การเจริญเติบโตและสัณฐานวิทยาของรากข้าวไร่ 5 สายพันธุ์ ที่มีผลผลิตต่างกันในภาคเหนือของประเทศลาว

Root Growth and Morphology of Five Different Yielding Upland Rice Varieties in Northern Laos

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Abstract

The yield of upland rice in northern Laos rapidly decline. The cause of this is not well understood. But it may be a result of a combination of reduced soil fertility, increased weed pressure, and increased pests and diseases. Root systems play an important role in the uptake of nutrients and water, so the distribution and activity of the roots may affect upland rice productivity and its capacity to cope with reduced soil fertility. The goal of this study was to evaluate the root systems of five upland rice varieties: Makhinsung (MS), Laboun (LB), Chaomad (CM), Nok (NK), and Vieng (VG). These varieties perform differently in soil which has been cropped continuously. Root and shoot samples were taken for a measuring of growth at 15, 25, and 45 days after emergence (DAE).

The data showed differences in root number, root, length and thickness among the five varieties. CM, the variety that performed well in an intensively cropped system, had more roots, longer root length, finer roots and a higher root to shoot ratio than the other varieties NK and VG, the two varieties that performed poorly under a continuously cropped systems, had fewer, shorter and thicker roots, and a lower root to shoot ratio. In the last sampling, the average root length of MS and CM were greater than that of other three varieties. These differences in the characteristics of the root systems did not lead to differences in total N, P, K and Ca uptakes per plant in this experiment. This might be attributed to the limited soil volume in the pots and water. The benefits of the different characteristics

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of root systems have been discussed in relation to the use of water and nutrient, leading to an increased productivity under field conditions.

Keywords: Laos, root, shoot, upland rice. variety

บทคัดย่อ

ผลผลิตของข้าวไร่ที่ปลูกหลายปีอย่างต่อเนื่องลดลงอย่างรวดเร็วในภาคเหนือของประเทศลาว สาเหตุของการลดลงดังกล่าวยังไม่เป็นที่เข้าใจแน่ชัดนัก แต่สันนิษฐานว่าอาจเป็นเพราะปัญหาหลายอย่างประกอบกันเช่น ความอุดมสมบูรณ์ของดินที่ลดลง การแข่งขันจากวัชพืช ตลอดจนปัญหาโรคแมลง ระบบรากมีความสำคัญต่อการดูดธาตุอาหารและน้ำ ดังนั้นการกระจายตัวและกิจกรรมของราก อาจมีอิทธิพลอย่างมากต่อความสามารถในการให้ผลผลิตของข้าวไร่ ในสภาพที่ดินเสื่อมความอุดมสมบูรณ์ ดังนั้นจึงทำการศึกษาในกระถาง โดยมีวัตถุประสงค์เพื่อประเมินระบบรากของข้าวไร่ 5 พันธุ์ คือ พันธุ์หมากหินสูง ลาบุญ เจ้ามัด นก และเวียง ซึ่งข้าวเหล่านี้มีการเจริญเติบโตและผลผลิตแตกต่างกันในระบบการปลูกข้าวไร่แบบต่อเนื่อง โดยเก็บตัวอย่างรากและส่วนเหนือดินของพืช เพื่อนำมาวัดการเจริญเติบโตของข้าวเมื่ออายุ 15, 25 และ 45 วันหลังจากต้นโผล่พ้นผิวดิน

