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Water regimes and phosphorus on dry matter production, root porosity, transpiration and ion uptake of *kharif* rice (*Oryza sativa* L.)

N.K. Das[1,2], A.K. Saha[1] and Partha Pratim Adhikary[2,3]

[1]*Uttar Banga Krishi Viswavidyalaya, Pundibari-736165, Cooch Behar, West Bengal;* [2]*ICAR-Indian Institute of Soil and Water Conservation, Research Centre, Sunabeda, Koraput-763002, Odisha.*
[3]*E-mail: ppadhikary@gmail.com*

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ABSTRACT

A pot experiment was conducted on clay loam soil to study the influence of phosphorus and water regimes on dry matter production, root porosity, transpiration and nutrient uptake of rice, grown under flooding and field capacity. The results revealed that root porosity, transpiration, nutrient uptake, dry matter production and grain yield of rice increased greatly with increase in levels of phosphorus and soil water regime. With the increase of phosphorus level from 0 to 60 kg ha^{-1}, dry weight of shoot at harvest was increased by 1.68 times under flooding and 1.40 times under field capacity. The total amount of water transpired by rice plant under flooding was 1.85 to 1.95 times more than under field capacity. Positive correlation was also obtained between the amount of water transpired day^{-1} pot^{-1} and the total root porosity and nutrient uptake. The uptake of N, P, K, Ca was slow up to 30th Days After Transplanting (DAT) and for Mg, up to 60th DAT except in P level of 60 kg ha^{-1} under flooding. Although the uptake of nutrients continued up to the final stage of harvest, but, the rate of uptake was maximum between 30th and 90th DAT for N, 60th and 90th DAT for P, K, Ca and Mg. The uptake of all the nutrients (N, P, K, Ca, and Mg) increased with increase in soil water regimes and plan growth. More availability of nutrients in soil together with greater transpiration of water and ion facilitated by increased root porosity might have increased nutrient uptake resulting increase in dry matter production and yield of rice plant with increase in levels of phosphorus under flooded condition.

1. INTRODUCTION

Rice (*Oryza sativa* L.) is one of the chief grains of India. Moreover, India has the largest area under rice cultivation, as it is one of the principal food crops. India is one of the leading producers of rice and being a tropical plant, it flourishes comfortably in hot and humid climate. Rice is grown in all the states of India under diverse agro-climatic conditions from below the sea level in Kerala to an altitude of 3000 m in Uttarakhand (Samal *et al*., 2012). Rice consumes much more water than other cereals and nearly 3000-5000 litres of water is required to produce one kg of rice (Bouman, 2009). The projected demand for rice in India will be 113 M tonnes by 2020-21 and to achieve this target, the projected productivity of rice (un-milled) has to be 4 tonnes ha^{-1} (Kumar *et al*., 2009).

Morphologically rice is a non aquatic plant, yet rice plant thrives better under flooded condition (Mandal *et al*., 1991; Singh *et al*., 1997). Better growth of rice under flooded condition may be due to increased nutrient uptake as a result of increased availability of nutrient in soil (Ponnamperuma, 1984; Roger, 1996), change in root growth (Bingsong *et al*., 2006) and root porosity. Flooding develop inducible aerenchyma in addition to the constitutive aerenchyma to facilitate oxygen transport through plants and poor aeration of soils increases root porosity (Gibberd *et al*., 1999). Phosphorus has also a great role in the growth and development of root and influence root porosity (Lopez Bucio *et al.,* 2003; Chevalier *et al.,* 2003).

Although a huge amount of research was done on the effect of water regimes (Sharma *et al*., 2012) and integrated nutrient management (Sepehya *et al*., 2012) on rice yield, but the cause of better growth under flooding condition and increased levels of phosphorus is not clearly understood. Very little work has been done to know the effect of soil water regimes and phosphorus levels on the anatomical changes like root porosity and physiological process like transpiration which might have increased the growth of rice plant by transferring more amounts of water and nutrient elements. The present study was therefore, carried out with the objectives, (i) to ascertain the influence of phosphorous and soil water regimes on root porosity and transpiration; and (ii) to assess the effect of phosphorous and soil water regimes on nutrient uptake and dry matter production of rice plant at different stages of growth.

