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# Upland Rice Root Characteristics and Their Relationship to Nitrogen Uptake

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## ABSTRACT

Nitrogen and phosphorus efficiencies are the main constraints to food production in the sub-humid and humid tropic soils. A laboratory and glasshouse study was initiated to examine the differences in the root architecture of Malaysian upland rice landraces and relate them to efficiency of the nitrogen fertilizer uptake. Six upland rice landraces, obtained locally, were soaked in water and allowed to germinate using the cigar role method. The seedlings were fertilized with a complete nutrient solution daily and the roots which were allowed to develop after 14 days were measured using the WINRHIZO. The same landraces were planted in the glasshouse in polybags containing 25 kg soil in four replications. N-15 labelled urea was applied at 170 kg N/ha and N use efficiency was measured at harvest. Significant differences in root length, surface area, root volume, average root diameter, and number of forks, between the 6 landraces were studied. Nitrogen in the plant (derived from fertilizer applied) was found to range from 6.22 – 27.6%. Nevertheless, a poor correlation was obtained between the length of root and the dry matter yield and the total N uptake. Five of the landraces tested showed a good potential in taking up the fertilizer N applied.

**Keywords: Upland rice, root architecture, nitrogen fertilizer, nitrogen use efficiency, nitrogen derived from fertilizer**

## INTRODUCTION

Upland rice is grown by subsistence farmers on approximately 20 million hectares in the sub-humid and humid tropics, generally on infertile, strongly weathered soils. The main constraint to food production in these soils is the deficiency of N and P. The low yield of upland rice obtained is largely a consequence of its production being limited to infertile or drought-prone upland soils and to a low harvest index (HI) of traditional cultivars (George *et al*., 2001). IRRI (2000) reported the importance of N input in determining yield. It has been shown that root architecture, the spatial configuration of a root system in the soil, varies between and among species, and plays an important role in below-ground resource acquisition (Lynch, 1995).

Various strategies have been developed to synchronize plant N demand and N supply from soil and fertilizers. These include proper timing, rate, placement, and the use of modified form of fertilizer (IAEA, 2006). Modifying the soil-plant environment with fertilizers and amendments may not be the most practical or economical solution to address all the mineral nutrient problems in plants and soils. On the

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contrary, genetic selection and plant breeding techniques have been used to develop rice varieties which are resistant to diseases and adverse environmental conditions, such as drought, nutrient deficiencies, toxicities, and salinity. However, genetic selection to improve the efficiency of N use in the upland rice crop has not been carried out. In addition, little information is available on the upland rice cultivar differences in response to N fertilization in Asia (Saito *et al*., 2006).

Our study was aimed at identifying the genotypic differences in soil and fertilizer N-use efficiency and the relationship between the seedling root characteristics to yield.

## MATERIALS AND METHODS

Six upland rice landraces obtained locally (AN 1334A, AN 753, AN 582, and AN 1084 obtained from the Department of Agriculture, Sabah, and Bertih and Satang obtained from Jerantut, Pahang) were soaked in water and allowed to germinate between two sheets of moistened filter paper, placed on a water-proof brown paper, rolled up like a cigar (cigar role method) and placed in a standing position in a plastic container. The seeds were sprayed with complete Hoagland nutrient solution twice daily (morning and evening) and allowed to grow for 14 days. The roots which developed after 14 days were scanned using the WINRHIZO. The root parameters, such as their length, diameter, volume, and number of root tips were recorded. The same landraces were planted in the glasshouse in polybags containing 25 kg soil in four replications. The soil used was Munchong series (Typic hapludox) with the following properties: pH of 4.38, Bray-1P of 4.16 mg/kg and total N of 0.16%. An equivalent rate of 100 kg P/ha as triple super phosphate (20% P) was mixed into the top 20 cm of the soil prior to seed planting. Nitrogen and potassium fertilizers were applied at an equivalent rate of 170kg N, and 150 kg K/ha applied in three split applications at 10, 45 and 60 days after planting. The source of nitrogen used was ammonium sulphate (21% N), which was enriched with 5% N-15 atom excess. Potassium was applied as muriate of potash (50% K). The seeds were planted on $20^{th}$ November 2007 and harvested on 10 April 2008 (i.e. 140 days after planting).

