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Effect of irrigation practices on root growth and yield of rice

(Kesan amalan pengairan pada pertumbuhan akar dan hasil padi)

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Key words: root growth, rice yield, flooded, non flooded-saturated, field capacity

Abstract

Rice root development, which is essential for growth and yield, is influenced by soil water condition. A planthouse study was conducted to evaluate the effectc of irrigation practice on rice root growth and yield. Three irrigation practices imposed on MR 220 were flooded, non flooded-saturated (NFsat) and non flooded-field capacity (NFfcap). Total root length increased rapidly from maximum tillering to panicle initiation stage irrespective of irrigation practice, and after heading, under flooded and NFsat conditions. At maturity, total root dry weight of rice grown under NFfcap was only 25% of the total root dry weight of rice grown under flooded and NFsat conditions. Root growth and root length density decreased with the increase in soil depth during all growth stages measured under flooded and NFsat conditions. However, root length density under NFfcap conditions was high at the top 10 cm soil layer, decreased in the second 10 cm layer and increased again with depth especially during panicle initiation and heading stages. Shoot dry weight and grain yield of rice did not differ significantly between flooded and NFsat, but significantly lower under NFfcap condition. Results suggested that reducing irrigation water and maintaining the soil at NFsat conditions will not affect root as well as shoot growth and yield of irrigated rice.

Introduction

Root development is essential for rice growth and yield. The rice root system absorbs nutrients and conducts water from soil to the upper parts of the plant. Root growth and functions, however, are directly affected by the influence of water or soil moisture content and indirectly affected by other physical factors such as aeration, mechanical impedance, temperature and transport of nutrients towards the root in the soil. Soil moisture significantly influences root morphology, and the development and distribution of root system.

Beyrouty et al. (1988) observed a rapid root elongation up to panicle initiation stage and fluctuated more after panicle initiation possibly as a response to changes in status of flood water. A continuously submerged condition was reported to have adverse effects on rice roots (Jeon 2006). However, when adequate percolation is provided under submerged condition, it increases rice root porosity which was associated with greater root length, increases dry weight of roots and shoots, and higher nutrient content in shoots (Das and Jat 1977).

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Rice grown in a flooded condition, at least during reproductive growth, was reported to produce considerably more roots than rice grown without flood but with supplemental irrigation (Beyrouty et al. 1997). Rice grown under upland condition normally has deeper rooting systems than that grown under submerged conditions without percolation. In general, rooting depth tends to be greatest for plants grown under dry land soil condition, intermediate under submerged soil condition with adequate water percolation and shallowest under submerged soil condition without ample water percolation.

Stevenson and Laidlaw (1985) observed the inhibited development of root hairs under too dry or too wet soil conditions and smaller root quantity under drier soil. On the other hand, the root elongation rate of cereal become slower during prolonged periods of wet condition but faster or to a greater depth, during dry conditions (Ellis and Barnes 1980).

Greater yields and productivity are normally obtained from flooded rice. However, research in the International Rice Research Institute (IRRI) showed that it is not necessary to flood rice to obtain high grain yield, and maintaining a saturated soil throughout the growing season can save up to 40% of water in clay loam soils without reduction in rice yields (CGIAR 1996). Farmers prefer to flood their land continuously as an assurance against water shortages. However, lower yield and yield losses of 16–34% were observed when rice was grown under saturated soil condition as reported by Castillo et al. (1992) and Borell et al. (1997). Lilley and Fukai (1994) reported that rice yield was not significantly reduced if water deficit was imposed during vegetative growth, but about 20–70% yield reduction of flooded rice was observed if water deficit was imposed during reproductive period.

Alternate wetting and drying practice whereby irrigation water is applied after a certain number of days the flood disappeared resulted in a decreased water input but at the expense of decreased yield. Bouman and Tuong (2001) reported yield losses which ranged from 0 to 70% from such practice as compared with flooded treatment, depending on the number of days between irrigations and existing soil conditions. The lower rice yield (58% lower than flooded rice) from alternate wetting and drying practice was mainly due to low leaf area index (LAI) at booting and anthesis, less shoot dry weight and lower root length density from booting to harvest as reported by Grigg et al. (2000).

