VOL. 5, NO. 2, MARCH 2010 ISSN 1990-6145
ARPN Journal of Agricultural and Biological Science

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ROOTS SPATIAL DISTRIBUTION AND GROWTH IN BAMBARA GROUNDNUTS (*Vigna subterranea*) AND NERICA RICE (*Oryza sativa*) INTERCROP SYSTEM

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ABSTRACT

Intercropping offers advantages if well planned including improved soil fertility and yields. Bambara groundnuts have been shown to yield in low fertility soils and have been described as a complete food. NERICA rice has been reported to offer higher yields and shorter growing seasons. Cropping systems that combine both these crops in production systems will help alleviate malnutrition and food insecurity. Despite these benefits, interaction of the intercrop species in the intercrop system is key to its success. Differential niche resource mobilization is required for the two crop species to interact positively and eliminate un-necessary competition. Therefore the objective of this study was to evaluate the roots spatial distribution and their growth in Bambara groundnuts (*Vigna subterranea*) and NERICA rice (*Oryza sativa*) intercrop system. Greenhouse experiments was set up involving root zone partitioning to allow the roots of the two crops grow separately and unpartitioning which allowed the roots of the two crops to intermingle and interact. The roots length, root density, and root volume was evaluated and subjected to analysis of variance and means separated by LSD at 5% level of significance. Root length, root volume and root density of bambara groundnuts did not show any significant ($P>0.05$) differences at 24 and 38 DAS but showed significant ($P\leq0.05$) differences in some root diameter classes at 52 DAS. Root length was significantly ($P\leq0.05$) higher in bambara groundnuts grown in association with NERICA rice in the same root zone in the greenhouse at 52 DAS than roots of plants grown in separated root zones as sole crops. On the other hand NERICA rice 11 grown as sole crop in partitioned root zones showed significantly ($P\leq0.05$) higher root length per diameter class as compared to NERICA rice 11 grown in association with bambara groundnuts as intercrops in unpartitioned root zones. The soil volume occupied by bambara roots grown in association with NERICA rice was significantly ($P\leq0.05$) higher than volume occupied by roots of plants grown in sole system in partitioned root zones. NERICA rice 11 roots of plants grown in sole system in partitioned root zone showed significantly ($P\leq0.05$) higher root volume occupation than roots of NERICA rice grown in association with bambara groundnuts in intercrop system in unpartitioned root zone at 52 DAS. The root length of bambara groundnuts grown in association with NERICA rice 11 was higher while the root length of NERICA rice was reduced. Similarly growing the two crops in the same root zone resulted in bambara groundnuts occupying greater soil volume and having higher root density. Therefore this demonstrates differences in niche activities of the two crops showing better resources mobilization under intercropping system.

Keywords: Bambara groundnut, NERICA rice, intercropping, root density, growth, yield.

INTRODUCTION

Legume-cereal intercropping is a method to obtain greater and more stable crop yields, improve the plant resource utilization (water, light, nutrients), increase the input of leguminous symbiotic nitrogen fixation to the cropping system and reduce negative impacts on the environment [1]. However, due to agricultural intensification of plant breeding, mechanization, and fertilizer and pesticide use over the last 50 years, intercropping has received less attention in many farming systems. Motivations for reintroducing grain-legume-cereal intercropping relate to the problems faced by intensive farming systems. It has become evident that agricultural production systems often characterized by monocultures, nutrient surpluses, and large external input of fertilizer, pesticides and feed concentrates are not sustainable in the long term. On the medium and long term this causes undesirable economic, ecological, environmental and social effects. Intercropping offers the potential for; generating more stable yields, due to self-regulation in the crop. This will give the farmer better insurance against crop failure and will safeguard the farmer's earnings, improving product quality such as greater protein content of cereals, via planned competition, providing an ecological method via competition and natural regulation mechanisms and planned biodiversity to manage weeds and pests, hence reducing the cost of energy for weed and pest control, and improving the synchrony between microbial immobilization-mineralization and crop N demand, due to differences in the quality of the residues and thereby aiding in the conservation of N in the cropping system.

Implementation of legume-cereal intercropping into viable crop rotations may solve some of the problems current farming practices are facing. However, knowledge on competitive interactions in intercrops is required to better predict and manage the outcome of competition and thus the symbiotic nitrogen fixation input into the cropping system.

Bambara groundnut has been reported as one of the indigenous food crop found in western Kenya that has a potential for reducing food and nutritional insecurity [2,3]. It is an Indigenous African crop that has been cultivated in Africa for centuries [4]. It's a highly nutritious plant which plays a crucial role in people's diets and is currently grown throughout Africa. Despite its usefulness, Bambara groundnuts remain one of the neglected crops by scientific community and are commonly referred to as 'a poor mans crop' [4].

Rice is a staple food for nearly 2 billion people and Kenya produces around 1.7 tones of rice under rainfed conditions [5]. Rice (*Oryza sativa L*) is a major source of food throughout Asia and other parts of the world and is consumed by half of the world population as a staple food [5]. Area under rice cultivation is approximated to be 150,000,000 ha worldwide while its production stands at 500,000,000 tonnes. Therefore, evaluation of its performance when intercropped with a legume in this region is key to alleviating poverty and crops diversification

REVIEW OF LITERATURE

Root system morphology and fine root distributions are cardinal factors in determining the magnitude of belowground interspecific competition in mixed species systems. To improve the utilization efficiency of soil nutrient resources by intercropping systems, the spatial distribution and activities of roots requires elucidation [6]. However, a limited number of studies have dealt with these aspects due to the considerable cost and time involved in examining root systems. Root studies should preferably be carried out under field conditions, where both the influences of plant height and boundary effects as well as the restrictions on root growth due to a limited volume of soil are avoided. However, many root studies have been carried out within confined soil volumes and under controlled environmental conditions and the results of these should be considered with some caution [7]. In the field techniques employing the using of radioisotopes for measuring root development may be able to overcome some of the disadvantages posed by digging and washing of soil and root material. Increased knowledge about intercrop belowground roots distribution may improve the management of crop soil exploration, and the search for nutrient and water through allowing induced changes to the root growth dynamics.

Estimating root growth dynamics and biomass is also important for understanding nutrient cycling. The most common approach to root measurement of field-grown plants has been to physically remove the roots from soil. Roots systems have been recovered by excavation, sampling into trench sides or by means of auger boring and soil coring [7]. Given the difficulty in quantitatively recovering roots it is recognized that such procedures are likely to underestimate the amount of roots present. Nonetheless physical recovery has been used in several novel field experiments. Root observation is an alternative method, whereby a viewing surface is inserted into the soil. This *in situ* system can be used to repeatedly measure root distribution, diameter, longevity, periodicity and turnover [8]. Several methods such as mini-rhizotrons, miniature windows and root observations laboratories have been used in the past. However, during the installation of root-viewing equipment, e.g. rhizotron tubes changes in soil structure and compression of soil material around the tube may influence the pattern of root growth.