ข้าวไร่ทั้ง 5 พันธุ์ มีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติในแง่ จำนวน ความยาว และความหนาของราก พบว่าเจ้ามัดซึ่งเป็นพันธุ์ที่มีการเจริญเติบโตและผลผลิตดีที่สุดในการปลูกข้าวไร่แบบต่อเนื่องในสภาพไร่ มีจำนวน ความยาว ตลอดจนสัดส่วนของรากต่อส่วนเหนือดินสูงกว่าข้าวไร่พันธุ์อื่น ๆ โดยที่รากของเจ้ามัดมีความหนาน้อยกว่าพันธุ์อื่นๆ ในทางตรงกันข้ามพบว่า นกและเวียงซึ่งเป็นพันธุ์ที่มีการเจริญเติบโตและผลผลิตต่ำ ภายใต้ระบบการปลูกข้าวแบบต่อเนื่อง มีจำนวน ความยาว ตลอดจนสัดส่วนของรากต่อส่วนเหนือดิน ต่ำกว่าพันธุ์อื่นๆ แต่มีความหนาของรากมากกว่าพันธุ์อื่นๆ นอกจากนี้ความยาวเฉลี่ยต่อรากของพันธุ์นกและเวียง ยังน้อยกว่าพันธุ์อื่นอีกด้วย ในการเก็บตัวอย่างครั้งสุดท้าย พบว่าพันธุ์หมากหินสูงและเจ้ามัด มีความยาวเฉลี่ยของแต่ละราก สูงกว่า 3 พันธุ์ที่เหลือ ความแตกต่างของระบบรากไม่ได้มีผลทำให้การดูดธาตุ N, P, K และ Ca ทั้งหมดต่อต้น ของข้าวไร่แต่ละพันธุ์มีความแตกต่างกันในทางสถิติ สาเหตุที่เป็นเช่นนี้อาจเนื่องมาจากการทดลองครั้งนี้ ดินในแต่ละกระถางถูกจำกัดให้มีปริมาตรเท่ากัน และมีการให้น้ำอย่างพอเพียงและไม่เป็นตัวจำกัดในการเจริญเติบโต ความแตกต่างของระบบรากดังกล่าวอาจมีผลทำให้ประสิทธิภาพของการดูดใช้น้ำและธาตุอาหารในสภาพไร่แตกต่างกันและทำให้ผลผลิตของข้าวไร่ของข้าวทั้ง 5 พันธุ์แตกต่างกันด้วย

คำสำคัญ: ข้าวไร่ ประเทศลาว พันธุ์ ราก ส่วนเหนือดิน

Introduction

In the highlands of Laos, upland rice has traditionally been grown in slash and burn systems with long fallows. The farmers rely on extended fallow period to restore soil fertility and to reduce problems from weeds and pests. However, increasing population pressure has recently led to shorter fallow periods and declining upland rice yields (Roder, 2001; Saito, 2005). In various field studies, it has been shown that upland rice yields cannot be sustained in continuously annual upland rice cropping systems (Roder et al., 1995; Kondo, 1996; Saito, 2005). The reason for yield declining is not well understood but results from other studies (Saito, 2005; Sengxua, 2007) suggest that it may be related to limited nutrient availability and root pests. Furthermore, in continuous upland rice cropping systems high weed populations and increases in aphid infestation (*Tetraneuta nigriabdominalis*) of rice roots have also been reported (Van Keer, 2003). In this case, the root systems have to compete with weed for water and nutrients absorption and maintain root formation and development against pest infestations. The hydraulic and nutrient uptake properties of roots vary with species, with variety, and with environmental conditions (Brewig, 1937; Brouwer, 1954; Weatherley, 1982; Kramer and Boyer, 1995), these varieties may be important in maintaining upland rice yields.

In order to enhance the exploitation of water and nutrients from the soil, upland rice needs more extensive root systems. Other researchers have reported genetic variation in root characteristics (Bertrand, 1971; Kondo, 1996). The fineness of root, total length of root systems and the total volume of soil exploited are the characteristics of root morphology that may affect growth of continuously cropped upland rice. These are critical factors for root systems that may vary between genotypes/varieties (Kondo, 1996). An understanding of the genotypic differences in development of the root systems may help in selecting appropriate varieties and effective nutrient management approach for upland areas of northern Laos. The objective of this study was to evaluate root systems, shoot growth and nutrient uptake of five upland rice varieties (Makhinsung, Laboun, Chaomad, Nok and Vieng). These varieties have been shown to perform differently under continuous annual cropping (Sengxua, 2007).

Materials and Methods

A pot study was set up to evaluate root and shoot growth and the development of five traditional Lao upland rice varieties: Makhinsung (MS), Laboun (LB), Chaomad (CM), Nok (NK) and Vieng (VG) at early growing stage. Vieng is a popular variety in the study area and was used as a control, the other varieties are being recommended to farmers growing rice in short fallow and in more intensively cropped upland rice fields. Plastic pots, 40 cm in diameter and 50 cm tall, were used. In the bottom of each pot, four 1 cm diameter holes were made to prevent soil water saturation. The soil used in this experiment was collected from the top 20 cm of a field that had been planted to upland rice in each of the past three years (soil properties are shown in Table 1). The soil was well mixed and passed through 1 cm sieve. Each pot received 29 kg of dry soil compacted to a uniform root penetration resistance of 28 to 33 kg/cm^2 as measured by a "Lang" penetrometer (Lang, 1987).

