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Relatively Simple Irrigation Scheduling and N Application Enhances the Productivity of Aerobic Rice (*Oryza sativa* L.)

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Abstract: A Field experiment was conducted at wetlands (*Vertic Ustochrept*), Agricultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore during *Kharif* (June to October) season of 2005, to ascertain the optimum irrigation method and nitrogen dose to enhance aerobic rice (*Oryza sativa* L.) productivity with PMK 3 cultivar. Four irrigation regimes *viz*., irrigation at IW/CPE ratio of 0.8, 1.0, 1.2 and micro sprinkler irrigation once in three days, four N levels *viz*., 100, 125, 150 and 175 kg ha^{-1} were tested in strip-plot design with three replications. Irrigation at 1.2 IW/CPE ratio recorded significantly higher crop growth rate and yield with no moisture stress, minimal proline accumulation and sterility coefficient. N levels followed the quadratic response (R^2>0.973), with 150 and 175 kg N ha^{-1} produced on par growth and yield. Hence, irrigation at 1.2 IW/CPE ratio with 150 kg N ha^{-1} will be optimum to realise the maximum productivity under aerobic rice cultivation.

Key words: Aerobic rice, IW/CPE ratio, nitrogen application, proline, crop growth rate, sterility co-efficient

INTRODUCTION

Among the crops cultivated, rice crop consumes the maximum of about 90% of the fresh water resources in Asia used for agriculture which threatens the sustainability of flooded rice (Barker *et al*., 1999; Gorantla *et al*., 2005). To match with ever increasing food grain demand with less and less water, the term Aerobic rice was coined by IRRI, which means growing high yielding rice in non-puddled and non-flooded aerobic soil with the support of external inputs like supplementary irrigation and fertilizers (Bouman *et al*., 2002). Aerobic rice has its own advantages and disadvantages, as water use seems to be 60% less than that of flooded rice, requires less labour (55%) and can be highly mechanized than low land rice (Wang *et al*., 2002). But yields of aerobic rice said to be 20-30% lower than that flooded rice (Belder *et al*., 2005) without realizing the fact that number of research attempts to tap the maximum potential of aerobic rice with suitable management strategies is meagre.

Most researchers primarily focused on the advantages of flooded rice like neutralization of low or high soil pH and certain favorable changes in soil chemistry (Sanchez, 1976). Less attention gets paid to the countervailing benefits of aerobic soil conditions or to the negative effects of hypoxia (flooded condition). Standing water decreases redox potential and reduces roots ability to respire, consequently slowing their metabolism, ion transport and growth (Jayakumar *et al*., 2005). The reduced soil condition with hypoxia often increases methane production becomes major issue to the environmentalist and solubilize Fe^{2+} and Mn^{2+} often beyond optimum levels for plant growth (Savithri *et al*., 1999).

Nitrogen is pivotal in yield realization of irrigated rice ecosystems. Available N as NH_4^+ ion ought to be more beneficial to plants as a source of nitrogen because NH_4^+ requires less energy to metabolize

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than does NO_3^-. In flooded rice soil, NH_4^+ ions forms the major source of N whereas in aerated soil NO_3^- ion is more common. Kronzucker *et al*. (1999) reported that N as NO_3^- produces 40 to 70% more yield than an equal amount of N as NH_4^+ and those combinations of NH_4^+ and NO_3^- lead to better yields than provision of either N by itself. Thus growing aerobic rice with alternating wetting and drying seems to be more beneficial than continuous flooding (Ceesay and Uphoff, 2002).

With these perspectives, here we present evidence of increased aerobic rice yield under relatively simple irrigation scheduling method and nitrogen management practice on a promising aerobic rice cultivar PMK 3.

