# Influence of Cropping System on Root Distribution of Annual Crops

**Article** *in* Journal of Agronomy · December 2016



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ISSN : 1812-5379 (Print)
ISSN : 1812-5417 (Online)
http://ansijournals.com/ja

# JOURNAL OF AGRONOMY

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

OPEN ACCESS Journal of Agronomy

ISSN 1812-5379
DOI: 10.3923/ja.2017.12.22

# Research Article
# Influence of Cropping System on Root Distribution of Annual Crops

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## Abstract
**Background:** Root distribution of annual crops is critical for agroecosystem management on sloping dry land. The objectives of this study are to examine the root interactions at intercropping system using combination of annual crops of five species (Rice, maize, peanut, red bean and cassava) and to understand their effects on root distribution and soil physical conditions (Bulk density and soil porosity). **Materials and Methods:** Seven combinations of annual crops ("Rice+maize", "Peanut+maize", "Red bean+maize", "Peanut+cassava", "Red bean+cassava", "Rice+cassava" and "Red bean") were observed by measuring root biomass, root length, bulk density and soil porosity. **Results:** Combination of "Red bean+maize" resulted in larger biomass of thin root at 0-5 cm soil layer, longer Root Length Density (RLD) of fine root at 10-15 cm soil layer, longer RLD of fine and thin root at 15-20 cm soil layer, decrease in bulk density and increase in soil porosity. The result of PCA indicates that vertical root distribution is restricted if biomass of fine root is concentrated at 0-5 and 5-10 cm soil layers, if Root Area Ratio (RAR) of fine root is concentrated at 0-5 cm soil layer and if RAR of thin root is concentrated at 15-20 cm soil layer. Horizontal root distribution is restricted if biomass of fine root is concentrated at 10-15 cm soil layer and if biomass of thin root is concentrated at 15-20 cm soil layer. The parameters related to bulk density are RLD of thin root in soil layer 10-15 cm, RLD of fine root in soil layer 5-10 cm and RAR of thin root in soil layers 5-10 and 15-20 cm. **Conclusion:** The combination of "Red bean+maize" has higher ability of root penetration and it improves the physical conditions of the soil.

Key words: Annual crops, bulk density, cropping system, porosity, root distribution

Received: October 27, 2016 Accepted: November 28, 2016 Published: December 15, 2016

Citation: Aos, Endah Sulistyawati and Tati Suryati Syamsudin, 2017. Influence of cropping system on root distribution of annual crops. J. Agron., 16: 12-22.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

## INTRODUCTION

Erosion is a main cause of land degradation in sloping dry land agroecosystem. It causes nutrients loss and decreasing soil fertility[1]. Erosion control has often been focused on managing the effect of land cover, such as annual crops cultivation by intercropping system, on increasing of land productivity and pest control. Less attention has been given to the role of roots interaction at intercropping system for erosion control. Plant roots affect structure and soil drainage[2], the coarse and fine root plants affect pore size[3]. The ability of roots to penetrate soil is influenced by root density[4] and root growth[5,6].

Roots spreading horizontally and vertically penetrate into the soil deeper layers. At intercropped plants, the effect of plant roots depends on root distribution and its interaction[7]. In intercropping system, roots occupy larger space than in monoculture system[8]. In a field experiment conducted at Kiarapayung, Sumedang District and West Java, Indonesia, using combination of annual crops planted in intercropping system, it found that the smallest erosion and the highest soil porosity resulted from the combination of "Red bean and maize"[1]. Root distribution of annual crops in intercropping system is very important to study in order to increase land productivity and erosion control activities at the sloping dry land agroecosystem.

The objectives of this study are to examine the root interactions at intercropping system using combination of annual crops of five species (Rice, maize, peanut, red bean and cassava) and to understand their effects on root distribution and soil physical conditions (Bulk density and soil porosity).

## MATERIALS AND METHODS

The experiments were conducted in Tanjungsari (850 m a.s.l., S: 06°53'32.3" and E: 107°48'27.1") Sumedang District, West Java, Indonesia. Experiments of root interaction on different cropping systems were conducted in wooden boxes (200×120×25 cm). The boxes were filled by 20 cm thick of topsoil (Andisol Tanjungsari soil type). The experimental boxes were laid at 25% of slope and the soil was left to stabilize for 1 week before planting. Cropping system experiments consist of five species of annual crops: Rice, maize, peanuts, red bean and cassava. The cropping system experiments were set up using seven combinations (Table 1) with planting density varied according to the species. Planting density of rice was 133,333 seeds $ha^{-1}$ (at 30×25 cm), maize and cassava was 20,000 seeds $ha^{-1}$ (at 100×50 cm), peanut and red bean was 62,500 seeds $ha^{-1}$ (at 40×40 cm). These experiments were repeated three times.