The experiment was initiated at the beginning of the 2005 wet season at the Northern Agricultural and Forestry Research Center (NAFReC) in Luang Prabang province in northern Lao PDR. The experiment was designed for three sampling times and separate pots were used for each sampling time. Each sampling time was set

Table 1 Physical and chemical properties of the soil used in the root system evaluation experiment

Soil properties	Value
Physical properties[1/]	
Sand (%)	20
Silt (%)	38
Clay (%)	42
Chemical properties	
pH (1:2.5 H_2O)	5.5
OM (%)[2/]	2.03
N (%)[3/]	0.16
Available P (mg/kg)[4/]	1.7
Available K (mg/kg)[5/]	201.56

[1/]Hydrometer method, [2/]Hence method, [3/]micro-Kjeldahl method, [4/]Olsen method, [5/]1N ammonium acetate pH 7.0

up as a randomized complete block design with varieties as treatments. Sampling times were 15, 25 and 45 days after emergence (DAE). All of those three sampling dates were replicated three times.

Ten rice seeds were sown in each pot. Five days after sowing (when the seedlings had emerged) the plants in the pots were thinned so that those pots to be sampled at the 15 DAE had three seedlings per pot, those to be sampled at 25 DAE had two seedlings per pot, and those pots to be sampled at 45 DAE had one seedling per pot. At planting time, six litres of water was added to each pot to obtain field moisture capacity and each pot was weighed. The pots were placed in an open field at the research station. The replications were re-randomized at least once a week and pots within a replication were re-randomized every four days. When the surface soil was dry the pots were weighed and water was added to bring the pot back to field capacity weight.

At 15, 25 and 45 DAE, the pots to be sampled were placed in water for 2 to 3 hours before carefully removing the soil and other organic debris from the roots. The roots were separated from the shoots and shoot dry weight was measured after plants were dried in an oven at 75°C. The number of main roots (roots directly connected to the root crown) was determined for each plant. Root length was measured using the intersect method developed by Newman (1966) and modified by Tennant (1975). A 1 cm grid unit (Gn) was used and root length (RL) in cm was calculated as:

$$RL = \frac{11}{14} xNxGn$$

where: N = number of times a root intersected a grid line.

Root dry weight (RDW) was determined after drying the root in an oven at 75°C for 48 h. The root thickness (Rt) was expressed as mg/cm

(Boonstra, 1931) and calculated using the following equation:

$$Rt = \frac{RDW}{RL}$$

The plant materials sampled at 45 DAE were analyzed for nutrient contents. For total N determination, plant samples were digested with concentrated H2SO4 and measured by a flow injection analyzer (FIA) (Evelina, 1986). For P, K and Ca determination, samples were digested by HNO_3+$HClO_4$ (wet oxidation method), P was measured by a spectrophotometer, K and Ca me asured by a flame photometer.

The experimental data was analyzed using analysis of variance (ANOVA) and comparison of means (Gomez and Gomez, 1984), with the program "STATISTIX 8" (Analytical Software, 2003).

Results

All rice varieties grew well during the experimental period. Between 15 and 45 DAE, shoot dry weights of all varieties increased exponentially. Only at 15 DAE, there were significant differences in shoot dry weight between varieties. At 15 DAE, VG had the lowest total dry weight and this trend continued through 25 and 45 DAE. At 15 DAE the total dry weights of all varieties ranged from 0.19 to 0.28 g/plant (Fig. 1a) and increased to 1.22-2.40 g/plant at 25 DAE (Fig. 1b), and at 45 DAE they increased further to 13.95 to 27.54 g/plant (Fig. 1c).

At the first two sampling times (Fig. 1a, b), root dry weight did not differ significantly among varieties. Root dry weights of different varieties at 15 DAE ranged from 0.037 to 0.05g/plant. They increased rapidly between 25 and 45 DAE ranging from 0.24 to 0.48 and 1.78 to 5.5 g/plant, respectively (Fig. 1a, b, c).