MATERIALS AND METHODS

Experimental Site and Initial Soil Characteristics

A Field experiment was conducted at wetlands, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore during *Kharif* (June to October) season of 2005, to ascertain the possible irrigation and nitrogen management practices to enhance aerobic rice productivity. The farm is situated in Western agro-climatic zone of Tamil Nadu at 11°N latitude and 77°E longitudes at an elevation of 426.7 m above the mean sea level. Soil of the experimental site was clay textured (68.7% clay, 18.1% silt, 7.3% coarse sand, 5.9% fine sand) belonging to Noyyal series, classified as *Vertic Ustochrept*. The soil analysed 246, 22.2 and 523.6 kg ha^{-1} of $KMnO_4$-N, Olsen-P and NH_4OAc-K, respectively with organic carbon content of 0.53%, EC of 0.65 dS m^{-1} and pH of 6.7. The irrigation water used in this study was neutral in reaction (pH = 7.76) with medium level of soluble salts (EC = 1.21 dS m^{-1}).

Selection of Cultivar, Experimental Design, Sowing and Fertilizer Schedule

Based on promising performance under previous irrigation and fertilizer response screening experiment (data not sown) cultivar PMK 3 (UPLRI X CO 43) was selected for this particular study. This variety is characterised by semi-dwarf, non-lodging, drought tolerant, early maturing (110-115 days) and fertiliser responsive.

Experiment was conducted in strip-plot design with 3 replications. Main plot treatments include four irrigation regimes *viz*., irrigation at IW/CPE ratio of 0.8, 1.0, 1.2 and micro sprinkler irrigation once in three days with the discharge rate of 120 L h^{-1}. These main plots were superimposed with 4 levels of N *viz*., 100, 125, 150 and 175 kg ha^{-1} as subplots (6×3 m^2).

Rice cultivar PMK 3 was direct-dry seeded in non-puddled soil with the spacing of 20×10 cm by adopting the seed rate of 60 kg ha^{-1}. Two weeks later the plots were thinned to maintain uniform population. The entire dose (50 kg ha^{-1}) of P_2O_5 as single super phosphate, zinc sulphate and $FeSO_4$ at the rate of 25 kg ha^{-1} each and gypsum at the rate of 500 kg ha^{-1} were applied basally to all the plots. Later foliar spray of 2% $FeSO_4$ was given at tillering and panicle initiation (PI) stages as the crop showed iron deficiency symptom. K_2O (50 kg ha^{-1}) as muriate of potash were applied in four equal splits at 20 DAS, tillering, panicle initiation and heading stages.

Irrigation Scheduling and N Fertiliser Application

As neutron probing, gravimetric moisture determination methods found to be laborious, time consuming and expensive, the relatively simple, inexpensive, practicable climatological approach (Prihar *et al*., 1976) was followed to schedule the irrigation. Thirty millimeter depth of Irrigation Water (IW) was given when the Cumulative Pan Evaporation (CPE) reached the level of 37.5, 30 and 25 mm in order to get IW/ CPE ratio of 0.8, 1.0 and 1.2, respectively. By multiplying the depth of irrigation (30 mm) and area of the plot (6×3 m^2), the volume of water required for each plot was arrived. Calculated volume of water was irrigated to each plot by measuring through Parshall flume set up at

Table 1: Summary of irrigation treatments and their effects on yield and water productivity

Irrigation treatments	No. of irrigations	Total water used (mm)	Yield ($kg\ ha^{-1}$) Grain	Straw	Water productivity ($kg\ rice\ ha\ mm^{-1}$)
IW/CPE ratio 0.8	15	498	4289^c	6823^b	8.61
IW/CPE ratio 1.0	18	556	4776^b	7624^a	8.58
IW/CPE ratio 1.2	21	618	4916^a	7804^a	7.95
Micro sprinkler	25	659	1888^d	2948^c	2.86

Within each column the treatments sharing common alphabet are not statistically significant at 5% level

the experimental field. Micro sprinkler discharge time also adjusted based on the volume of water required and irrigation was given once in three days. Total water consumed by each irrigation treatment was summarized in Table 1.

Nitrogenous fertiliser treatments were given as urea in four equal splits at 20 DAS, tillering, panicle initiation and heading stages.

Sampling, Biometrics and Yield Observations

Sampling and biometric observations were done at important physiological crop growth stages *viz*., panicle initiation (PI), flowering and maturity stage. Root volume was measured by placing the oven dried roots into a measuring cylinder containing known volume of water. By measuring the increase in the water column, root volume was assessed and expressed in CC per plant. Productive tillers per m^2 were recorded during the maturity stage. During the harvest, fresh grain and straw yield were recorded then they were expressed on oven dry (70°C for 4 days) basis.