2. MATERIALS AND METHODS

Experimental Site

A pot culture experiment was conducted during *kharif* seasons (June-September) of 2005-06 and 2006-07 in the glasshouse of Teaching and Instructional Farm of Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, (Terai Region of West Bengal) situated at 26°19′ N latitude and 89°23′ E longitude with an altitude of 43 m above msl. The study area comes under tropical and sub-humid to humid type of climate, with annual mean maximum and minimum temperatures of 32.5°C and 20.2°C, respectively. Mean annual rainfall is 3201 mm, which is characterized by heavy rainfall during the monsoon and slight rainfall in the month of October to mid-November.

Rice Cultivation in Glasshouse

Twenty days old three rice seedlings of *Ranjit* variety were transplanted in the plastic pots containing 6 kg soil (air dried 2 mm sieved). The basic physico-chemical properties of the soil are presented in Table 1. To maintain the adequate fertility level, N and K were applied @ 40 kg N ha^{-1} as urea and 40 kg K_2O ha^{-1} as muriate of potash, respectively. P was applied @ 0, 20, 40 and 60 kg P_2O_5 ha^{-1} as single super phosphate before transplanting under two different moisture levels *viz.* flooding (FD) and field capacity (FC). The moisture content at FC (30.5%) was maintained by replenishing with water after weighing the pot every day. Evaporation and evapotranspiration were measured by weighing the loss in weight of the pot every day without plant and with plant, respectively. Root and shoots were collected at the time of transplanting the seedling and at different stages of growth like 30, 60, 90 days after transplanting (DAT) and at harvesting stage. Shoots were dried in an oven at 70°C and dry weight was recorded. The dry samples were grinded, digested and analyzed for N, P, K, Ca and Mg by standard methods (Table 1). Root porosity (volume of gas space/unit volume of root) was determined by pycnometer method as given by Jensen *et al.* (1969) and per cent root porosity was calculated using the following formula:

$$\text{Root porosity (\%)} = \frac{W_n - W_{r+w}}{W_w + W_r - W_{r+w}} \times 100$$

Where, W_r is the weight of root samples alone, W_{r+w} is the weight of root samples in a pycnometer bottle filled with water, W_n is the weight of ground root in pycnometer bottle filled with water and W_w is the weight of the pycnometer bottle filled with water only. Total root porosity was determined by multiplying the value of root porosity with that of total fresh volume of roots pot^{-1}.

Table: 1
Basic physico-chemical properties of the soils used for the study

Properties	Values	References
PH (1:2)	4.49	Richards (1954)
Electrical conductivity (dS m^{-1})	0.86	Richards (1954)
Organic carbon (g kg^{-1})	10.4	Walkley and Black (1934)
Available N (kg ha^{-1})	182	Subbiah and Asija (1956)
Available P (kg ha^{-1})	22	Bray and Kurtz (1945)
Available K (kg ha^{-1})	235	Hanway and Heidel (1952)
Texture	Clay loam	Bouyoucos (1962)

Statistical Analysis

All treatments were replicated thrice and the analysis of variance was done using 3 factors CRD considering factor 1 for moisture levels, factor 2 for P doses and factor 3 for stages of growth. Statistical analysis was performed by SPSS version 17.0.

3. RESULTS AND DISCUSSION

Dry Matter Production, Root Porosity and Transpiration

Dry matter production was significantly increased with the increase of the levels of phosphorus under both the soil water regimes (Table 2). As the phosphorus level increased from 0 to 60 kg ha^{-1}, dry weight of shoot at harvest was increased by 1.68 times under FD and 1.40 times under FC. The differences were significant from 60^{th} DAT onward between two soil water regimes with regards to phosphorus levels (Saha *et al*., 1973). At higher levels of phosphorus (P 40 and P 60) the difference was significant even on 30^{th} DAT onwards. The grain yield also increased with increased levels of phosphorus for both the soil moisture regimes (Fig. 1). The grain yield pot^{-1} was 1.47 to 2.15 times higher under FD than FC (Tarafdar and Saha, 2005).