The root-to-shoot ratios ranged from 0.22 to 0.25, 0.23 to 0.26 and 0.11 to 0.29 at 15, 25 and 45 DAE, respectively (Fig. 2). Root-to-shoot ratios of all varieties at the first two sampling times was similar, however, at 45 DAE, the root-to-shoot ratio of CM was significantly greater than the other varieties. In contrast, the root-to-shoot ratio of NK was the lowest.

Total root length per plant of the five upland rice varieties was significantly different at all three sampling times. At 15 DAE, root length ranged from 89 to 180 cm per plant and the varieties LB and CM had significantly greater root length than NK and VG. However, at 25 DAE there was no significant difference in root length between the five varieties. At this sampling time the root length ranged from 788 to 1361 cm per plant (Fig. 3). At 45 DAE, the values of total root lengths per plant were 7848, 7880, 14400, 2963 and 3943 cm per plant for MS, LB, CM, NK and VG, respectively. So, CM had longer root length per plant than MS, LB, NK and VG by 83, 83, 386 and 265% respectively (Fig. 3). This also implies that between 25 and 45 DAE, the differences in total root length between the five varieties (especially CM) emerged.

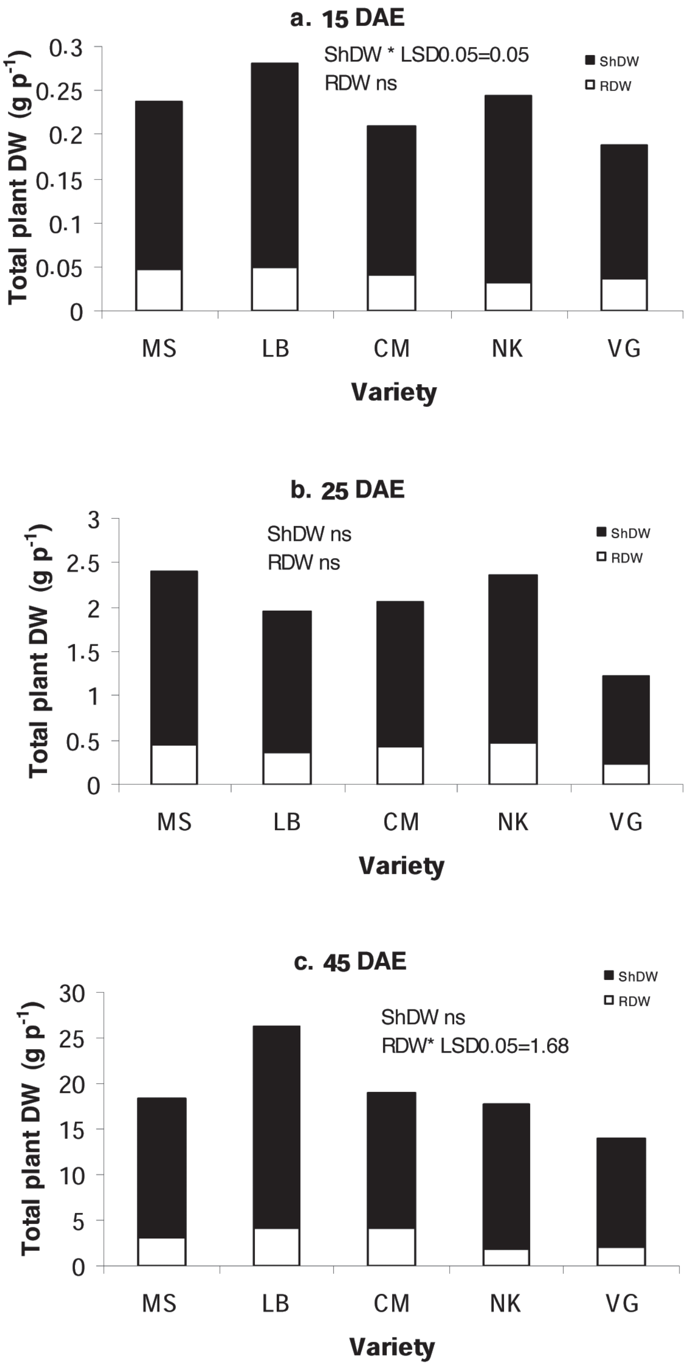

Fig. 1 Dry weights (g/plant) of five upland rice varieties at 15, 25 and 45 DAE of pot experiment conducted at NAFReC, Luang Prabang province in 2005. Values presented are the means of three replications. ShDW-shoot dry weight, RDW-root dry weight, DAE-days after emergence, MS-Makhinsung, LB-Laboun, CM-Chaomad, NK-Nok, VG-Vieng.