Some studies have employed an indirect technique using radioisotopes for measuring root development. It is assumed that such methods are able to overcome some of the disadvantages of digging and washing soil and root material as well as inserting root-viewing equipment into the soil profile. Little work has been reported on roots distribution and functioning in an intercrop system. The resources utilization is key element in success of an intercrop system. Utilization from different niches both at above ground and below ground for the two intercropped species is encouraged and could serve as a basis for selecting the intercrop crops.

MATERIALS AND METHODS

Boxes/pots measuring 30 cm by 40 cm and height of 60 cm were used. Six boxes were fixed with thin plastic barrier from the bottom to the top while other six boxes were not fixed with the barrier. All the twelve boxes were filled with sand media and randomized completely. They were then watered to 80% water holding capacity and then planted with the NERICA 11 and Bambara groundnuts. Boarder boxes were also installed to ensure the safety and less interference of the boxes to be harvested for evaluations

Roots were carefully harvested for both crops in both partitioned and non partitioned roots zones. The root length was taken immediately and the roots including broken root parts were packaged in beakers and taken to the freezer waiting scanning with subsequent determination of root dry weights. Scanning of the roots was done by Epson Perfection 4990 Photo using the WinRHIZO programme. The roots were first washed carefully ensuring that no roots were lost. The roots were then floated in water in acrylic trays on the scanner. This allowed the roots to be arranged to reduce overlap and crossing. WinRHIZO and the scanner allowed the roots to be lit from above and below while being scanned. This Dual Scan reduced shadows on the root image. Optimum scanning resolution depends on the type of samples. Since bambara and rice roots have no specific scanning resolutions recommended, the recommended *Phaseolus vulgaris* roots resolution of 200-400 dpi in 20 x 30 cm trays, was used [9]. The scanning results identified and classified the roots in terms of diameter by assigning each diameter class a different colour. Therefore the data on root length, root volume and number tips was obtained based on root diameter class which ranged from 0.00 mm to 2 mm with intervals of 0.1mm. Similarly the scanning yielded root density by length per volume of soil.

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Data obtained was subjected to analysis of variance (ANOVA) using COHORT computer statistical package to determine if the treatment effects were significant at 5% level. Separation of means was done by Least Significant Difference (LSD) at 5% level.

RESULTS

Root length

Bambara groundnuts

The root length of bambara groundnuts classified based on diameter class when grown in both partitioned and non partitioned root zones showed non significant differences at 24 DAS (Figure-1a). The results in Figure-1a clearly indicated the wide range of bambara root sizes within the soil environment and to what length each can grow. The roots with diameter less than 1mm were less than 30cm in length. The longest roots were in the diameter classes of 0.1mm to 0.2mm, 0.3mm to 0.4mm and 0.5mm to 0.6mm (Figure-1a). But generally the bambara root were spread across all the diameter class ranges from 0.1mm to greater than 1.9mm. At this stage of growth the results showed that roots in unpartitioned root zones had slightly higher root lengths values in all diameter classes except in diameter class of 0.00mm to 0.1mm (Figure-1a). Despite these observations, analysis of variance did not reveal any significant differences in length of roots grown in both root zones at 24 DAS.

At 38 DAS the bambara crop did not show significant differences in root length based on diameter classes in both the root zones (Figure-1b). The same trend observed at 24 DAS was replicated at 38 DAS with roots in unpartitioned root zones having higher root lengths values as opposed to at 24 DAS (Figure-1a). Unlike at 24 DAS, at 38 DAS the bambara roots were observed to increase in length with increasing diameter (Figure-1b). Generally continued growth of the roots was observed but the roots in unpartitioned root zone were found to have higher root length values in almost all the root diameter classes at 38 DAS (Figure-1b). Roots in diameter class of 0.1mm to 0.2mm had the longest length followed by roots in diameter class of 0.3mm to 0.4mm (Figure-1b). The length of roots which had thickness greater than 1.9mm had increased in both root zones as compared to roots at 24 DAS.

The unpartitioned root zone significantly ($P \leq 0.05$) increased bambara root length in the root diameter classes of 0.2 mm to 0.6mm as well as in diameter class of between $0.6 < L \leq 0.7$mm as compared to the root length in partitioned root zone at 52 DAS (Figure-1c). These differences started emerging at 38 DAS though no significant differences were realized (Figure-1c). In all the other diameter classes, the bambara root length values in unpartitioned root zones were above values observed in partitioned root zones though no significant differences were detected by statistical analyses (Figure-1c). At this point of growth the root length of bambara groundnuts was observed to reduce significantly with increasing root diameter class (Figure-1c). The roots in diameter classes of between 0.2mm and 0.7mm were observed to dominate the length of the bambara crop in both partitioned and unpartitioned root zones. Generally the root length of bambara groundnuts in both root zones showed varied responses at 24 DAS, at 38 DAS the root length in unpartitioned root zone showed steady values above length in partitioned root zone and this was able to result in significant differences at 52 DAS (Figure-1c).

VOL. 5, NO. 2, MARCH 2010 ISSN 1990-6145
ARPN Journal of Agricultural and Biological Science