Table: 2
Dry weights of shoots of rice plant grown under two soil water regimes and varying levels of phosphorus at different stages of growth

	Dry weight of shoot (g pot^{-1})*							
	P 0		P 20		P 40		P 60	
DAT	FD	FC	FD	FC	FD	FC	FD	FC
0	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
30	0.33	0.31	0.53	0.52	1.19	0.61	2.16	1.32
60	4.71	2.85	6.28	4.14	9.77	5.39	12.73	7.57
90	19.74	12.01	21.82	13.52	23.88	15.58	31.68	18.01
145	23.78	18.81	26.17	19.59	35.18	21.05	40.34	25.66

Treatments	CD at p=0.05
A) For two water levels	0.211
b) For four levels of P	0.299
c) For stages of growth	0.299

*P 0 = 0 kg P_2O_5, P 20 = 20 kg P_2O_5, P 40 = 40 kg P_2O_5, P 60 = 60 kg P_2O_5, DAT = Days after transplanting, FD = Flooding, FC = Field capacity

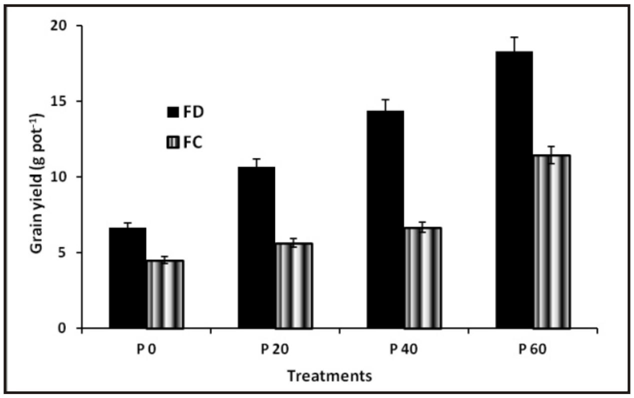


Fig. 1. Grain yield of rice plant grown under two soil water regimes and varying levels of phosphorus

Total root porosity also increased significantly with stages of growth and levels of phosphorus. It raised a peak value on 90th DAT except in P 60 where it peaked at 60th DAT (Table 3). Total root porosity was significantly higher under FD than FC. The percent root porosity was also followed the same trend as that of total root porosity (Tarafdar and Saha, 2005). It also varied with stages of growth and attained the maximum value on 90th DAT and then decreased rapidly. The rate of increase was highest between 60th and 90th DAT in all the treatments. Higher root porosity under FD was due to the development of inducible aerenchyma in addition to the constitutive aerenchyma to facilitate oxygen transport through plants (Gibberd *et al*., 1999).

Table: 3
Root porosity of rice plant grown under two soil water regimes and varying levels of phosphorus at different stages of growth

	Total root porosity (cm^3)*							
	P 0		P 20		P 40		P 60	
DAT	FD	FC	FD	FC	FD	FC	FD	FC
0	0.14 (10.73)	0.14 (10.73)	0.14 (10.73)	0.14 (10.73)	0.14 (10.73)	0.14 (10.73)	0.14 (10.73)	0.14 (10.73)
30	1.38 (12.25)	0.33 (11.39)	2.91 (16.09)	0.92 (12.84)	3.88 (19.20)	2.43 (18.97)	4.95 (20.33)	3.83 (21.22)
60	6.55 (14.33)	2.33 (13.22)	13.34 (17.59)	4.23 (16.51)	18.80 (20.61)	5.28 (19.93)	39.02 (25.56)	7.56 (23.26)
90	27.23 (17.14)	8.23 (15.33)	33.67 (18.34)	11.80 (19.35)	42.15 (21.12)	14.25 (20.79)	84.72 (23.82)	25.66 (23.08)
145	23.80 (13.98)	3.23 (11.20)	26.47 (15.72)	6.36 (12.91)	31.24 (17.79)	7.65 (14.42)	62.48 (2067)	9.74 (16.57)

Treatments	CD at p=0.05
A) For two water levels	0.181(0.027)
b) For four levels of P	0.256 (0.039)
c) For stages of growth	0.256 (0.039)

*The figures within brackets denote percent root porosity

The total amount of water transpired by rice plant under FD was 1.85 to 1.95 times more than under FC (Table 4). It increased sharply upto 90th DAT and then decreased. The increased transpiration under FD condition may be due to increased availability of water to roots. Restricted supply of water in the soil under FC might have decreased the availability of water to plants. Lower unsaturated hydraulic conductivity under FC condition further limited the flow of water to root zone. As a result, the amount of water transpired was less in FC (Tarafder and Saha, 2005). Transpiration amount was also increased with the increase in the levels of phosphorus. More root growth due to increasing levels of phosphorus might have facilitated more absorption of water by plants. The amount of water transpired was closely related with total root porosity (r=0.78 for 1st year and 0.79 for 2nd year, respectively). As soil water regime varied from FC to FD and as phosphorus levels increased from P 0 to P 60, total root porosity increased greatly which may be due to greater root volume. It shows that root porosity facilitated greater transpiration of water.