Table 1: Combination of annual crops in cropping system experiments

| Treatments | Crops combinations |
|---|---|
| 1 | Rice (fibrous root)+maize (fibrous root) |
| 2 | Peanut (taproot)+maize (fibrous root) |
| 3 | Red bean (taproot)+maize (fibrous root) |
| 4 | Peanut (taproot)+cassava (taproot) |
| 5 | Red bean (taproot)+cassava (taproot) |
| 6 | Rice (fibrous root)+cassava (taproot) |
| 7 | Red bean (taproot) (planted in monoculture) |

Sixty days after planting, in every wooden box, soil samples were collected from different interval of soil depth (0-5, 5-10, 10-15 and 15-20 cm). For every layer, 2000 $cm^3$ of soil was examined, all plant roots were collected and sorted by floating then they were separated based on root color and flexibility[3]. Based on the size, root samples were separated between fine root (>0.0-2.0 mm) and thin root (>2.0-10.0 mm)[8] and then dried at 85°C.

The influence of cropping system on root distribution was examined by root interaction of annual crops in each soil layer of the seven treatments. Considering the different root character of seven combinations, the measurements of root biomass and root length were conducted on dry conditions. In this study, cassava tuber and peanut pods were not considered as plant roots.

**Root distributions:** According to Lynch[9], studies on root distribution are generally concerned with root biomass or root length as a function of soil depth. Therefore, in this study, root distribution was determined by root biomass (%), root area ratio (kg $m^{-3}$) and root length density (m $m^{-3}$) in every soil depth (0-5, 5-10, 10-15 and 15-20 cm). The root area ratio for each soil layer was calculated as the proportion of root biomass to the total volume of soil[8,10]. The Root Length Density (RLD) of fine and thin root for each soil layer was calculated following the method of Stokes *et al.*[8].

**Root interactions and the soil physical conditions:** The effect of roots interaction on soil physical condition was examined from the bulk density and soil porosity for each combination. Soil sampling was done by core method[11] on the soil depth layer of 5-10 cm. Soil bulk density was calculated based on dry weight of soil per unit of volume[11-14] and soil porosity was calculated following the standard method of USDA[11]. Bulk density and soil porosity were measured in two periods that were before soil tillage and at 60 Days after Planting (DAP).

**Data analysis:** The effect of each treatment on the root characteristics and soil physics were analyzed using ANOVA. Vertical and horizontal root distribution and its interaction were determined by Principal Component Analysis (PCA) calculated using IBM SPSS Statistic 20.

## RESULTS

### Root distribution

**Root biomass proportion:** Combination of annual crops of five species produced variation in root biomass proportion for different soil depth. In the soil surface of 0-5 cm, the combination of "Rice+cassava" resulted in the highest proportion of fine root biomass (93.63%) and showed no significant difference with the combination of "Peanut+cassava" (Fig. 1). The highest proportion of thin root biomass (68.22%) was found in the combination of "Red bean+maize" and this combination showed significant difference with "Peanut+cassava" and "Rice+cassava". In the subsequent soil layers (soil depth 5-10, 10-15 and 5-20 cm), there were no significant differences of root biomass for all combinations of cropping system.

Based on soil depth, fine root biomass at 5-10 cm was lower than at to 10-15 cm in almost all treatments. This indicates that fine root biomass increased with depth up to 15 cm (Fig. 2). In subsequent depth intervals, the fine root biomass tended to decrease with depth. Meanwhile, increase in biomass of with depth for thin root was only found between the interval of 0-5 to 5-10 cm and the interval of 10-15 to 15-20 cm.

At the interval of 0-5 to 5-10 cm depth, the combination of "Rice+cassava" resulted in an increase of 1.86 times in thin root biomass. At the interval of 5-10 to 10-15 cm depth, the combination of "Red bean+maize" resulted in an increase of 1.27 times in fine root biomass. At the interval of 10-15 to 15-20 cm, the combination of "Rice+cassava" resulted in increase of 2.07 times in thin root biomass. These results showed that the rooting of "Red bean+maize" combination can penetrate to deeper soil layer. Meanwhile, the rooting of "Rice+cassava" tends to occupy the larger area of soil than the others.