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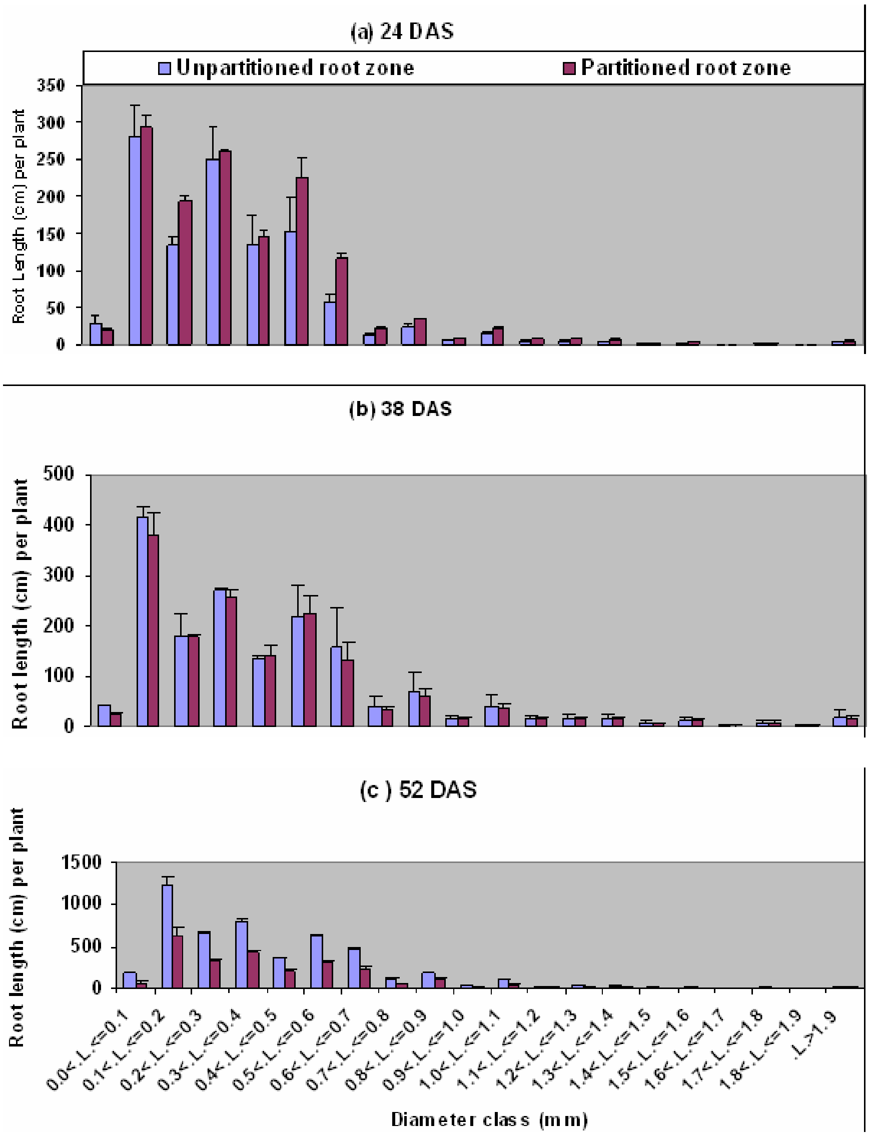

Figure-1 a, b, c: Effect of the root zone partitioning on the root length per diameter class of bambara groundnuts at different stages of growth in the greenhouse.

NERICA 11 rice

The root length in NERICA rice 11 grown in combination with bambara in both root zones did not show significant differences at 24 DAS in all the root diameter classes (Figure-2a). The NERICA 11 roots within the thickness range of 0.0mm to 0.1mm were longer and this was in contrast to bambara roots (Figure-2a). This was similar to thickness range of 0.1mm to 0.2mm. The root length in both root zones decreased with increasing thickness and at thickness of 0.7mm and more, the root length was less than 4.3.4cm and at thickness of 0.9mm and more the root length was less than 1cm (Figure-2a). Analysis of variance at 38 DAS did not detect any significant differences in root length of NERICA 11 grown in both partitioned and non partitioned root zones in all the root thickness classes (Figure-2b). All the roots showed continued increase in length in all the diameter classes as compared to length at 24 DAS. The longest roots were in the thickness range of 0.0mm to 0.2mm. The trend of reducing root length with increasing thickness was observed at 38 DAS with roots at thickness of 0.9mm onwards having length less than 5cm (Figure-2b).

Unlike in bambara groundnuts, the effect of root zone partitioning on NERICA rice 11 root length at 52 DAS was significantly ($P \leq 0.05$) different among some root diameter classes (Figure-2c).Root length in diameter classes; 0.0mm to 0.2mm, 0.5mm to 0.7mm and 0.8mm to 0.9mm were significantly ($P \leq 0.05$) higher in partitioned root zone than in unpartitioned root zone (Figure-2c).The finer roots of less than 0.2mm dominated the rice root length as compared to the other diameter classes. Rice root length was significantly observed to decrease beyond root diameter of 1.2mm (Figure-2c). Partitioned root zone steadily maintained higher values of root length in all the root diameter classes from 24 DAS up to 52 DAS where significant differences were detected (Figure-2c).

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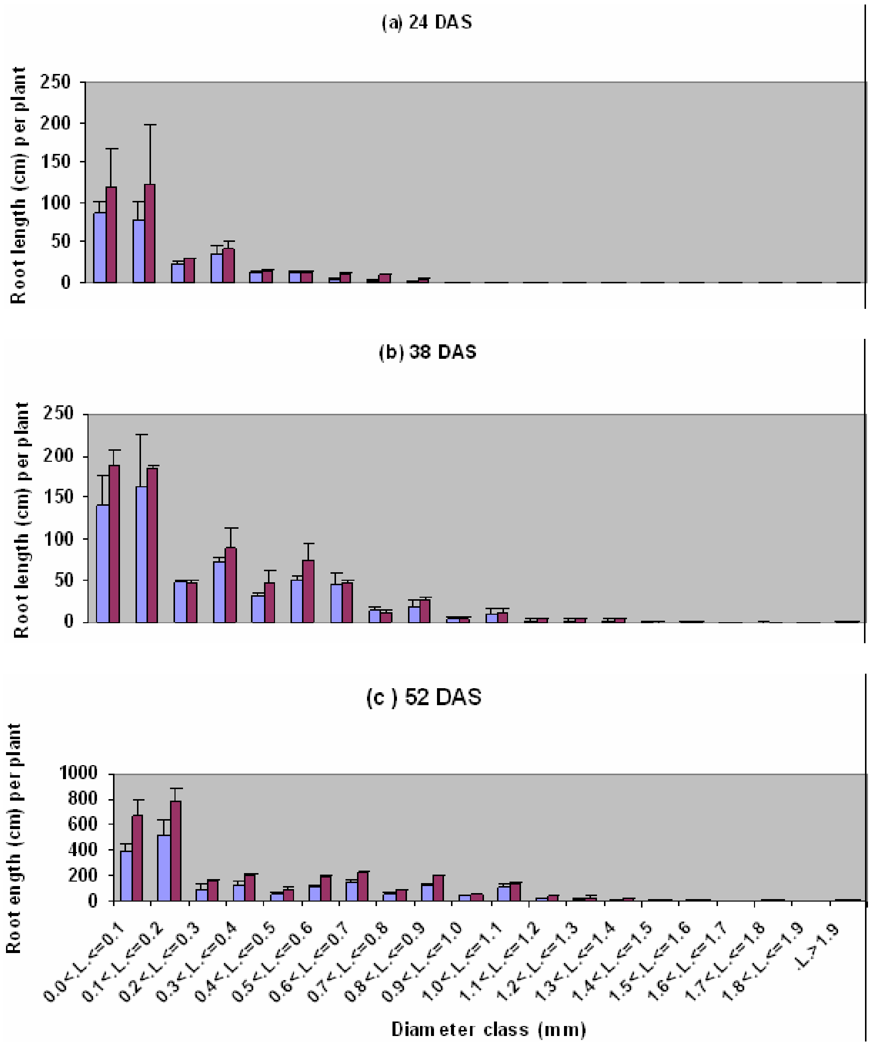

Figure-2 a, b, c: NERICA rice 11 root lengths per diameter class variations during growth in the green house when grown in partitioned and unpartitioned root zones.