The increase in dry matter production due to increase in water regimes and levels of phosphorus appeared to be positively correlated with total amount of water transpired (r=0.95 for1st year and 0.96 for 2nd year, respectively). Therefore, the higher transpiration of water appeared to be related to the increased growth and dry matter production (Saha *et al.,* 1973, Sharma and Bhushan, 1999, Tarafder and Saha, 2005). Thus increased hydrostatic pressure in soil together with increased root growth and root porosity might have increased growth and yield of rice under FD condition with the increase in levels of P.

Table: 4
Total amount of water transpired per pot under different soil water regimes and varying levels of phosphorus at different stages of growth

	Total amount of water transpired (cm^3 pot^{-1})							
	P 0		P 20		P 40		P 60	
DAT	FD	FC	FD	FC	FD	FC	FD	FC
30	1128.6	755.3	1200.3	896.7	1331.5	985.4	1489.9	1108.7
60	5724.3	3452.6	6057.1	3653.1	6396.3	3873.9	6888.8	4060.1
90	15178.4	7910.9	16076.5	8251.3	17217.5	8570.7	17698.2	8813.2
145	15944.0	8376.2	17649.4	8899.7	19649.1	9797.5	20705.1	10033.6

Treatments	CD at p=0.05
A) For two water levels	3.035
b) For four levels of P	4.293
c) For stages of growth	4.293

Uptake of Nutrients

Changes in N and P content at different levels of phosphorus were significant under both the soil water regimes (Fig. 2). The content of N, P and K increased to a maximum value on 30th DAT in all the treatment and then decreased with plant age, although the values between 30th and 60th DAT for two phosphorus levels remained almost constant. The variations of N and P contents for two soil water regimes were significant. N content decreased as soil water regime increased from FC to FD. But P content increased as soil water regime varied from FC to FD. The variations in Ca content for two soil water regime were significant. Its content tended to be more under FD than FC.

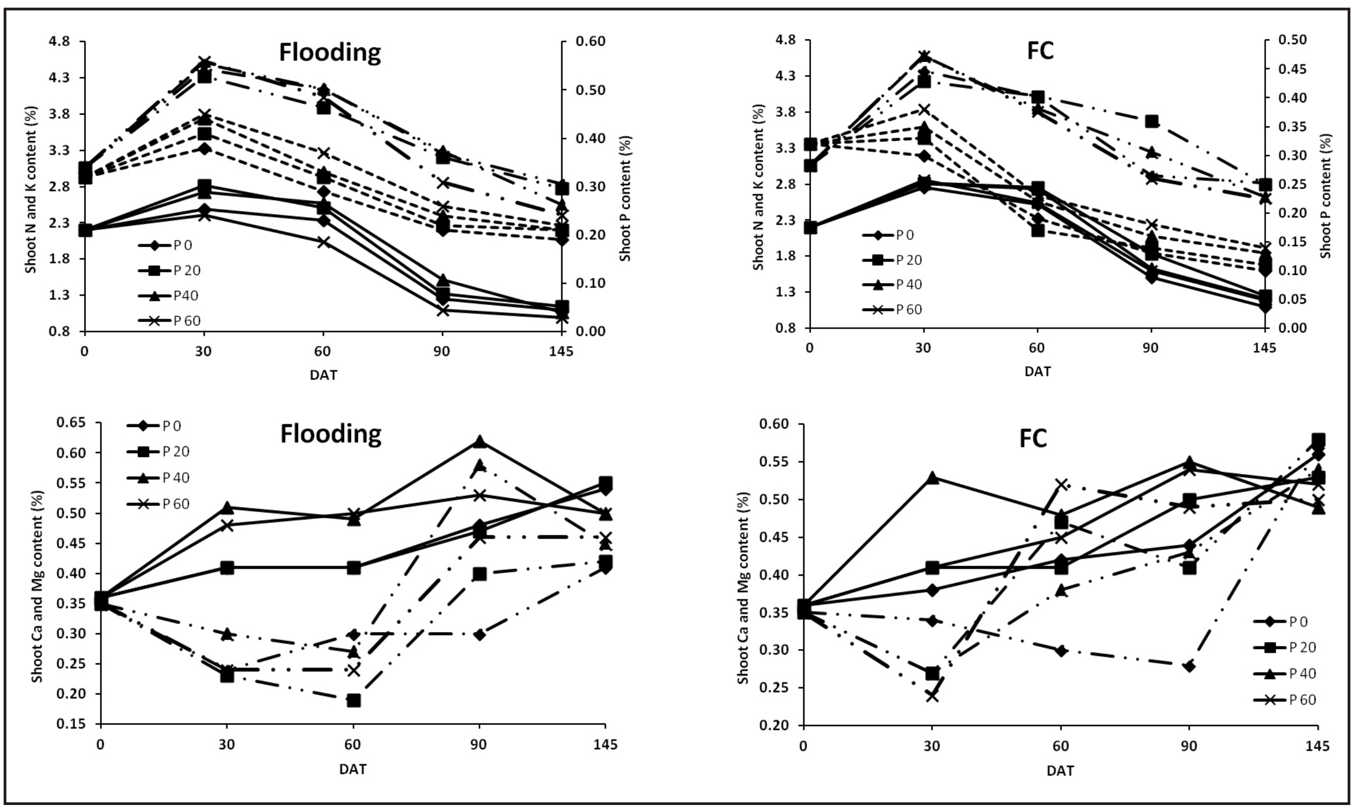
The difference in Ca content between two soil water regimes was significant in 1st year but insignificant in 2nd year. The difference in K content for two SWR was also insignificant. The N, P, K, Ca, Mg contents between different levels of phosphorus were irregular but P content tended to increase with increase in levels of phosphorus (Fig. 2).