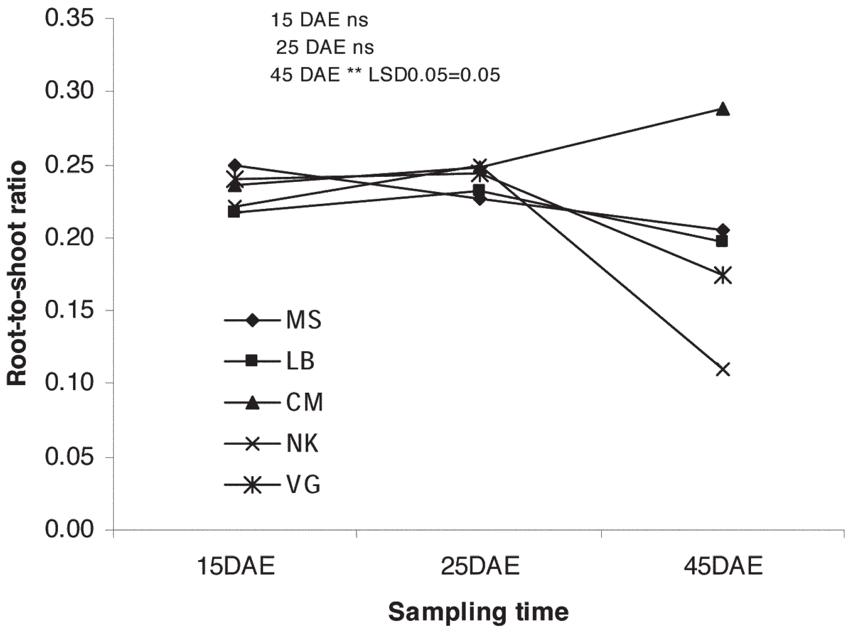

Fig. 2 Root-to-shoot ratios of five upland rice varieties under three different sampling times (15, 25 and 45 DAE) of pot experiment conducted at NAFReC, Luang Prabang province in 2005. Values presented are the means of three replications. DAE-days after emergence, MS-Makhinsung, LB-Laboun, CM-Chaomad, NK-Nok, VG-Vieng.

The number of main roots per plant differed significantly between varieties at 15 and 45 DAE sampling times. The pattern of increasing root number among the five rice varieties was similar to that for root length (Fig. 3). The number of roots at 15 DAE ranged from 12 to 20 roots per plant (Fig. 4), CM had significantly more roots than NK and VG. At 25 DAE, root number increased by 313, 261, 260, 271 and 250% for MS, LB, CM, NK and VG, respectively compared to the root number at 15 DAE. At this sampling time NK and VG had the lowest root number. At 45 DAE, the root numbers increased to 139, 227, 232, 95 and 107 roots per plant for MS, LB, CM, N and V, respectively as compared to those at 25 DAE. At 45 DAE, CM and LB varieties had comparable root number and had the highest number of roots, whereas NK and VG had the least, as in the previous two sampling times. The root growth pattern of NK differed from those of the other varieties as its root number increased linearly across the sampling times.

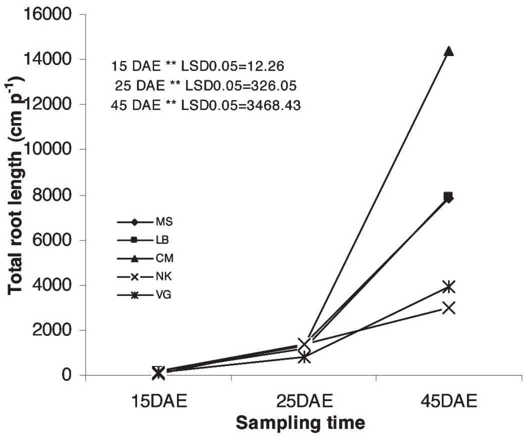

Fig. 3 Total root length (cm/plant) of five upland rice varieties during the vegetative phase in the pot experiment conducted at NAFReC, Luang Prabang province. DAE-days after emergence. MS-Makhinsung, LB-Laboun, CM-Chaomad, NK-Nok and VG-Vieng. Values presented are the means of three replications.