The straw and grains were weighed and sub-sampled. The sub-samples were dried in an air-forced oven at 70°C, until constant weights were achieved. They were ground to pass through a 1 mm sieve size and stored in plastic containers. Total nitrogen was determined using the Kjeldahl method (Bremner and Mulvaney, 1982) and the N-15 enrichment of the samples was determined using the emission spectrometer at the Malaysian Nuclear Agency. The analysis of variance for the data obtained was carried out using the SAS version 9.0 package and the comparison of the means was made using the studentised Tukey method.

## RESULTS AND DISCUSSION

### *Root Characteristics*

The two landraces obtained from Pahang showed significantly longer roots than those obtained from Sabah (Table 1). Significantly lower root surface area and the root volume were observed for AN 1334. Nevertheless, there were no significant differences between the landraces for the number of root tips produced.

It has been known that plant root systems are highly plastic in their development and can adapt their architecture in response to prevailing environmental conditions (Zhang and Forde, 1998 and Zhang *et al*., 1999). In *Arabidopsis*, it has been shown that uniformly high nitrate (10 mM) suppresses lateral root development, while for plants grown at low levels of nitrate (10 µM), and when a section of the primary root was exposed to a high nitrate level, lateral root production was stimulated specifically in that area. The main effect of nitrate appears to be on the rate of the lateral root elongation rather than on the lateral root initiation. The elongation rate of the primary root is identical at 10 µM and 10 mM nitrate and the metabolism of nitrate is not required for the architectural changes (Zhang and Forde, 1998). Since metabolism of nitrate

TABLE 1
Root characteristics of the upland landraces, 14 days after germination

| Upland rice landraces | Root length | Root Surface Area | Root Volume | No. of root tips |
|---|---|---|---|---|
| | cm | $cm^2$ | $cm^3$ | |
| AN1334A | 72.36 c | 6.96 b | 0.053 b | 818.3 a |
| AN753 | 97.37 b | 10.79 a | 0.096 a | 1026.7 a |
| AN582 | 91.55 b | 11.56 a | 0.117 a | 951.7 a |
| AN1084 | 93.09 b | 12.34 a | 0.131 a | 1017.3 a |
| SATANG | 114.53 a | 13.28 a | 0.125 a | 791.3 a |
| BERTIH | 102.60 ab | 12.74 a | 0.129 a | 1090.3 a |

is not required for the root architectural changes, the differences observed in the root length of the upland rice landraces shown must be due to their genetic differences.

*Agronomic Characteristics*

The agronomic parameters which showed significant differences among the upland rice landraces were only observed for plant height and panicle length (Table 2). AN 1334A, Satang, and Bertih showed no significant differences in their height but they provided the tallest plant. AN 1084 was about 10 cm shorter, while AN 753 and AN 583 were about 20 cm significantly shorter than the tallest plant. The plant height obtained was much taller than those grown in the field, as described by the Department of Agriculture, Sabah. This was due to the lower light intensity available in the greenhouse, where the experiment was carried out. The date to maturity was at 140 days while under field conditions, these landraces upland rice could be harvested at 110 to 150 days.

The straw yield obtained from Satang was the highest amongst the 6 landraces tested, while the grain yield was lowest. All the other landraces showed a similar grain yield (Table 3). The total N yield was also highest in Satang, due to the high straw yield produced. The weight/1000 seeds (Table 2) showed similar values, except for Bertih.