The uptake of N, P, K, Ca was slow up to 30th DAT and for Mg up to 60th DAT except in P 60 under FC (Fig. 3). Although the uptake of nutrients continued up to the final stage of harvest, but, the rate of uptake was maximum between 30th and 90th DAT for N, 60th and 90th DAT for P, K, Ca and Mg. The uptake of all the nutrients (N, P, K, Ca and Mg) increased with increase in soil water regimes and plant growth (Bora and Goswamy, 1980). The variation of N, P, K, Ca and Mg uptake between different levels of phosphorus were significant. They tended to increase with increase in levels of phosphorus.

It appears from the study that the total amount of water transpired is closely related with the nutrient uptake. A strong positive correlation was obtained between the total amount of water transpired and uptake of nutrients. Uptake of all the nutrients were highly correlated ($r \geq 0.9$) with water transpired. The magnitude of correlation for the different nutrients have followed the order K > Ca > P > N > Mg. The beneficial effect of FD and the phosphorus on growth of roots and shoots, dry matter production and yield of rice may be attributed to the increase in uptake of nutrients elements. As the doses of phosphorus increased as well as the soil water regime varied from FC to FD, the uptake of N, P, K, Ca and Mg has progressively been increased. Because of FD, the availability of these nutrient elements increased in soil due to occurrence of reduction reaction, increase of CO_2 concentration and occurrences of various physicochemical and biological reactions. As a result of increase in the levels of phosphorus the growth of root increased causing increase in root surface for more absorption of water and nutrients (Tarafdar and Saha, 2005).