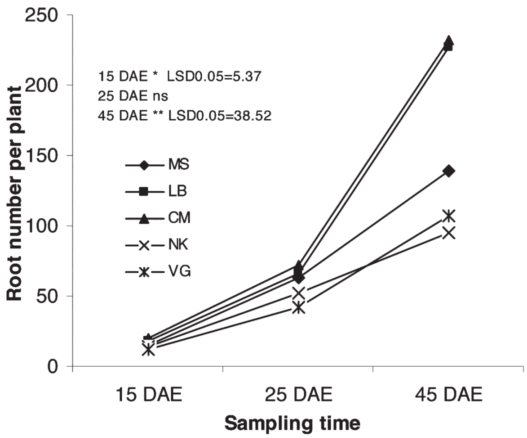

Fig. 4 Root number per plant of five upland rice varieties during the vegetative phase in the pot experiment conducted at NAFReC, Luang Prabang province. DAE-days after emergence. MS-Makhinsung, LB-Laboun, CM-Chaomad, NK-Nok and VG-Vieng. Values presented are the means of three replications.

There were large differences between varieties in average root thickness. Root thickness of NK was greatest at both 15 and 45 DAE (Fig. 5), indicating that the roots of NK were thicker than the other varieties. CM had the lowest root thickness at both sampling dates, indicating that its root system was finer than other varieties and significantly different at the 45 DAE sampling time. However, there was no significant difference between the five rice varieties in root thickness at 25 DAE.

There were significant differences in the average root length (root length to root number) between the five rice varieties at 15 and 45 DAE sampling time (Fig. 6). The average root length at 15 DAE ranged from 6 to 11cm and increased to 18 to 26 cm at 25 DAE and 31 to 63 cm at 45 DAE. MS and VG had the longest whereas NK possessed the shortest average root length at 15 DAE. However, CM had the longest average root length at 45 DAE. In contrast to root thickness, the average root length (root length to root number) of almost all varieties increased with the growing duration.

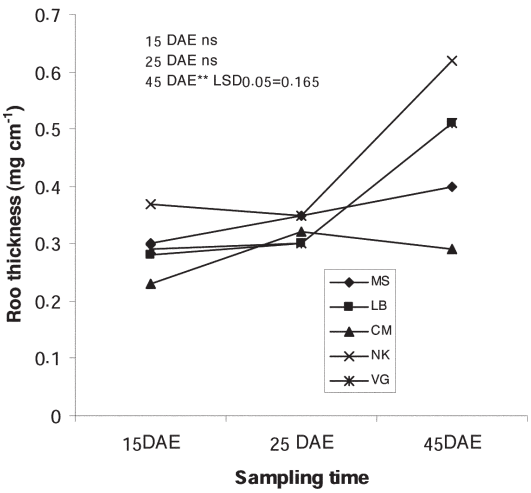

Fig. 5 Root thickness (mg/cm) of five upland rice varieties during the vegetative phase in the pot experiment conducted at NAFReC, Luang Prabang province. MS-Makhinsung, LB-Laboun, CM-Chaomad, NK-Nok and VG-Vieng. Values presented are the means of three replications.

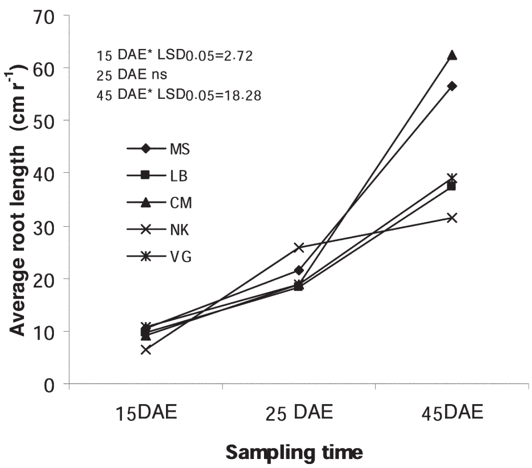

Fig. 6 Average root length (cm/root), of five upland rice varieties during the vegetative phase in the pot experiment conducted at NAFReC, Luang Prabang province. MS-Makhinsung, LB-Laboun, CM-Chaomad, NK-Nok and VG-Vieng. Values presented are the means of three replications.

