RDF (33.86). Use of fertigation was favourable with increased number of spikelets per unit area. This was more prominent for higher category of 100 and 125 % RDF.

Production of grains and their filling percentage was significantly influenced by the irrigation regimes and fertilizer levels. Nevertheless, the drip irrigation treatment given at 125% PE level was better placed than drier or wetter moisture regimes. Similar results were observed by Lanceras *et al*. (2004) indicating that the drought stress occurring during the reproductive stage (as observed with 100 % PE level) increased the per cent spikelet sterility and consequently decreased the grain yield. Increased grain number (29.88) was evident with the drip fertigation scheduling of 125% PE + 100% RDF, which was significantly superior to the rest of the treatments studied. Least grain production was observed with the treatment receiving 100 % PE + 75 % RDF level (T_2: 20.71). Further evidence was also reported by Boonjung and Fukai (1996), in which the yield reduction to the tune of 40 per cent was due to the increment of per cent spikelet sterility when drought occurred during grain filling period (Jongdee *et al*., 2002).

Since the water stress caused abnormalities of gamete formation (Namuco and O'Toole, 1986) and panicle exertion (O'Toole and Namuco, 1983; Cruz and O'Toole, 1984), the reduction in the number of filled grains produced and its percentage as noticed in the present investigation could be reasonable with distinct variations among the fertigation treatments. Towards this, the unfavourable situation faced by the treatment of 100 % PE and at 75 % RDF level might be due to the embryo abortion owing to the perturbation of consequential events such as gamete production, poor panicle growth and exertion, anthesis and fertilization under stressed scenario (Saini and Lalonde, 1996). They further highlighted that the changes in carbohydrate levels and enzyme activities associated with the inhibition of starch as well as solute accumulation in the cells of pollen, were some of the potential causes of spikelet sterility due to lower osmotic adjustment.

With regard to panicle harvest index (PHI), a reliable parameter for assessing the degree of spikelet fertility, the values were greatly influenced by the water as well as fertilizer levels. Higher PHI (85.12) was evident with the drip fertigation treatment at 125 % PE + 100 % RDF (T_6), which was also comparable with T_9 (84.28), T_7 (84.23), T_5 (84.02), T_1 (82.71) and T_8 (82.69), which might be attributable to higher filled grain percentage as observed by Lafitte *et al*. (2003) for water stressed transplanted rice and Gowri (2005) for aerobic environment. The positive role of biofertigation practice used in the present study in registering higher values of PHI with moderate level of fertilizers (125 % RDF) was also worth mentioning especially under the conditions of drip fertigation practice.

Table 1 : Yield and yield components as influenced by drip fertigation treatments in PMK (R) 3 rice under aerobic condition

Treatments		Panicle Nos. m^{-2}	Spikelet Nos. $x10^3$ m^{-2}	Grain Nos. $x10^3 m^{-2}$	Filled grain (%)	Mean panicle weight (g)	Panicle harvest index (%)	1000 grain weight (g)	Grain Yield (kg ha^{-1})	Harvest Index (%)
T_1:	Conventional method	351	30.12	26.53	88.08	2.85	82.71	24.55	4865	42.64
T_2:	100 % PE + 75 % RDF	258	26.89	20.71	77.02	2.07	75.56	22.41	3470	36.30
T_3:	100 % PE + 100 % RDF	280	28.06	22.89	81.58	2.28	76.36	22.86	3885	36.76
T_4:	100 % PE + 125 % RDF	289	29.25	23.14	79.11	2.31	74.01	23.01	4004	37.34
T_5:	125 % PE + 75 % RDF	350	29.12	24.79	85.12	2.08	84.02	24.00	4853	46.42
T_6:	125 % PE + 100 % RDF	407	33.86	29.88	88.25	2.31	85.12	24.78	5643	46.79
T_7:	125 % PE + 125 % RDF	368	34.06	27.73	81.42	2.33	84.23	24.12	5107	41.55
T_8:	150 % PE + 75 % RDF	357	29.74	25.68	86.36	2.67	82.69	24.56	4806	40.91
T_9:	150 % PE + 100 % RDF	375	30.46	26.52	87.07	2.80	84.28	24.55	5207	40.49
T_{10}:	150 % PE + 125 % RDF	366	31.34	25.29	80.70	2.92	80.36	24.08	5077	37.88
	Mean	340	30.29	25.32	83.47	2.46	80.93	23.89	4692	40.71
	S.E.±	8.2	0.716	0.605	1.957	0.058	1.901	0.559	113.0	0.970
	C.D. (P=0.05)	17.2**	1..504**	1.272**	4.111**	0.121**	3.994**	1.174**	237.4**	2.039**

data expressed in the percentage are given a transformed values

The test weight of grains (1000 grain weight) is an important parameter influencing grain yield of rice, showed wide variations in the drip fertigation system. Fertigation had proved to be beneficial in enhancing the test weight due to higher rate of filling of developing grains because of increased translocation efficiency for photoassimilates. Higher weight of 24.78 g the drip fertigation treatment at 125 % PE + 100 % RDF (T_6), which was at par with T_1, T_5, T_7, T_8, T_9 and T_{10}.