Root volume

Bambara groundnuts

The volume occupied by the bambara roots in the different root zones was not significantly different for different classes of root thickness at 24 DAS (Figure-3a). The roots in thickness class of 0.5mm to 0.6mm had the largest volume of 0.5cm^3 in partitioned root zone though it was not significantly different from root volume occupied by roots in the unpartitioned root zone (Figure-3a). Generally the root volume occupied was observed to increase with increasing root thickness from 0.0mm to 0.5mm and then started decreasing with varying volume for different root thickness and increasing sharply for foe roots with thickness greater than 1.9mm (Figure-3a).

The same trend was replicated at 38 DAS with roots having thickness greater than 1.9mm occupying the most volume of 0.4.3.3cm^3 and 0.4.3.2cm^3 in unpartitioned and partitioned root zones respectively (Figure-3b). The root volume between the thickness ranges of 0.0mm and 0.6mm had not changed much as compared to root volume at 24DAS (Figure-9). Unlike at 24 DAS, root volume for bambara grown in unpartitioned root zone was consistently slightly higher than those in partitioned root zone at 38 DAS. Bambara roots with thickness less than 1mm had almost negligible volume at both 24 and 38 DAS.

The root volume of bambara roots in the unpartitioned root zone had significant ($P \leq 0.05$) differences in some diameter classes from the volume occupied by rots in the partitioned root zone at 52 DAS. Root volume in diameter classes of 0.2mm to 1.1mm had significantly ($P \leq 0.05$) higher occupied volume in unpartitioned root zone than in partitioned root zone (Figure-3c). The rest of the diameter classes did not show significant differences in their root volume in both root zones. The root volume was observed to increase rapidly with increasing root diameter to 0.7mm diameter and progressively started to decrease with further increase in root diameter up to 1.9mm and increased sharply for roots with diameter greater than 1.9mm (Figure-3c).

ISSN 1990-6145

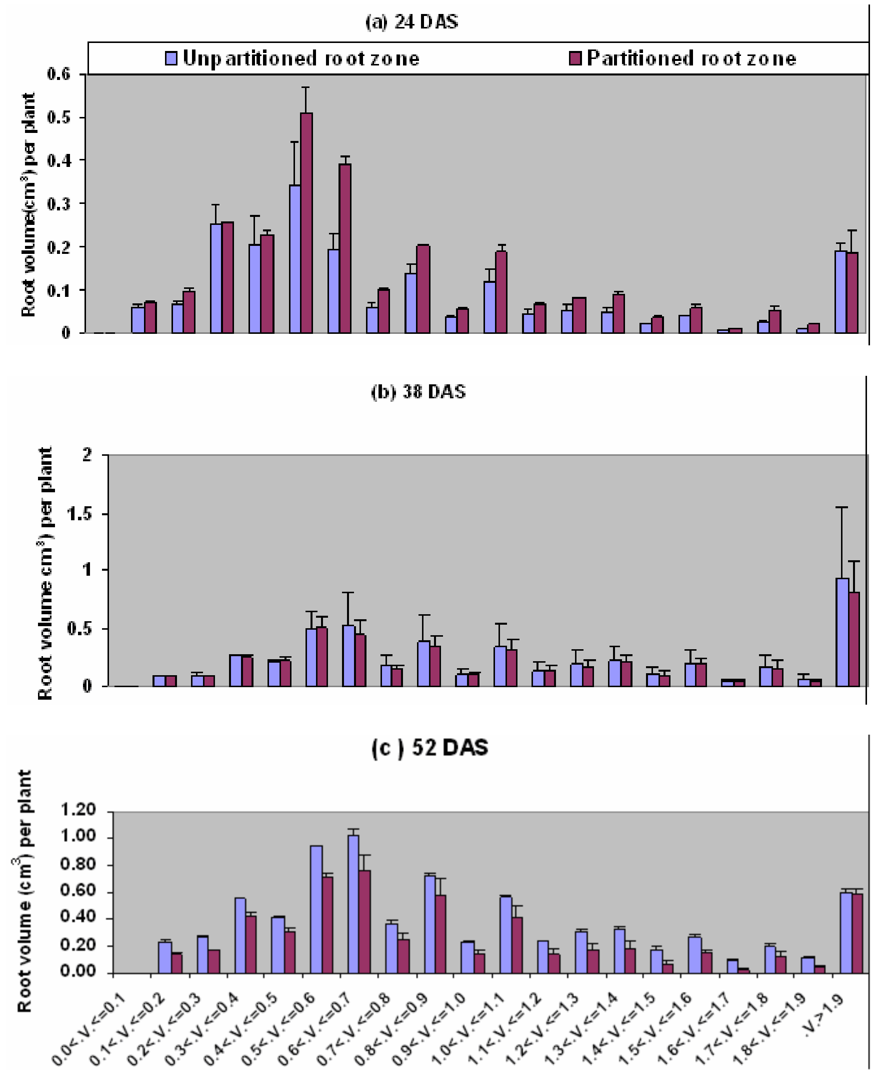

Figure-3 a, b, and c: Root volume per diameter class of bambara groundnuts grown in partitioned and unpartitioned root zones at 24, 38 and 52 DAS in the greenhouse.

NERICA rice 11

The NERICA 11 root volume occupied in both root zones at different diameter classes was not significantly different (Figure-4a). Different root thickness classes had varying volumes occupied with no defined pattern with increasing thickness from 0.0mm to 1.2mm (Figure-4a). From 1.2mm root thickness, root volume consistently reduced up to 1.9mm root thickness and was observed to increase sharply for roots with thickness grater than 1.9mm (Figure-4a). The volume occupied by NERICA 11 roots at 24 DAS by different roots in different thickness classes were generally less than 0.05cm^3, and this was much lower as compared to bambara roots in both partitioned and unpartitioned root zones.

The volume occupied by NERICA rice11 roots was observed to increase with increasing root thickness from 0.00mm to 0.70mm in both root zones and thereby started reducing steadily up to 1.9mm root thickness and increasing sharply for roots with thickness higher than 1.9mm (Figure-4b). The roots within the range of 0.50mm and 0.70mm thickness had higher volume as opposed to 24DAS. Though the values of root volume between the crops grown in partitioned and unpartitioned root zones were different, statistical analyses did not reveal any significant differences (Figure-4b).

The NERICA rice root volume at 52 DAS did not show significant differences in both root zones except for root volume in diameter class of 0.0mm to 0.1mm where root volume in partitioned root zone was significantly ($P \leq 0.05$) higher than in unpartitioned root zone (Figure-4c).