**Root area ratio (kg m$^{-3}$):** At different soil depths, the combinations of annual crops resulted in variation of Root Area Ratio (RAR) (Fig. 3). At the soil layer of 0-5 cm, the combination of "Rice+cassava" resulted in the highest RAR of fine root (5.19 kg m$^{-3}$) and it significantly differs with other combinations. In the subsequent soil layers (5-10, 10-15 and 15-20 cm), the combination of "Red bean+cassava" resulted in RAR of fine root 1.68, 2.84 and 3.31 kg m$^{-3}$, respectively.

Meanwhile, for RAR of thin root, significant differences among treatments were only found in the soil layer of 5-10, 10-15 and 15-20 cm. The combination of "Peanut+maize" at the soil layer 10-15 cm resulted in RAR of fine root 0.95 kg m$^{-3}$ and it showed no significant difference with "Red bean+cassava". Meanwhile, the combination of "Rice+cassava" in the soil layer of 15-20 cm resulted in RAR of thin root 1.48 kg m$^{-3}$.

Distribution patterns of RAR for fine and thin root at different soil layers were almost similar (Fig. 4). Generally, the RAR of fine and thin root tend to increase from 0-5 to 5-10 cm. In the combination of "Rice+cassava", the RAR of fine root at the interval of 0-5 to 5-10 cm decreased 0.87 times. Meanwhile, at the same successive intervals, the combination of "Rice+maize" resulted in decrease of 0.85 times in thin root.

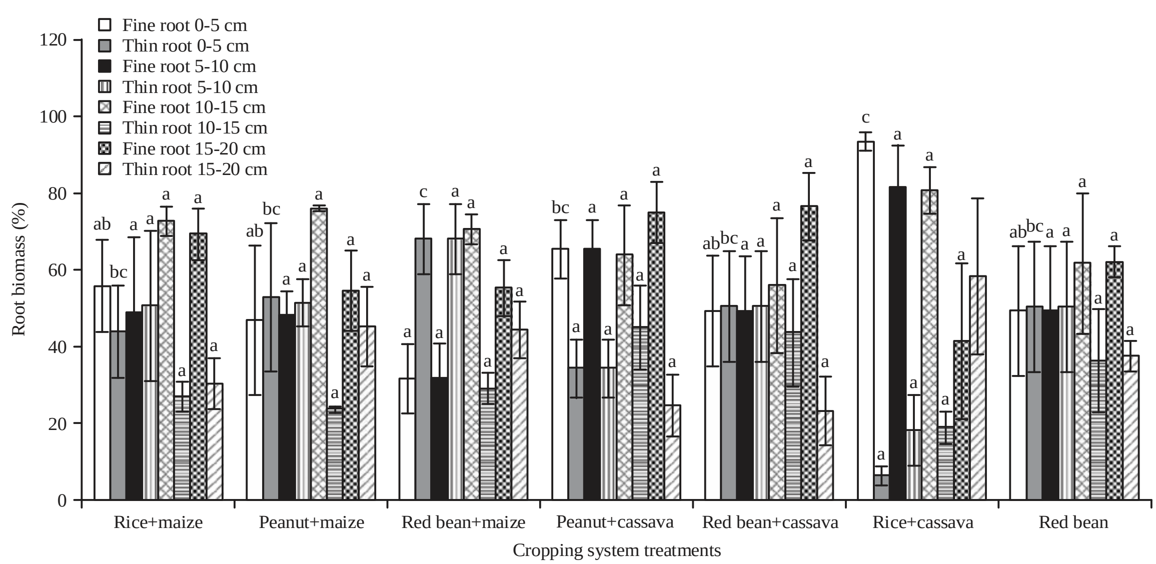


Fig. 1: Effect of cropping system treatments on proportion of root biomass at 60 days after planting. The same letters in each root parameters indicated no significant difference between treatments by DMRT (α = 5%)