The N contents in grain were similar for all the landraces used, while for the N content

TABLE 2
Agronomic parameters obtained from the harvested upland rice

| Upland rice landraces | Plant height | No of tillers/pot | No of panicles/pot | Panicle Length | No of Spikelet/ panicle | Weight/1000 grains |
|---|---|---|---|---|---|---|
| | cm | | | cm | | g |
| AN1334A | 151.8 a | 6.75 a | 10.25 a | 26.49 ab | 254 a | 23.15 a |
| AN753 | 133.4 b | 9.25 a | 13.00 a | 25.21 ab | 252 a | 21.61 a |
| AN582 | 134.9 b | 7.75 a | 10.75 a | 27.88 ab | 136 a | 24.96 a |
| AN1084 | 142.3 ab | 4.25 a | 6.25 a | 29.17 a | 361 a | 29.03 a |
| SATANG | 151.0 a | 8.25 a | 12.50 a | 20.50 b | 124 a | 25.45 a |
| BERTIH | 151.7 a | 8.25 a | 12.50 a | 22.45 ab | 104 a | 16.20 b |

TABLE 3
Straw, grain and nitrogen yield and harvest index of the upland rice landraces

| Upland rice landraces | Straw Yield | Grain Yield | Total Yield | Straw N Yield | Grain N Yield | Total N Yield | N in Grain | Straw: Grain Yield | Straw: Grain N |
|---|---|---|---|---|---|---|---|---|---|
| | g pot$^{-1}$ | | | mg pot$^{-1}$ | | | (g kg$^{-1}$) | | |
| AN1334 | 38.88 d | 11.27 a | 50.15 c | 1268.7 cd | 408.8 a | 1677.6 ca | 24.37 a | 5.08 b | 4.61 b |
| AN753 | 51.33 c | 15.96 a | 67.29 b | 1532.6 c | 637.0 a | 2169.6 c | 29.36 a | 3.96 b | 2.92 b |
| AN582 | 35.02 d | 11.68 a | 46.70 c | 1208.8 cd | 457.5 a | 1666.2 cd | 27.46 a | 3.96 b | 4.15 b |
| AN1084 | 29.82 d | 12.26 a | 42.08 c | 971.1 d | 475.7 a | 1446.8 d | 32.88 a | 3.27 b | 2.89 b |
| SATANG | 111.96 a | 7.04 b | 119.00 a | 3702.1 a | 263.4 a | 3965.5 a | 6.64 c | 21.39 a | 19.04 a |
| BERTIH | 88.27 b | 14.41 a | 103.36 a | 2506.1 b | 602.2 a | 3136.6 b | 19.20 b | 9.46 b | 6.49 b |

in straw, only AN 753 and Bertih showed significantly lower values than the others (Table 3). Similar values were also seen in the upland rice varieties in Brazil (Arf *et al*., 2003).

The harvest index (HI) (grain yield/total yield) was similar to the traditional upland rice variety from Northern Laos used by Saito *et al*. (2006). This low HI has been contributed to the low yield obtained from the upland rice (Table 3). The percentage of N in the grain was the lowest in Satang (6.64%), due to the low grain yield obtained. All the AN lines showed between 24 to 33% of the total N in grain. Thus, showing a clear difference in the ability to take up and mobilize the N in the plants.

Fertilizer nitrogen contributed 20 to 27% of the total N taken up by the AN lines, 16% in Bertih, and only 6% in Satang; they were equally distributed in the straw N and the grain N (Table 4). Nitrogen use efficiency in the range of 23 – 30 % has been recently reported for the upland rice when 300 kg N $ha^{-1}$ was applied (Wang *et al*., 2008).

Significant relationships between root length and dry matter weight, root length and total N uptake were obtained (*Figs. 1* and *2*), indicating the suitability of using root characteristics and agronomic parameters. It has also been mentioned that rooting depth is one of the root characteristics which determines the ability of a crop to intercept N, particularly $NO_3^-$ during the periods of leaching (Gastal and Lemaire, 2002). Since upland rice landraces are grown under aerobic conditions, most of the N will be in the