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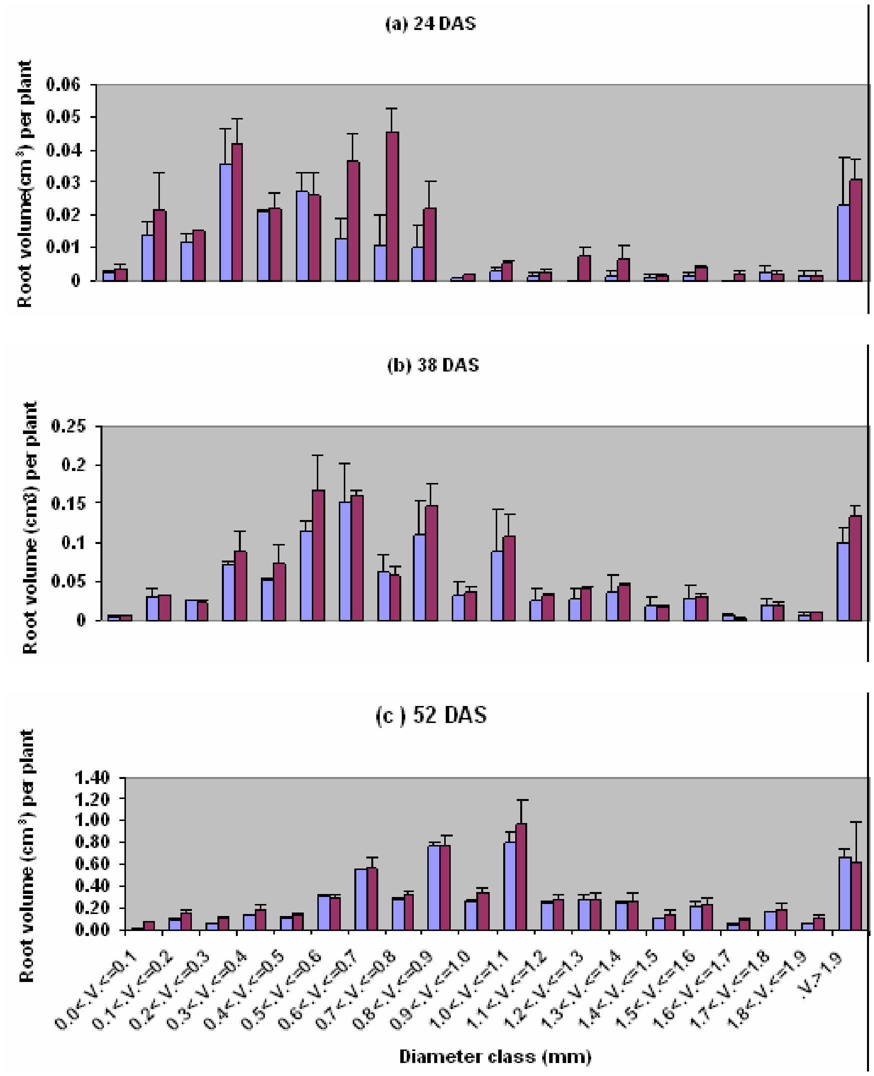

Figure-4 a, b and c: Root volume of NERICA rice 11 per diameter class when grown in greenhouse under partitioned and unpartitioned root zones at 24, 38 and 52 DAS.

Root density

Bambara

The bambara root density given as length per volume was not significantly different in both partitioned and non partitioned root zones at 24 DAS (Figure-5). The value for root density in partitioned root zone was higher than for unpartitioned root zone. At 38 DAS, analysis of variance did not reveal any statistical differences in root density of bambara in both the two root zones (Figure-5). In contrast to higher root density in partitioned root zone at 24DAS, the unpartitioned root zone had the highest root density value at 38DAS (Figure-5).

Root density of bambara groundnuts in unpartitioned root zone showed significantly (P≤0.05) higher results as compared to root density in partitioned root zone at 52 DAS (Figure-5). The root density in unpartitioned root zone was twice the root density in partitioned root zone at 52 DAS (Figure-5).Based on diameter class, the root density of bambara grown in association with rice in unpartitioned root zone had significantly (P≤0.05) higher root density in the diameter class of between 0.00mm and 0.1mm at 52 DAS (Figure-6a). Similar observations were made in all other root diameter classes except the classes between 0.1mm to 0.2mm, 1.4mm to 1.5mm, 1.7mm to 1.8mm and greater than 1.9mm in which no significant differences were observed in the root densities in both root zones.

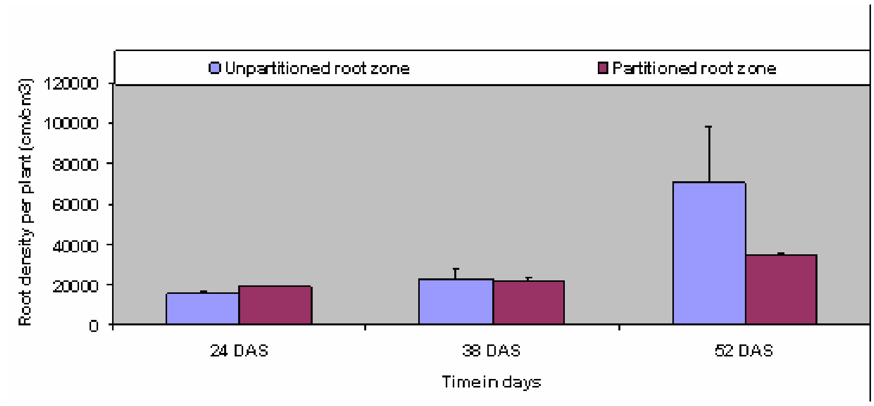

Figure-5. Effect of root zone partitioning on the root density of bambara groundnuts at different stages of growth in the greenhouse.