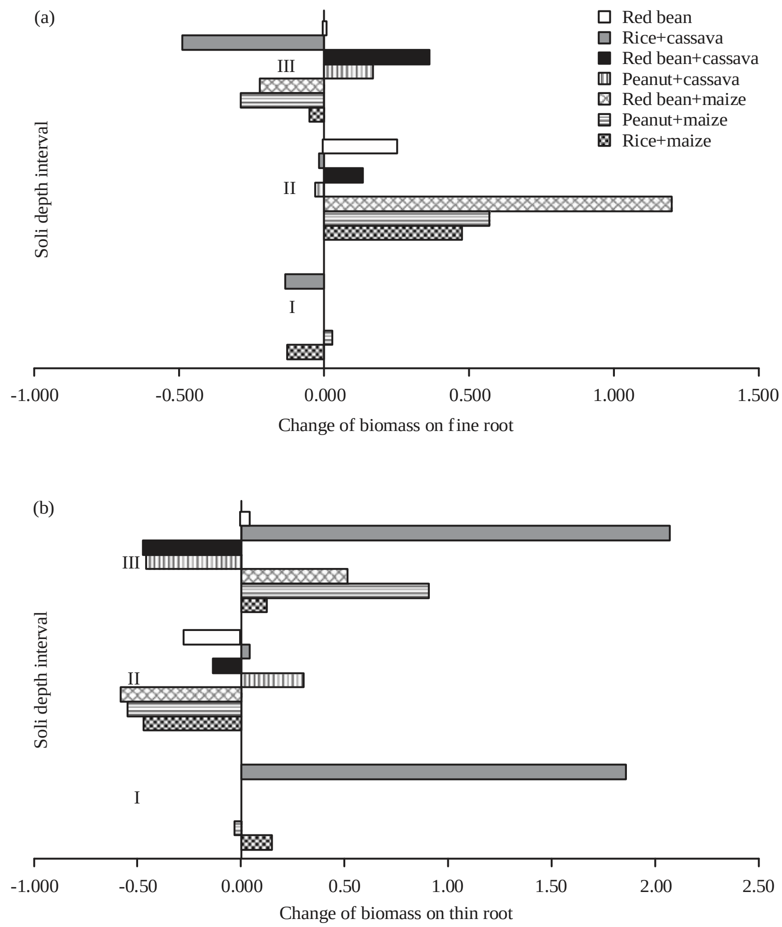


Fig. 2(a-b): Change of biomass on fine and thin root at 60 days after planting (a) Fine root and (b) Thin root. I: Soil depth interval 0-5 to 5-10 cm, II: Soil depth interval 5-10 to 10-15 cm, III: Soil depth interval 10-15 to 15-20 cm

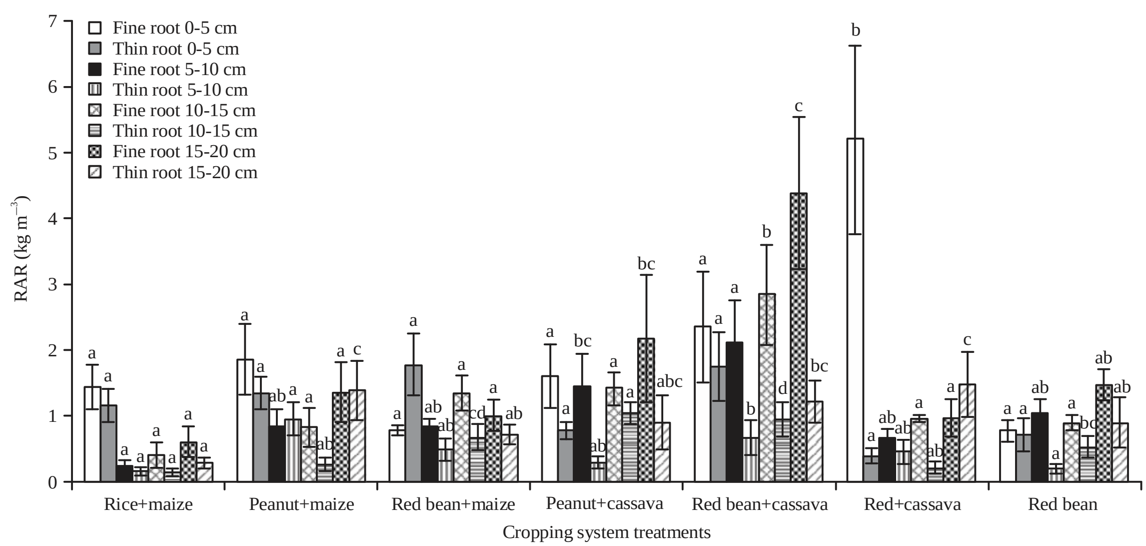


Fig. 3: Effect of cropping system treatments on RAR at 60 days after planting. Same letters in each root parameters indicated no significant difference between treatments by DMRT (α = at 5%)