Proline Analyses, Crop Growth Rate (CGR), Water Productivity, Sterility Percentage Calculation

The free proline concentration was determined at panicle initiation (PI), flowering and maturity stage by adopting rapid determination method described by Bates *et al.* (1973) and expressed in μ moles g^{-1} fresh weight.

The crop growth rate (CGR) was calculated by using the formula of Watson (1956) and expressed in $g\ m^{-2}\ day^{-1}$.

$$CGR = \frac{W_2 - W_1}{P(t_2 - t_1)}$$

where, W_1 and W_2-Whole plant dry weight at time t_1 and t_2 respectively; t_2 and t_1-Time in days; P-Ground area occupied by plant (m^2).

The water productivity (WP) was worked out from the yield of paddy and the amount of water used and expressed in $kg\ ha\ mm^{-1}$

$$WP = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{Total water requirement (ha mm)}}$$

The sterility coefficient was calculated by working out ratio of unfilled grains to the total number of grains in the panicle and expressed as percentage.

Statistical Analysis

All the recorded data were analysed statistically as per the method suggested by Gomez and Gomez (1984). Wherever the treatment differences were significant, critical differences were calculated at five per cent probability level and used for interpretations.

RESULTS AND DISCUSSION

Results of irrigation treatments on moisture stress, growth parameters, proline accumulation, sterility coefficient, yield and water productivity discussed here under.

Moisture Stress

High water consumption observed under micro sprinkler irrigation due to high irrigation frequency (once in three days), followed by 1.2, 1.0 and 0.8 IW/CPE ratios (Table 1). Though micro sprinkler consumed more water, the contribution to wet top 15 cm soil was less (data not shown), there by plants experienced highest moisture stress than 1.2, 1.0 and 0.8 IW/CPE ratios.

Growth Parameters

The growth parameters like plant height, root volume, crop growth rate and productive tillers increased significantly under irrigation at IW/CPE ratio 1.2 followed by 1.0 and 0.8 IW/CPE ratios and micro sprinkler irrigation (Table 2). The reduction in growth parameters increased with severity of water stress (Adriano *et al*., 2005; Gowri, 2005) as water deficit reinforce many anatomical changes in the plant, include decrease in cell volume, cell division, cell elongation, intercellular space and thickening of cell wall thereby limits over all plant growth. Similar observations made by Prasad *et al.* (1987) and Banga *et al.* (1994) in maize. The observed increase in root volume under 1.2 IW/CPE ratio was due to root thickening and dense proliferation of root at the top layer in response to lower water stress (Vijayalakshmi and Nagarajan, 1994). The higher crop growth rate (CGR) under 1.2 IW/CPE ratio could be due to beneficial effect of water in maintaining normal cell turgidity, cell elongation and functioning of biopolymers apart from enhancing nutrient uptake (Singh 2004). Under 1.0 and 0.8 IW/CPE ratios the reduction in CGR might be due to the inhibition of physiological activities by water stress condition (Zhang *et al*., 1997; Gowri, 2005).

Proline Accumulation

Increased proline content observed with decreasing moisture level (Fig. 1) might be due to the transcriptional activation of the NADPH-dependent PSC5 (Babiychuk *et al*., 1996) and the concomitant increase in protease activity, which induce the breakdown of proteins under water stress conditions (Agarwal *et al*., 1995; Jain *et al*., 1996). The accumulated proline, because of its zwitterionic and highly hydrophilic character, acts as a compatible solute (Sampras *et al*., 1995), stabilizes sub cellular structures (Chain and Dandekar, 1995), aid in solubility of proteins and other biopolymers. This helps to maintain turgor pressure of both root and shoot while plant experiencing water stress (Ludlow and Muchaw, 1990).