Thus, this adjustment in root growth with changes in soil moisture as a result of changes in irrigation practices may have impact particularly on fertilizer management. The study was conducted to observe the effect of irrigation practices on rice root growth and distribution as well as shoot growth and yield of rice. The results obtained will determine if irrigated rice can be grown under minimal water input without seriously affecting root growth and distribution, and eventually the growth and yield of rice.

Materials and methods

Experiments were conducted in planthouse at MARDI Seberang Perai during April–July 2005 (off season) and October 2005 to January 2006 (main season). The soil used for the experiments was Sogomana soil series with a soil texture of sandy clay loam. The soil has a pH of 4.5, 0.52% organic C, 0.13% total N and cation exchange capacity of 7.0 $cmol_c\ kg^{-1}$. About 15 kg of air-dried soil was packed into a 20 cm diameter by 50 cm high PVC cylinder, which made up approximately a 40 cm soil column.

Three irrigation practices viz., normal flooded with 5.0 cm standing water, non flooded-saturated (NFsat) where the soil is kept saturated throughout the rice growth period, and non flooded-field capacity (NFfcap) were compared. Irrigation for NFfcap was done when the water potential fell between –0.03 and –0.05 MPa as measured with a tensiometer at 15 cm soil depth. Five seedlings of MR 220 were maintained in each pot after thinning at 10 days after seeding (DAS). The treatments were arranged in a randomized complete block design with five replications.

Total root length and root dry weight were recorded at early tillering (ET), active tillering (AT), maximum tillering (MT), panicle initiation (PI), heading and maturity stages. The soil column for each treatment was cut into 10-cm sections at each sampling date. The root mass of each section was washed carefully and dried with tissue paper. Five 1.0-g fresh root samples per section were taken for root length measurement using GSRoot – automated root length measurement program (Guddanti and Chambers 1994). The remaining root mass of each section was weighed, oven dried at 70 °C for 72 h and weighed for root dry weight. Root length density (RLD) which is the root length per unit volume of soil (cm cm^{-3}) was calculated by dividing the total root length by the volume of the soil section.

At maturity, the plants in each pot were harvested for the determination of yield. Grain yield per pot was obtained from the weight of filled grains adjusted to 14% moisture content.

Results and discussion

Root dry weight

The rice total root dry weight at various growth stages was significantly affected by irrigation practice as shown in (*Table 1*). In general, root dry weight increased with time and maximum root dry weight was achieved at maturity especially for rice grown under flooded and NFsat conditions. On the other hand, total root dry weight under NFfcap was lower at maturity than PI stage during off season 2005 and slightly higher at maturity during main season 2005/06. A lower total root dry weight was observed for rice grown under NFfcap than flooded and NFsat conditions at all growth stages measured. At maturity, total root dry weight for rice grown under NFfcap condition was only 25% of the total root dry weight of rice grown under flooded and NFsat conditions. The smaller quantity of roots in a drier soil (NFfcap condition) agrees with the earlier observation made by Stevenson and Laidlaw (1985). A substantial increase in root dry weight was noted at maturity for rice grown under flooded and NFsat conditions. The increase in total root dry weight under flooded and NFsat conditions was attributed to the increase in root growth during the period after heading. However, not much difference in total root dry weight was observed between normal flooded and NFsat conditions at all growth stages. A similar trend of root dry weight in response to irrigation practice at various growth stages was observed in both main and off seasons.

Total root length

Total root length was significantly affected by irrigation practice at all growth stages except at MT and PI stages (*Figure 1*). Rice

Table 1. Total root dry weight (g/pot) at various growth stages as influenced by irrigation practices

Irrigation practice	Active tillering	Max. tillering	Panicle initiation	Maturity
Off season 2005				
Flooded	0.92a	3.60a	5.48a	11.66a
NFsat	0.75a	3.40a	4.34a	11.46a
NFfcap	0.21b	1.77b	2.44b	2.98b
Main season 2005/06				
Flooded	0.62a	4.88a	12.05a	16.04a
NFsat	0.51a	4.51a	9.98a	15.85a
NFfcap	0.45b	2.04b	5.58b	4.06b

Means in a column followed by a common letter are not significantly different (p = 0.05)