TABLE 4
Nitrogen derived from fertilizer by straw and grain, and the percentage of N derived from fertilizer N added

| Upland rice landraces | Straw N from Fertilizer | Grain N from Fertilizer | Total N from Fertilizer | N derived from Fertilizer |
|---|---|---|---|---|
| | mg $pot^{-1}$ | | | % |
| AN1334A | 172.82 b | 183.34 a | 356.2 b | 19.62 b |
| AN753 | 298.04 a | 232.25 a | 473.8 ab | 26.69 a |
| AN582 | 180.42 b | 196.65 a | 377.1 b | 21.35 ab |
| AN1084 | 209.64 ab | 212.38 a | 422.0 ab | 27.61 a |
| SATANG | 126.72 c | 118.62 b | 245.3 c | 6.22 c |
| BERTIH | 242.06 a | 278.37 a | 555.9 a | 16.32 b |

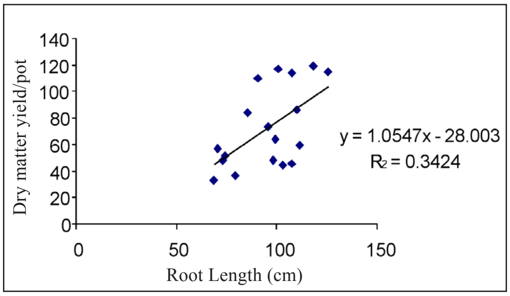


*Fig. 1: Relationship between root length and dry matter weight of upland rice*

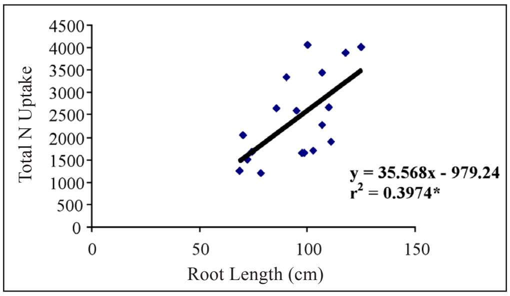


*Fig. 2: Relationship between root length and total N uptake*

form of $NO_3^-$, and is liable to be leached under heavy rainfall conditions of the tropics. Thus, varieties capable of producing long seminal roots will be potentially capable of producing deep roots. Other parameters, such as root surface area, root diameter and number of root tips did not correlate well with the agronomic parameters.

## REFERENCES

Arf, O., Rodrigues, R.O.F., Crusciol, C.A.C., de Sa, M.E. and Bezutti, S. (2003). Soil management and nitrogen fertilization for sprinkler-irrigated upland rice cultivars. *Scientia Agricola, 60,* 345 – 352.

Gastal, F. and Lemaire, G. (2002). N uptake and distribution in crops: An agronomical and ecophysiological perspective. *Journal of Experimental Botany*, *53,* 789 – 799.

George, T., Magbanua,R., Roder, W., van Keer, K., Trebuil, G. and Reoma,V. (2001). Upland rice response to phosphorus fertilization in Asia. *Agronomy Journal, 93,* 1362 – 1370.

IAEA. (2006). Guidelines on Nitrogen Management in Agricultural Systems. Training Course Series 29. Vienna, Austria. 237p.

IRRI. (2000). *IRRI Program Report for 2000: Upland Rice Ecosystem*. International Rice Research Institute, P.O. Box 933, Manila, Philippines p. 50 – 64.

Lynch, J. (1995). Root architecture and plant productivity. *Plant Physiology, 109,* 7 – 13.

Saito, K., Linquist, B., Atlin, G.N., Phanthaboon, K., Shiraiwa, T. and Horie, T. (2006). Response of traditional and improved upland rice cultivars to N and P fertilizer in northern Laos. *Field Crop Research*, *96,* 216 – 223.

Wang, Y., Zhu, B., Shi, Y. and Hu, C. (2008). Effects of nitrogen fertilization on upland rice based on pot experiments. *Communication in Soils and Plant Analysis*, *39,* 1733 – 1749.

Zhang, H. and Forde, B. (1998). An *Arabidopsis* MADS box gene that controls nutrient-induced changes in root architecture. *Science, 279,* 407 – 409.

Zhang, H., Jennings, A., Barlow, P.W. and Forde, B.G. (1999). Dual pathways for regulation of root branching by nitrate. *Proceeding of the National Academy of Sciences, 96,* 6529 – 6534.