Table 2: Effect of irrigation and nitrogen treatments on plant height, root volume, productive tillers and crop growth rate

Treatments	Observations at maturity stage: Plant height (cm)	Root volume (cc plant^{-1})	Productive tillers (m^{-2})	Crop growth rate (50-80 DAS) (g m^{-2} day^{-1})
Irrigation				
IW/CPE ratio 0.8	88.48^{c}	24.79^{c}	295.1^{c}	1.33^{bc}
IW/CPE ratio 1.0	89.93^{b}	26.17^{b}	329.2^{b}	1.41^{b}
IW/CPE ratio 1.2	92.74^{a}	29.33^{a}	361.9^{a}	1.57^{a}
Micro sprinkler	83.61^{d}	22.09^{d}	284.3^{d}	1.29^{c}
N levels				
N_{100}	85.73^{d}	23.43^{c}	301.5^{d}	1.30^{b}
N_{125}	87.95^{c}	24.88^{b}	308.4^{c}	1.35^{b}
N_{150}	90.10^{b}	26.68^{a}	326.6^{b}	1.47^{a}
N_{175}	91.00^{a}	27.39^{a}	333.9^{a}	1.49^{a}

Within each column the treatments sharing common alphabet are not statistically significant at 5% level. Irrigation and N level interactions are not significant

Sterility Coefficient

Retention of spikelet fertility appears important in maintaining high grain yield under flowering stage drought (Garrity and O'Toole, 1994). In this study sterility coefficient increased with severity of water stress (Fig. 2). This is in accordance with the findings of Gowri (2005) as water stress affects many complex and phenologically increasing biochemical and physiological events between panicle initiation and grain filling leads to abnormalities in gamete formation (Namuco and O'Toole, 1986) and panicle exertion (O'Toole and Namuco, 1983; Cruz and O'Toole, 1984).

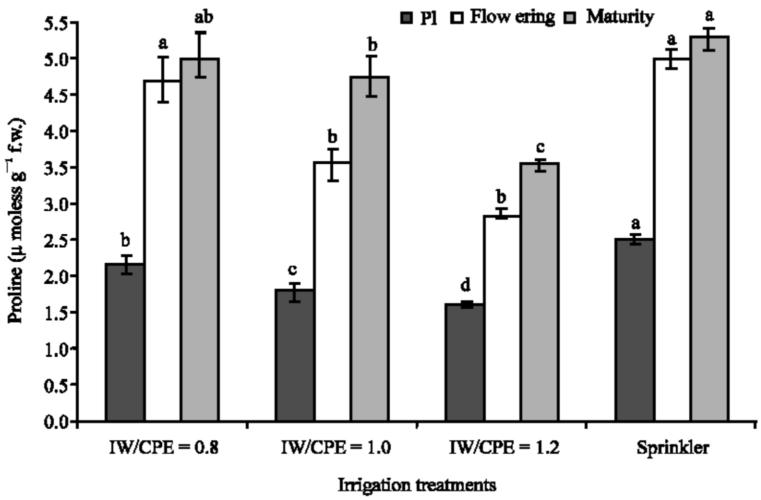

Fig. 1: Proline accumulation pattern under different irrigation treatments at different crop growth stages (within each growth stage the treatments sharing common alphabet are not statistically significant at 5% level)

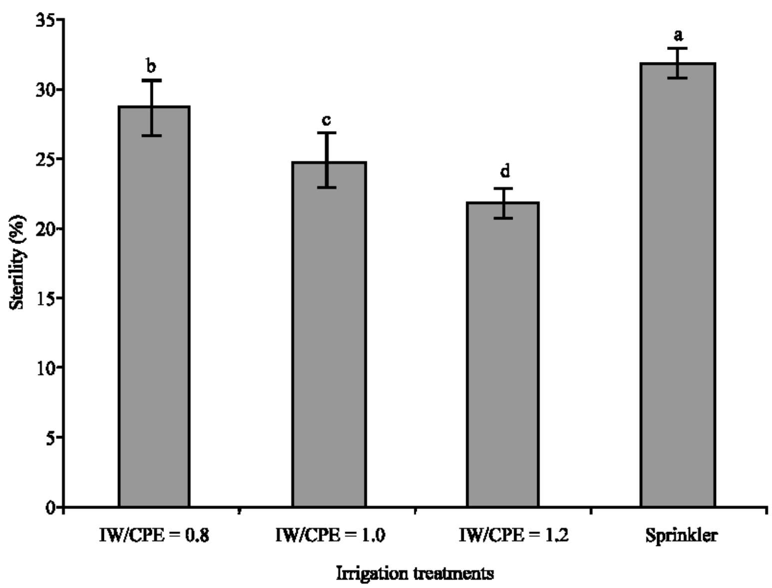

Fig. 2: Sterility percentage under different irrigation treatments (the treatments sharing common alphabet are not statistically significant at 5% level)