The harvest index (HI), proportion of total biomass partitioned to the developing spikelets, showed distinct variations for irrigation as well as fertilizer levels. With regard to the grain HI, significantly superior value of 46.79 per cent was recorded (Table 1) with the drip fertigation schedule of 125 % PE + 100 % RDF which was comparable with the treatment schedule of 125 % PE + 75 % RDF (46.42).

Nevertheless, Lanceras *et al*. (2004) indicated that the correlation between grain yield and HI increased dramatically as the drought stress increased, indicating that HI would be a primary determinant of grain yield under stress. Similar positive association between HI and grain yield was evident in the present investigation (r = 0.747**) (Table 3). Therefore, genetic improvement of HI would also improve grain yield in rice (Fukai *et al*., 1999; Babu *et al*., 2003) for the low water and fertilizer supplying situations. Thus, the general effect of drip fertigation treatment in increasing the values of HI under medium supply of water and fertilizer situations might be attributed to the fact of producing larger sink size and efficient transport of assimilates from leaves and stems (‘source’) into developing spikelets (‘sinks’) thus resulting in the increased grain yield.

The grain yield of rice is often influenced by sink capacity rather than source strength under stress-free environment (Fukai *et al*., 1991). Significantly higher grain yield of 5643 kg ha^{-1} was registered with the drip fertigation schedule at 125 % PE + 100 % RDF to the rest of the treatments tried. However, this was closely followed by the drip fertigation given at 150 % PE + 100 % RDF level (5207 kg ha^{-1}).

Conversely, limited water supply during reproductive and ripening phases appeared to affect the reproductive physiology by interfering with the pollination, fertilization and grain filling (Wann, 1978) and thus resulting in drastic reduction in the grain yield of the stressed plants of rice crop. Similar observation of yield reduction was noticed in both the low water as well as fertilizer supplying treatments. Earlier studies also indicated that the prevalence of water shortage during reproductive stage (terminal drought) was more detrimental for both transplanted (Maibangsa, 1998)

Table 2 : Parameters of water input and its use as influenced by drip fertigation under aerobic condition

Treatments		Irrigation water applied (mm)	Effective rainfall (mm)	Total water applied (mm)	Water productivity (g grains kg^{-1} water)
T_1:	Conventional method	390	121	511	0.952
T_2:	100 % PE + 75 % RDF	345	121	466	0.745
T_3:	100 % PE + 100 % RDF	345	121	466	0.834
T_4:	100 % PE + 125 % RDF	345	121	466	0.859
T_5:	125 % PE + 75 % RDF	416	121	537	0.904
T_6:	125 % PE + 100 % RDF	416	121	537	1.051
T_7:	125 % PE + 125 % RDF	416	121	537	0.951
T_8:	150 % PE + 75 % RDF	487	121	608	0.790
T_9:	150 % PE + 100 % RDF	487	121	608	0.856
T_{10}:	150 % PE + 125 % RDF	487	121	608	0.835

Table 3 : Correlations for yield attributes and yield as influenced by drip fertigation treatments **(n = 27)**

Parameters	Panicles	Spikelets	Grains	Filled grain %	Panicle weight	Test weight	Panicle HI	HI	Yield
Panicles	1								
Spikelets	0.831**	1							
Grains	0.943**	0.911**	1						
Filled grain %	0.738**	0.490**	0.756**	1					
Panicle weight	0.489**	0.298	0.391*	0.453*	1				
Test weight	0.861**	0.722**	0.844**	0.898**	0.578**	1			
Panicle HI	0.883**	0.721**	0.849**	0.841**	0.360	0.918**	1		
HI	0.748**	0.578**	0.759**	0.775**	-0.021	0.721**	0.829**	1	
Yield	0.997**	0.841**	0.946**	0.729**	0.484**	0.849**	0.873**	0.747**	1

and also for aerobic rice (Gowri, 2005). The reduction in yield under water stress was associated with reduced number of spikelets, filled grain percentage and number of panicles per unit area. Nevertheless, supplementation of fertigation was able to narrow down the yield reduction especially under limited water supply (as in 100 % PE) situation.

Water use (mm) and water productivity (g grains kg^{-1} water) results indicated that the total water applied through drip system was 466, 537 and 608 mm for 100, 125 and 150 % PE level, respectively. In the case of conventional method of irrigation (T_1), a total quantity of 511 mm of water was applied. With regard to the water productivity (Table 2), higher water productivity of 1.051 grains kg^{-1} water was obtained with the drip fertigation schedule of 125 % PE + 100 % RDF. The conventional method of irrigation and fertilizer application registered a moderate water productivity of 0.952 grains kg^{-1} water applied.

The grain yield grown under drip fertigation practice was significantly and positively correlated (Table 3) with all the yield attributes such as number of panicles per unit area (0.997**), grain number per unit area (0.946**), panicle HI (0.873**), 1000 grain weight (0.849**), spikelet number per unit area (0.841**), HI (0.747**) and filled grain percentage (0.729**) and mean panicle weight (0.484**).

Conclusions:

The major yield attributes such as panicle number, spikelet and grain number, filled grain percentage, 1000 grain weight, grain filling rate, panicle harvest index (PHI) and grain harvest index (HI) were sufficiently improved with the drip fertigation system. Ultimately, the increase in grain yield was more pronounced in the drip fertigation practice than the conventional method of irrigation and fertilizer application.

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