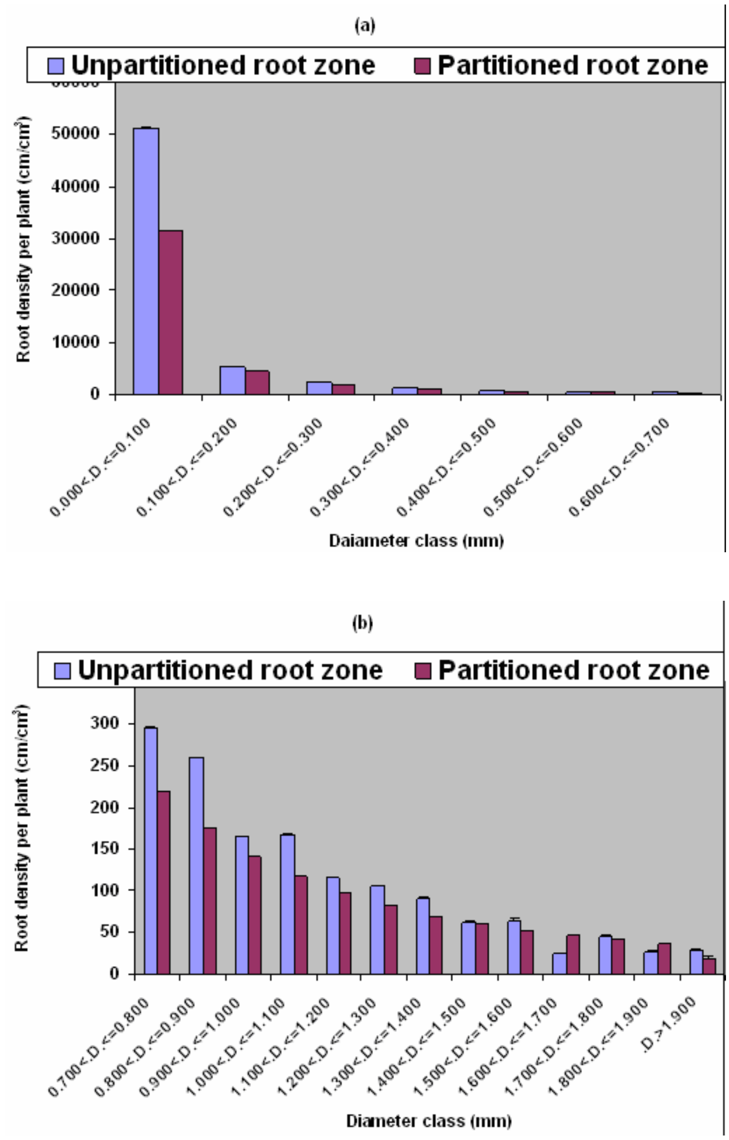

Figure-6 a and b: Influence of root zone partitioning and unpartitioning on root density of bambara groundnuts at 52 DAS in the greenhouse per diameter class.

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NERICA rice 11

NERICA rice root density was not significantly different at 24 DAS though roots in partitioned root zone had slightly higher value of density (Figure-7). This consistently was replicated at 38 DAS. Rice root density was approximately five times less than that of bambara at both 24 DAS and 35DAS for both root zones. At 52 days after sowing, the root density in partitioned root zone had significantly (P≤0.05) increased as compared to root density in unpartitioned root zone (Figure-7).

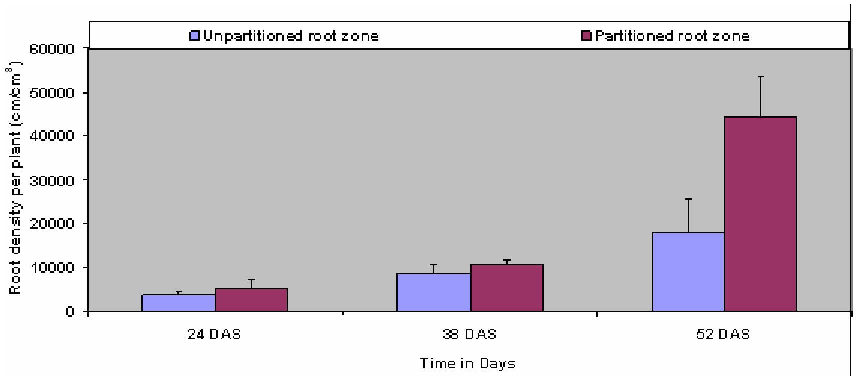
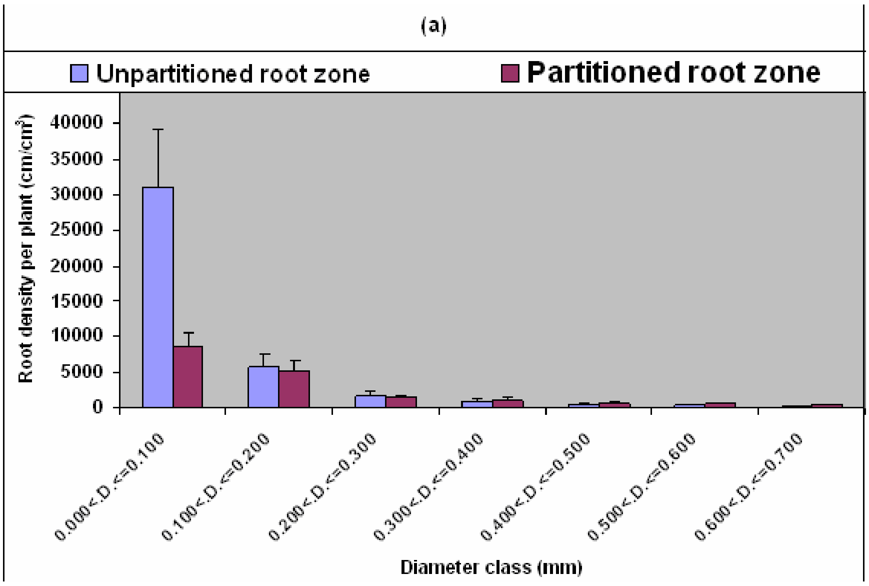


Figure-7. Effect of root zone partitioning and unpartitioning on the root density of NERICA rice 11 grown in the greenhouse at different stages of growth.

Interesting results for root density were observed for NERICA rice at 52 DAS. The root density of NERICA rice grown in association with bambara groundnuts in unpartitioned root zone was significantly (P≤0.05) higher than root density in partitioned root zone in diameter class of 0.00mm to 0.1mm (Figure-8). The subsequent root diameter classes up to 0.7 mm did not show significant differences. As the roots thickened from 0.8mm diameter, the root density of NERICA rice grown as sole crop in partitioned root zone increased significantly and was higher than root densities of NERICA rice grown in unpartitioned root zone in diameter classes of 0.7mm to 0.9mm and between 1.0mm to over 1.9mm (Figure-8).