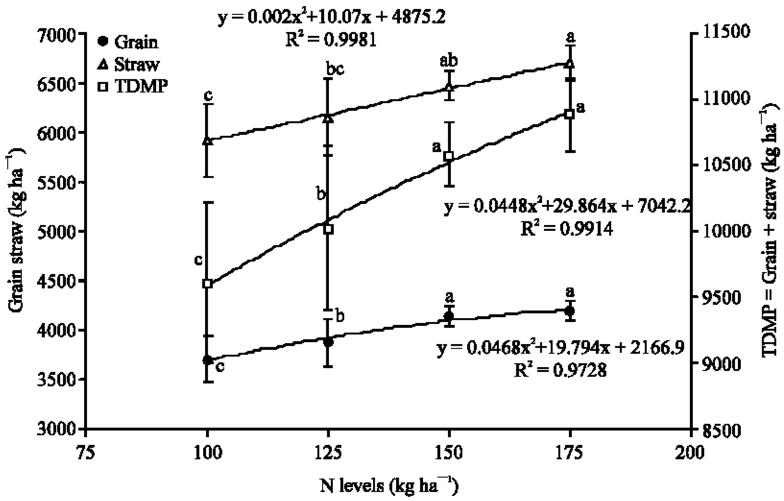

Fig. 3: Response of TDMP, grain and straw yield to N levels (the N levels sharing common alphabet are not statistically significant at 5% level)

Yield and Water Productivity

As 1.2 IW/CPE ratio produced more plant height, root volume, CGR and productive tillers, inturn yield also found to be higher (Table 1) in this irrigation regime followed by 1.0 and 0.8 IW/CPE ratios and micro sprinkler irrigation. This is clearly because of moisture stress as explained by low proline accumulation (Fig. 1) and sterility coefficient (Fig. 2) under 1.2 IW/CPE ratio irrigation regime. Though yield at 0.8 IW/CPE ratio was 13% lower when compared to 1.2 IW/CPE ratio, recorded highest water productivity (Table 1) implies water productivity may not be a accurate measure for experiments aiming for maximum growth and yield. It is supported by Tuong *et al.* (2004) and Belder *et al.* (2005) as they observed decreasing water productivity with increasing levels of irrigation.

Effect of N Levels on Growth and Yield

Application of 175 kg N ha^{-1} recorded the highest values in growth parameters *viz.*, plant height, root volume, CGR and productive tillers. Because, application of higher N levels resulted in taller plants and larger leaf area (data not shown), which increased the photosynthate production, inturn enhanced CGR and yield (Valarmathi, 1994). However, in the present investigation, the root volume and CGR showed a significant increase with N levels upto 150 kg ha^{-1} (Table 2) and beyond this level, the magnitude of increase was only marginal following the Mitcherlich's law of diminishing returns. Similar results were reported by Rajeswari (1990) in rice and Zhao *et al.* (2005) in sorghum. Total dry matter production (TDMP), grain and straw yield exhibited nice quadratic response with high R^2 values (>0.973) for N levels (Fig. 3). But all the above were in on par with 150 kg N ha^{-1}. Hence, 150 kg N ha^{-1} might be the economic optimum to realise maximum yield under aerobic rice cultivation.

CONCLUSIONS

Irrigation at 1.2 IW/CPE ratio significantly produced higher growth and yield with minimal proline accumulation and sterility coefficient. N levels followed the quadratic response, with 150 and 175 kg N ha^{-1} produced on par growth and yield. Hence, scheduling of irrigation at 1.2 IW/CPE along with 150 kg N ha^{-1} is proposed to realise maximum yield with PMK 3 cultivar under aerobic rice cultivation.

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