4. CONCLUSIONS

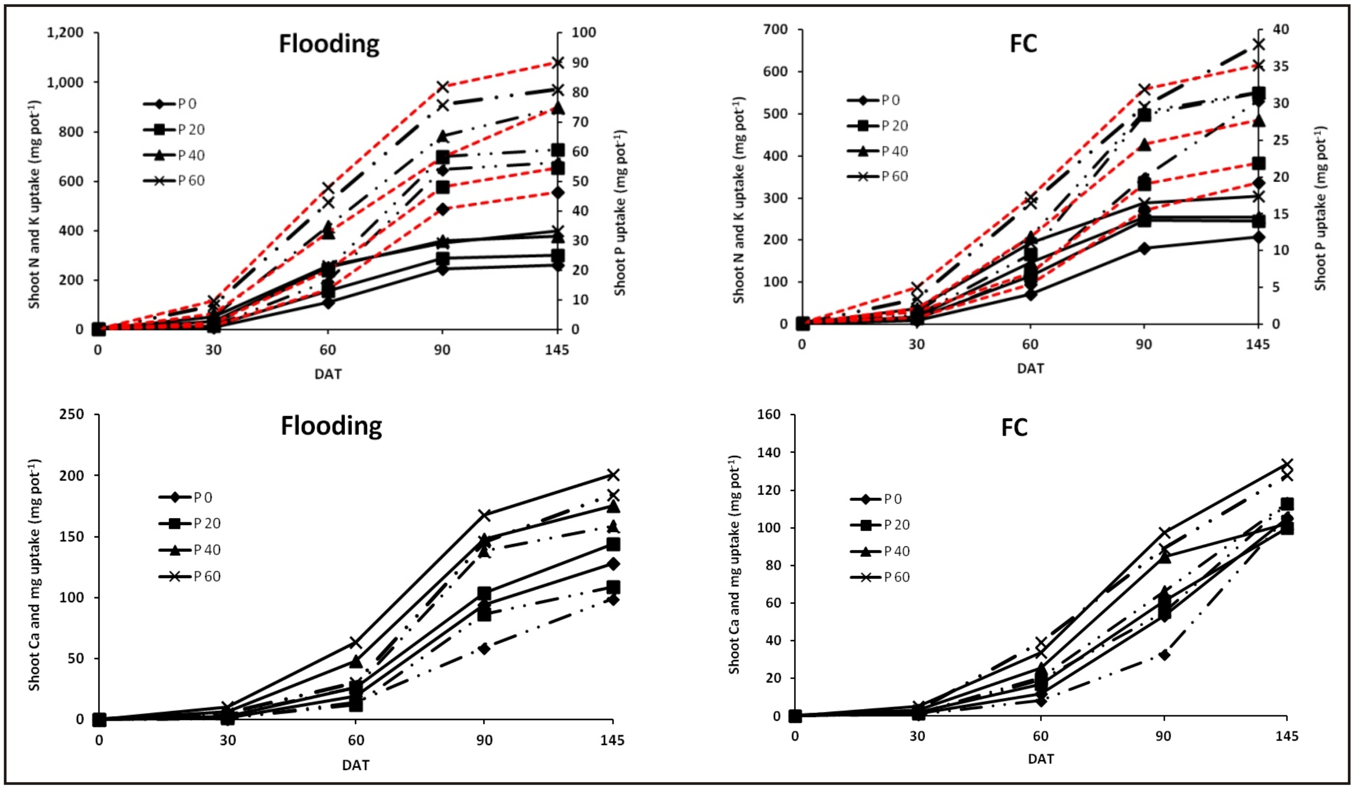
From the result, it may be concluded that the increased transpiration due to increased hydrostatic pressure in soil



Solid lines indicate N and Ca, doted lines P and combined solid and doted lines K and Mg

CD at p=0.05	N	P	K	Ca	Mg
a) For two water levels	0.021	0.020	0.050	0.009	0.024
b) For four levels of P	0.029	0.029	0.071	0.013	0.034
c) For stages of growth	0.029	0.029	0.071	0.013	0.034

Fig. 2. Nutrient content (%) in shoot of rice plant grown under two soil water regimes and varying levels of phosphorus at different stages of growth



Solid lines indicate N and Ca, doted lines P and combined solid and doted lines K and Mg

CD at p=0.05	N	P	K	Ca	Mg
a) For two water levels	4.879	3.108	8.529	1.888	2.676
b) For four levels of P	6.900	4.396	12.062	2.670	3.785
c) For stages of growth	6.900	4.396	12.062	2.670	3.785

Fig. 3. Nutrient uptake (mg pot^{-1}) by shoot of rice plant grown under two soil water regimes and varying levels of phosphorus at different stages of growth

together with increase in root porosity seems to have a favorable effect on growth, dry matter and grain yield production of rice plant under flooding condition. More nutrient uptake as a result of increased availability of nutrients in soil together with greater transpirational transfer of water and nutrient element facilitated by increased root porosity may have increased growth, dry matter and grain yield in rice. As levels of phosphorus increased, root porosity and transpiration increased under both the soil water regimes which ultimately increased the nutrient uptake, growth, dry matter and yield of rice, but the effect due to increased levels of phosphorus appears to be much lower than those of soil water regimes.

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