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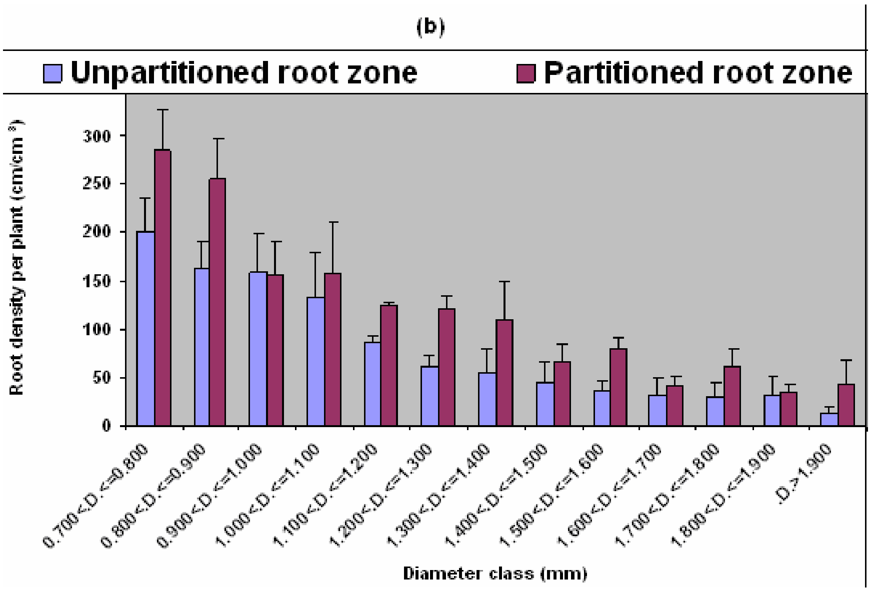

Figure-8 a and b: Effect of root zone partitioning and unpartitioning on the root density of NERICA rice 11 grown in the greenhouse at 52DAS per diameter class.

DISCUSSIONS AND CONCLUSIONS

Effect of root zone partitioning on dry matter allocation and roots interactions

Root zone manipulation by allowing the roots of both bambara groundnuts and NERICA rice 11 to intermingle and eliminating the intermingling completely had significant effect on the dry matter allocation in both roots and above ground organs. The above ground dry matter of bambara groundnuts was reduced while the allocation to the roots was increased when the bambara groundnuts roots were allowed to grow together in the same unpartitioned root zone when compared to bambara in separated root zones later in the growth cycle. The case for NERICA rice was different. The dry matter allocation in the shoots was greater for plants grown in association with bambara groundnuts than in the roots. The NERICA rice grown alone in separated root zone had much of the dry matter allocated in the roots in the initial growth stages. These results compares with the work of [10]. He reported higher above ground biomass in wheat when it was grown in association with white clover. That the largest total biomass was obtained in the absence of both above- and below-ground partitions, when the two species were allowed to fully interact and thus gain access to all available above- and below-ground resources [10]. [11 and 12] have also reported similar results with experiments on cereal legume intercrops.

The NERICA rice seems to alter its dry matter allocation patterns when grown in sole and intercrop systems. The shift in dry matter allocation of the two crops when sole and intercropped is a clear evidence of interspecific competition between the two crops. The root biomass of NERICA rice was reduced in the presence of bambara groundnuts roots when they were allowed to intermingle in unpartitioned root zone. [10] Found similar results with white clover and wheat intercrops with unpartitioned root zone. This suggests greater below ground competition for resources by the bambara roots than the NERICA rice roots. [13] working on intercropping experiments reported that below ground competition for resources is considered more intense than the above ground competition in agricultural fields. The results from root scanning further confirm these observations with bambara having higher root density when intercropped than when sole cropped.

The root systems of both crops shared same root zone volume and same pool for resources when they were grown in unpartitioned root zone. Due to competition the more aggressive bambara was able to ramify its roots deeper and increase its root length density therefore utilizing resources from deep in the root zone. The rice crop with its limited root length density as well as limited dry matter allocation to roots was observed to allocate highly in the above ground organs. This shows an indication of positive competition in which the bambara influences shift in dry matter allocation in rice towards the more important above ground reproductive structures by increasing the number tillers. This observation is further complemented by the results obtained in sole cropped rice crop, in which the allocation of dry matter was high in the roots at the expense of the shoots. This is because the rice plant grown in sole system need to establish a wider root base for resources acquisition therefore it's supplied with most of the photosynthates for development.

Below ground interaction is more important to any intercropping experiment since most of the resources required by the crops are found below ground. Therefore niche differentiation below the ground for uptake of resources for different species is important for a successful positive interaction. This was clear with bambara and NERICA rice intercropped through the shifts in dry matter allocation and differences in root length, root volume and root density. The bambara groundnuts have ability for symbiotic nitrogen fixation and therefore offers less competition for nitrogen. The intermingling of the roots facilitates nitrogen transfer from bambara to NERICA rice. This partly explains the higher allocation of dry matter to above ground reproductive structures development when intercropped with bambara.

Root length, volume and density

Root length, root volume and root density of bambara groundnuts did not show any significant ($P>0.05$) differences at 24 and 38 DAS but showed significant ($P\leq0.05$) differences in some root diameter classes at 52 DAS. Root length was significantly ($P\leq0.05$) higher in bambara groundnuts grown in association with NERICA rice in the same root zone in the greenhouse at 52 DAS than roots of plants grown in separated root zones as sole crops. On the other hand NERICA rice 11 grown as sole crop in partitioned root zones showed significantly ($P\leq0.05$) higher root length per diameter class as compared to NERICA rice 11 grown in association with bambara groundnuts as intercrops in unpartitioned root zones.

The soil volume occupied by bambara roots grown in association with NERICA rice was significantly ($P\leq0.05$) higher than volume occupied by roots of plants grown in sole system in partitioned root zones. NERICA rice 11 roots of plants grown in sole system in partitioned root zone showed significantly ($P\leq0.05$) higher root volume occupation than roots of NERICA rice grown in association with bambara groundnuts in intercrop system in unpartitioned root zone at 52 DAS.

Root growth within the soil is a function of many factors and their extension in both length, volume and density majorly depend on the existing soil conditions and above ground environmental conditions. The differences in root length and root volume and density of roots of the plants grown in association are necessary since it demonstrates the differences in niche activities and utilization of soil resources at different levels.

Roots of bambara groundnuts grown in association with NERICA rice had significantly higher root length, and root density as compare to NERICA rice. Therefore bambara groundnuts was able to occupy a larger volume and this seemed to benefit the associated rice crop since its roots volume and density were significantly lower than those of NERICA rice grown in sole system in partitioned root zone.

From the results there is a possible positive interaction between the bambara and NERICA rice roots below the ground. This is infact confirmed by the results of dry matter allocation, where the higher allocation was observed to occur in roots of bambara groundnuts intercropped while for intercropped rice, higher allocation occurred in the shoots. This difference in dry matter allocation with regard to crops association in intercrop has a direct influence on the yield of the crops. Root density of both bambara and NERICA rice showed significant differences in both root zones at 52 DAS. Root density is related to volume of soil occupied and this defines the acquisition of nutrients and resources require for plant growth from the soil environment.