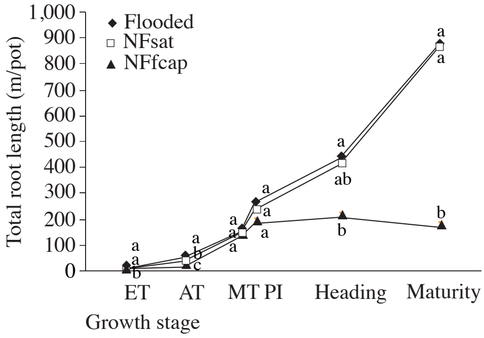

Figure 1. Total root length (m/pot) of MR 220 at various growth stages as influenced by irrigation practice during off season 2005. Common letters at each growth stage are not significantly different (p = 0.05)

grown in NFfcap condition produced less roots and thus lower total root length than rice grown in flooded and NFsat conditions. The decrease in total root length under NFfcap condition could be attributed to increased soil mechanical impedance as the soil becomes compacted and harder especially in the 10–20 cm soil depth when compared to soil under flooded and NFsat conditions. Cruz et al. (1986) also observed similar effect of soil mechanical impedance on total root length. Results also indicated that total root length under NFfcap condition started to plateau from PI to heading stage and decreasing thereafter. On the other hand, total root length increased with time and maximum total root length was achieved at maturity under flooded and NFsat conditions. The total root length of rice grown under normal flooded had an almost similar trend and magnitude to rice grown in NFsat condition.

There were two periods of rapid root growth for rice as shown by the rapid increase in total root length observed in this study. The first period was from MT to PI stage for all irrigation practices, and the second was from heading to maturity, but only under flooded and NFsat conditions. The rapid increase in total root length during the period from heading to maturity was probably related to an increase in very fine and shallow nodal roots under flooded and NFsat conditions.

This late root growth of rice is in agreement with earlier findings of Slaton et al. (1990) and Beyrouty et al. (1992). The late root growth could be because the additional assimilate available during this growth stage was too late to be used to increase plant height or for tiller production and thus, it is available for late root growth (Beyrouty et al. 1992).

Root length density (RLD)

RLD is one of the most important factors to improve the acquisition of nutrients of low mobility in the soil. RLD was highest in the top 10 cm soil layer regardless of irrigation practices at all growth stages measured (*Figure 2*). The RLD in the top 10 cm depth was between 0.84 and 1.16 cm cm^{-3} for flooded and NFsat conditions, but only 0.26 cm cm^{-3} under NFfcap condition at AT stage. However, at maturity, RLD in the top soil layer has increased to 12.94, 11.84 and 3.73 cm cm^{-3} for flooded, NFsat and NFfcap conditions, respectively.

Results also indicated that RLD decreased with the increase in soil depth at all growth stages measured under flooded and NFsat conditions. This shows that the rooting zone of rice grown under flooded and NFsat conditions expanded more horizontally from crop establishment to PI stage. On the other hand, the rooting zone under NFfcap condition was more vertical and maximum rooting depth (40 cm) was attained as early as AT stage (*Figure 2*). The RLD under NFfcap condition was higher in the 30–40 cm soil depth than the upper soil layers (0–30 cm) during PI and heading stages. This is probably due to wetter conditions at the bottom than the upper layer of the soil column as a result of alternate wetting and drying which encouraged root growth. This result is in agreement with earlier finding of Ellis and Barnes (1980). However, the rooting depth was restricted up to the 40 cm depth by the soil column used in this study. The roots from different