The total nutrient contents of the five rice varieties are shown in Table 2. There was no significant difference between varieties in all the nutrient parameters measured. Total N, P, K and Ca uptakes of all varieties ranged from 304 to 404, 17 to 24, 788 to 1045 and 44 to 60 mg/plant, respectively (Table 2).

When nutrient uptake was calculated per root length, significant differences among varieties were observed (Table 2). NK had the lowest root length but nutrient uptakes per cm root length were the greatest for all nutrients measured. In contrast, CM had the longest root system and the lowest nutrient uptake per cm of root (Table 2).

Discussion and Conclusion

Rooting characteristics of rice are basically genetically controlled (Bertrand, 1971) but they are also affected by soil conditions and crop management practices (Yoshida, 1981; Sharma et al., 1994). In this study, under similar soil, water and nutrient conditions there were significant variations in rooting characteristics between the five varieties. Varieties differed in number, length and thickness of roots.

Results from field experiments, where these five upland rice varieties have been compared on soil cropped continuously to rice for

Table 2 Total nutrient uptake and nutrient uptake related to root length in vegetative stage of five upland rice varieties under pot experiment conducted at NAFReC, Luang Prabang province in 2005.

Variety	N	P	K	Ca
		Total uptake (mg/plant)		
Makhinsoung	404	22	993	60
Laboun	403	20	1004	57
Chaomad	373	24	1042	59
Nok	361	23	1045	58
Vieng	304	17	788	44
F-test	ns	ns	ns	ns
C.V. (%)	40.7	46.1	36.7	34.6
		Uptake related to root length (μg/cm)		
Makhinsoung	51 bc	3 bc	123 bc	8 bc
Laboun	47 bc	2 bc	118 bc	7 bc
Chaomad	26 c	2 c	72 c	4 c
Nok	128 a	8 a	362 a	20 a
Vieng	73 b	4 b	190 b	11 b
F-test	** **	**	**	
C.V. (%)	26.2	25.5	23.0	26.1

ns- not significant.
** Significantly different at $P<0.01$
Values in a column followed by a common letter are not significantly different at LSD 0.05.

several years, CM out yielded the other varieties and that NK and VG performed poorly (Sengxua, 2007). This pot study was designed to determine if these differences in productivity were related to the root system characteristics. In continuously cropped fields where no fertilizer inputs are added, nutrient availability declines (Gupta and O'Toole, 1986) and a more extensive root system would allow for increased nutrient uptake (Kondo, 1996). Furthermore, water can often be limiting in the uplands and has been shown to limit rice productivity (Saito, 2005). A more extensive root system would allow the crop to better acquire water (Kondo, 1996; Puckridge and O'Toole, 1981, Yoshida and Hasegawa, 1982). In this study, CM had a more extensive root system with a greater number of roots, with greater average root length and on overall longer and finer root system. Furthermore, CM seemed to allocate a greater proportion of photosynthates to root growth as seen by the higher root to shoot ratio. All of these factors should allow CM to have greater access to limited nutrients and perform better under water and nutrient limiting conditions. In contrast, the varieties that had poor root systems such as NK and VG had low yields in continuously cropped soils, which may be related to having lower access to nutrients and water limiting conditions.

Our nutrient uptake data did not support the hypothesis that the plant with more extensive root system would take up more nutrients. It might be because the five rice varieties were grown in plastic pots that had limited amount of soil (29 kg soil contained in each pot with 40 cm in diameter and 50 cm tall) and were grown for only 45 days under non-limiting water conditions. This limited volume of soil had the same amount of nutrients per pot and might reduce the advantage of the rice variety that had longer root systems as shown by their same amount of total nutrient uptake per plant. When total nutrient uptakes were calculated per cm root length, the variety that had longer root system would naturally have lower nutrient uptake than the one with shorter root system. However, this phenomenon might not occur if they were grown under field conditions. If the root growth of the variety that has greater number of root and more extensive root system is not limited by the volume of the container, it might be able to explore a larger and deeper volume of soil. Thus, more water and nutrient would be absorbed by the rice variety with more extensive root system, thus leading to greater yield in the upland field condition (Sengxua, 2007). Moreover longer root system may help reduce the negative impact of root pest such as root aphid and lead to greater survival.

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