Root volume has been reported by several authors as a key parameter in evaluating the root system of any given plant [14]. Plants with larger root volumes are able to source resources from a wider soil area [15]. This was the case with bambara when intercropped with NERICA rice. It was able to occupy larger volume as compared to sole cropped bambara. This is important in mobilization of nutrients from wider soil area which benefits the associated crop, the NERICA rice. [16 and 14] reported higher hydraulic conductivity in plants with higher root volume than plants with smaller root volumes. Therefore the plants can source water from deeper soil layers in time of drought or limited water. [17 and 18] reported roots classification based on diameter classes as 0-2 mm (fine root) and 2-5 mm (small root). Root thickness is considered as an important root characteristic contributing to drought resistance [19]. Thick root have larger xylem vessels, persist longer, produce more and larger branch roots and there by increase root length density and water uptake capacity in crops [19 and 20]. Consequently, in practice, root systems must be able to enter and grow through hardpans of drought-hardened soils, in order to capture resources from deeper soil layers. Upland rice cultivars have been reported to have thicker roots than other rice cultivars [21, 22 and 23]. This observation was in line with the results of rice roots grown in partitioned rot zone. Thick roots are able to grow to deeper soil layers. [24] Postulated that thick roots are associated with deep root systems. Similarly studies by [25 and 26] denoted that thicker roots had greater penetration ability. Increase in thickness could also be related to response to root impedance [27] suggested that the increase in root thickness in response to impedance is caused by cortical cells enlarging radially rather than axially, with a corresponding change in the orientation of the cellulose microfibrils in the cell walls.

REFERENCES

[1] Frye W.W and Blevins R.L. 1989. Economically sustainable crop production with legume cover crops and conservation tillage. J. Soil and Water Cons. Jan-Feb. pp. 57-60.

[2] Musoth A.A. 2004. The role of gardening in household food security in Butere Division, Western Kenya. M.Sc. Thesis. Maseno University.

[3] Obuoyo Joyce. A 2005. The role of traditional crops in promoting food security in the dry Siays district, Kenya. M.A Thesis. Maseno University.

[4] Heller J., Begemann F. and Mushonga J. 1997. Promoting and conservation and use underutilized and neglected crops Bambara groundnuts. Proceedings of

the workshop on conservation and improvement of Bambara groundnuts. 14-16 Nov., 1995.

[5] Pal M., Deka J. and Rai R.K. 1996. Fundamentals of cereal crop production. Tata McGraw- Hill Publishing Company Ltd.

[6] Ito O Matsunaga R, Tobita S, Rao T P and Devi Y G. 1993. Spatial distribution of root activity and nitrogen fixation in sorghum/pigeonpea intercropping on an Indian alfisol. Plant Soil. 156: 341-344.

[7] Snaydon R W and Harris P. M. 1981. Interactions belowground- The use of nutrients and water. In: Proceeding of the International Workshop on intercropping, Hyberabad, India. Ed. R W Willey. pp. 188-201. Icrisat, Patancheru, India.

[8] Abbott M L and Fraley L J. 1991. A review: Radiotracer methods to determine root distribution. Env. Exp. Bot. 31: 1-10.

[9] Bouma T.J., Nielson K.L. and Koutstaal B. 2000. Sample preparation and scanning protocol for computerized analysis of root length and diameter. Plant Soil. 218: 185-196.

[10] Thorsted M D, Weiner J and Olesen J.E. 2006. Above- and below-ground competition between intercropped winter wheat *Triticum aestivum* and white Clover *Trifolium repens.* Journal of Applied Ecology. 43: 237-245.

[11] Anil L., Park R.H.P. and Miller F.A. 1998. Temperate intercropping of cereals for forage: a review of the potential for growth and utilization with particular reference to the UK. Grass Forage Sci. pp. 301-317.

[12] Hauggaard-Nielsen H.P. Ambus and E.S. Jensen. 2001. Interspecific competition, N use and interference with weeds in pea-barley intercropping. Field crops research. 70: 101-109.

[13] Wilson P. J, K. Thompson and J. G. Hodgson. 1999. Specific leaf area and dry matter content as alternative predictors of plant strategies. New Phytologist. 143(1): 155.

[14] Antony S. D, Douglass F and Jacobs. 2005. Quantifying root system quality of nursery seedlings and relationship to out planting performance. New Forests. 30: 295-311.

[15] Jacobs D.F., Rose R., Haase D.L. and Alzugaray P.O. 2004. Fertilization at planting inhibits root system development and drought avoidance of Douglars (*Pseudotsuga menziesii*) seedlings. Ann. For. Sci. 61: 643-652.

[16] Carlson W.C. 1986. Root system considerations in the quality of loblolly pine seedlings. South. J. Appl. For. 10: 87-92.

[17] Hayes D.C and Seastedt T.R. 1987. Root dynamics of tall grass prairie in wet and dry years. Canadian Journal of Botany. 65: 787-791.

[18] Joslin J.D and Henderson G.S. 1987. Organic matter and nutrients associated with fine root turnover in a white oak stand. Forest Science. 33: 330-346.

[19] Ekanayake I. J., J. C. Otoole D. P. Garrity and T. M. Masajo. 1985. Inheritance of root characters and their relations to drought resistance in rice. Crop Sci. 25: 927-933.

[20] Ingram K. T., F. D. Bueno O. S. Namuco E. B. Yambao and C. A. Beyrouty. 1994. Rice root traits for drought resistance and their genetic variation. pp. 67-77. In G.

[21] J. D. Kirk (Ed) Rice roots: Nutrient and water use. IRRI, Manila. Philippines. pp. 67-77.

[22] Nguyen H. T., R. C. Babu and A. Blum 1997. Breeding for drought resistance in rice: Physiology and molecular genetics considerations. Crop Sci. 37: 1426-1434.

[23] Samson B. K., M. Hasan and L. J. Wade. 2002. Penetration of hardpans by rice lines in the rainfed lowlands. Field Crop Res. 76: 175-188.

[24] Yu L. X., J. D. Ray, J. C. Otoole and H. T. Nguyen. 1995. Use of Wax-Petrolatum Layers for Screening Rice Root Penetration. Crop Sci. 35: 684-687.

[25] Yoshida S. H. 1982. The rice root systems: its development and function. In: Drought resistance in crop with emphasis on rice. International Rice Research Institute, Lobanos, Philippines. pp. 97-114.

[26] Materechera. S. A., A. M. Alston, J. M. Kirby and A. R. Dexter. 1992. Influence of Root Diameter on the Penetration of Seminal Roots into Compacted Subsoil. Plant Soil. 144: 297-303.

[27] Ray J. D., L. Yu S. R. McCouch M. C. Champoux G. Wang and H. T. Nguyen. 1996. Mapping quantitative trait loci associated with root penetration ability in rice (*Oryza sativa* L). Theoretical and Applied Genetics. 92: 627-636.

[28] Dang Q. N, Soe T, Naoki M, Tran D, Nguyen H.H and Toshihiro M. 2006. Evaluation of Root Penetration Ability in Rice Using the Wax-Layers and the soil cake methods. J. Fac. Agr., Kyushu Univ. 51(2): 251-256.