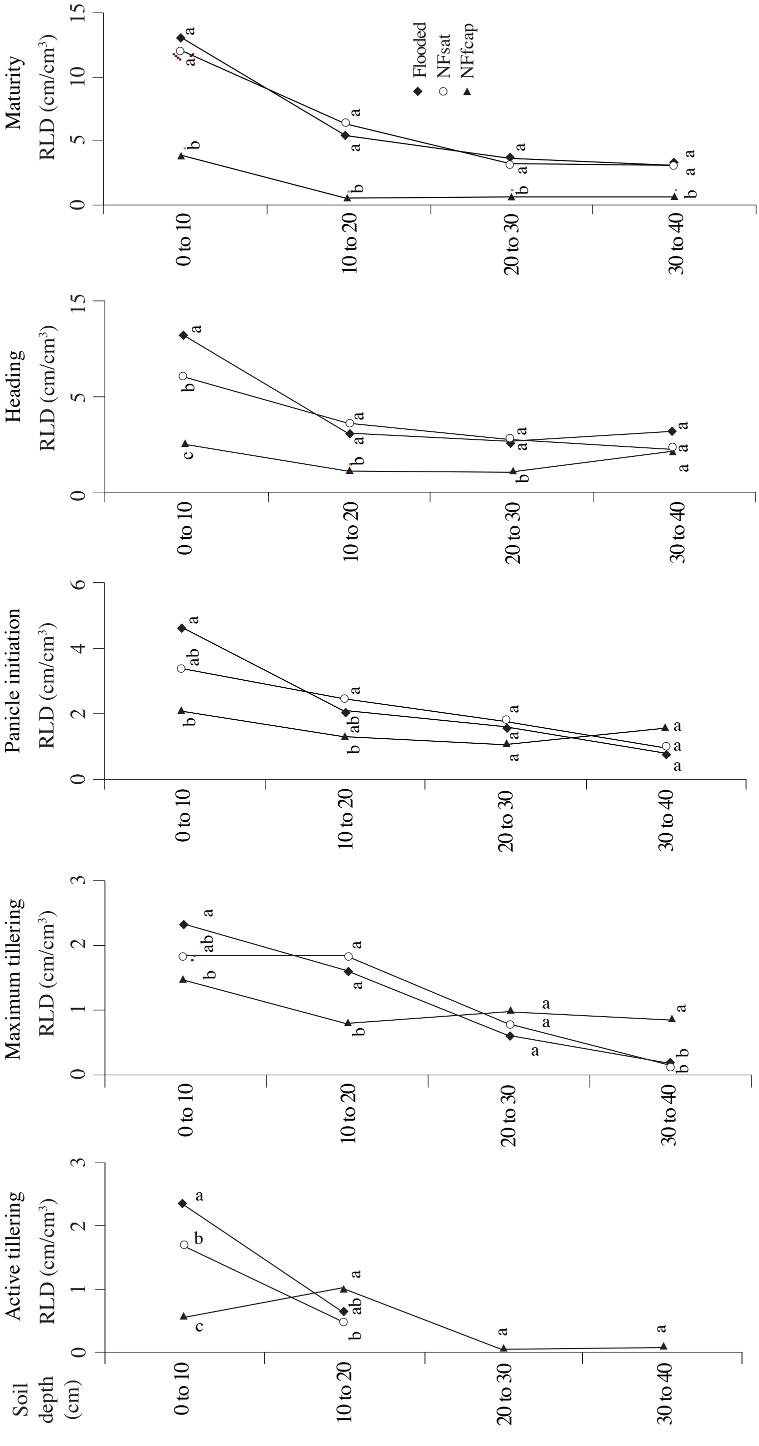

Figure 2. Root length density (cm/cm^3) of MR 220 at various soil depths and growth stages during off season 2005 Means at each soil depth followed by a common letter are not significantly different (p = 0.05)

Plate 1. Effects of irrigation practice on rice root growth at panicle initiation stage

irrigation practices at PI stage are shown in *Plate 1*.

Shoot dry weight and grain yield

Irrigation practice, however, significantly affected shoot dry weight harvested at various growth stages (*Figure 3*). Shoot dry weight for both seasons was significantly lower under NFfcap than NFsat and flooded conditions at all growth stages. However, shoot dry weight was not significantly different between flooded and NFsat conditions at all growth stages except during AT stage when it was significantly higher under flooded than NFsat conditions. A similar trend of shoot dry weight was observed in the main season 2005/06.

Grain yield was not significantly different in both seasons when rice was subjected to flooded and NFsat conditions. There was a yield reduction of 10.5% in off season 2005 and 3.6% in main season 2005/06 when rice was grown in NFsat as compared to flooded. The yield reduction of rice grown under NFsat condition from this study was smaller when compared with yield reduction of 16–34% observed by Borell et al. (1997).

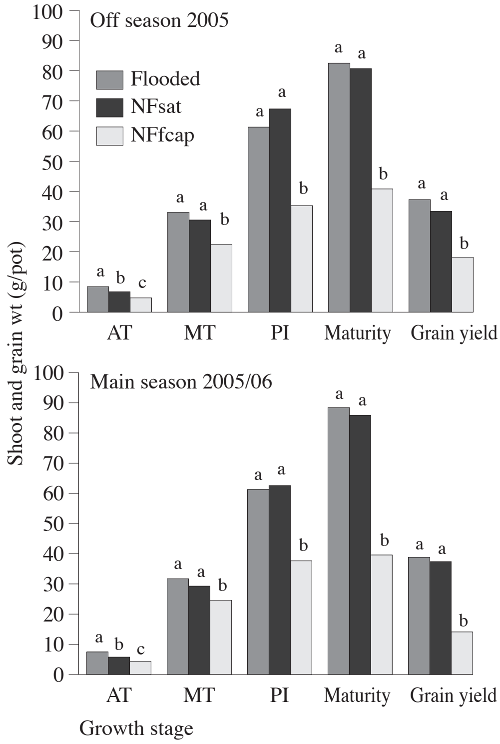

Figure 3. Shoot dry weight and grain yield (off season 2005 and main season 2005/06) as affected by irrigation practice.
Bars at each growth stage with common letter are not significantly different at LSD (p = 0.05)

However, the grain yield under NFfcap condition was significantly lower irrespective of growing seasons. The grain yield was 51.2% and 63.7% lower than in flooded condition during off season 2005 and main season 2005/06, respectively. Similarly, the grain yield from NFfcap was significantly lower (45.5% in off season 2005 and 62.3% in main season 2005/06) than NFsat condition. These ranges of yield loss are in agreement with those observed by Grigg et al. (2000) and Bouman and Tuong (2001).

Root trait such as root length has significant positive correlation with panicle number (Jeon 2006). The lower total root length of rice grown under NFfcap resulted in lower water and nutrient uptake from the soil. This will eventually affect the shoot growth and yield.

Conclusion

Rice root growth was greatly influenced by irrigation practice. Root growth was not significantly affected when rice was grown under a continuous NFsat condition and was as good as when grown in flooded condition. However, root growth was significantly reduced when rice was subjected to NFfcap condition throughout the crop growth period. There is a potential of growing rice with minimal water input under NFsat condition as root growth and distribution as well as rice growth and yield were not significantly affected under this irrigation practice.

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Abstrak

Pertumbuhan akar padi sangat penting untuk pertumbuhan pokok serta hasil dan ia dipengaruhi oleh kandungan air di dalam tanah. Kajian di rumah tanaman telah dijalankan bagi menilai kesan amalan pengairan terhadap pertumbuhan akar, pokok dan hasil padi. Tiga amalan pengairan iaitu pembanjiran, tanpa pembajiran – tepu (TBtepu) dan tanpa pembanjiran – keupayaan ladang (TBkl) telah diuji. Varieti padi MR 220 digunakan dalam kajian ini. Jumlah panjang akar meningkat dengan kadar yang cepat dari peringkat pembiakan maksimum sehingga peringkat awal pembentukan tangkai bagi semua amalan pengairan yang diuji dan selepas peringkat terbit tangkai untuk amalan pembanjiran dan TBtepu. Pada peringkat matang pula, berat akar keseluruhan bagi padi yang ditanam dalam keadaan TBkl didapati berkurangan dan hanya kira-kira 25% sahaja daripada jumlah keseluruhan akar padi yang ditanam dalam pembanjiran dan TBtepu. Pertumbuhan dan taburan akar padi yang ditanam dalam pembanjiran dan TBtepu didapati berkurangan dengan bertambahnya kedalaman tanah. Walau bagaimanapun, pertumbuhan kepadatan panjang akar padi pada TBkl adalah tinggi di lapisan 10 cm pertama, kemudian berkurangan di lapisan 10 cm kedua tetapi meningkat semula dengan bertambahnya kedalaman tanah, terutamanya pada peringkat awal pembentukan tangkai dan terbit tangkai. Tiada perbezaan ketara pada berat kering pokok dan hasil padi dari amalan pembanjiran dan TBtepu tetapi ketara lebih rendah pada TBkl. Hasil kajian menunjukkan bahawa mengurangkan input air dari pengairan dan mengendalinya pada tahap TBtepu tidak menjejaskan pertumbuhan akar, pokok dan hasil tanaman padi sawah.

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