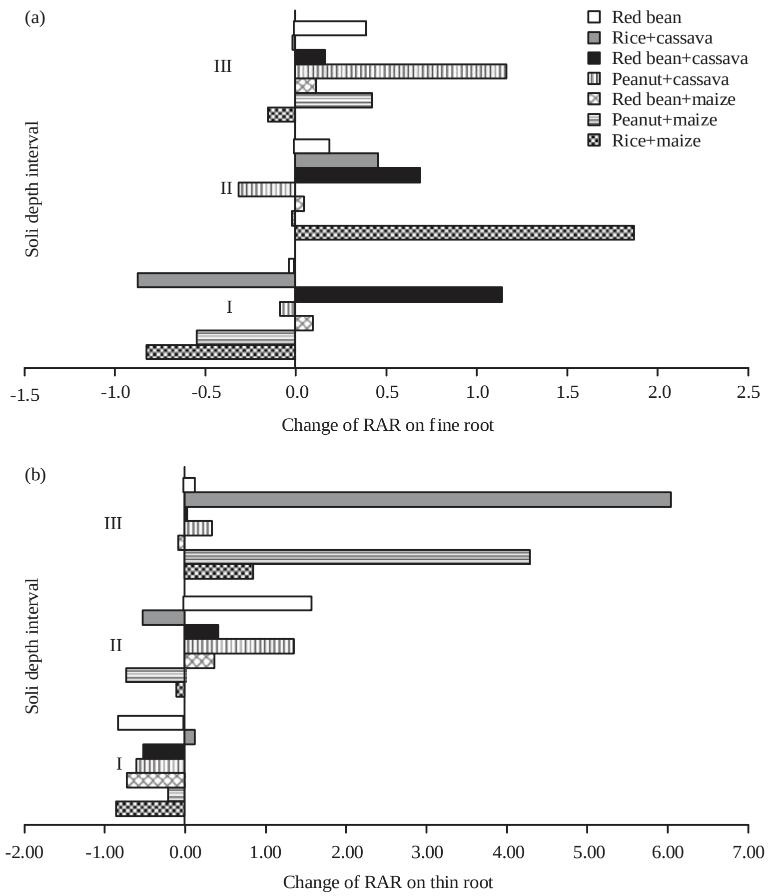


Fig. 4(a-b): Change of root area ratio on fine and thin root at 60 days after planting (a) Fine root and (b) Thin root. I: Soil depth interval 0-5 to 5-10 cm, II: Soil depth interval 5-10 to 10-15 cm, III: Soil depth interval 10-15 to 15-20 cm

At the interval 5-10 to 10-15 cm, the combination of "Rice+maize" and “Red bean” resulted in an increase in the RAR of fine and thin root 1.87 and 1.59 times, respectively. Meanwhile, at the interval of 10-15 to 15-20 cm, the combination of “Peanut+cassava" and "Peanut+maize" resulted in an increase in the RAR of fine and thin root 1.17 and 4.29 times, respectively.

**Root length density (m m$^{-3}$):** At different soil depths, the combinations of annual crops resulted in variation of Root Length Density (RLD) (Fig. 5). Among all treatments at each layer depth, significant differences on RLD of fine root were only found at the layer 5-10 and 10-15 cm. Meanwhile, for thin root, significant differences on RLD among all treatments were only found at the layer of 10-15 cm. The highest RLD of thin root at the layer 0-5 cm was found in the combination of “Peanut+maize” (33.29 m m$^{-3}$). The highest RLD of thin root was found in the combination of “Red bean+maize” for both at the layer 5-10 and 15-20 cm with the values of 21.53 and 16.63 m m$^{-3}$, respectively.

The highest RLD of fine root at the layer 5-10 cm was found in the combination of “Peanut+cassava” (107.28 m m$^{-3}$) and this significantly differs from the RLD of fine root in the combination of “Rice+maize”, “Red bean+cassava” and “Rice+cassava”. At the soil layer 10-15 cm, the highest RLD of fine root was found in the combination of “Red bean+maize” 115.72 m m$^{-3}$ and this was not significantly different with the combination of “Peanut+maize” and “Peanut+cassava”.

At soil depth interval of 0-5 to 5-10 cm, the combination of “Rice+cassava” resulted in an increase in RLD of fine root 0.95 times. The treatment of “Red bean+maize” resulted in an increase in the RLD of thin root 1.00 times. At interval 5-10 to 10-15 cm, the combination of “Red bean+cassava” resulted in an increase in RLD of fine root 0.62 times. Meanwhile, the combination of “Peanut+cassava” resulted in an increase in RLD of thin root 2.22 times. At interval 10-15 to 15-20 cm, the combination of “Rice+maize” resulted in an increase in RLD of fine root 0.37 times and in RLD of thin root 3.17 times (Fig. 6). The results showed that the combinations of “Rice+cassava” and “Red bean+maize” have the larger ability of root penetration than the others.

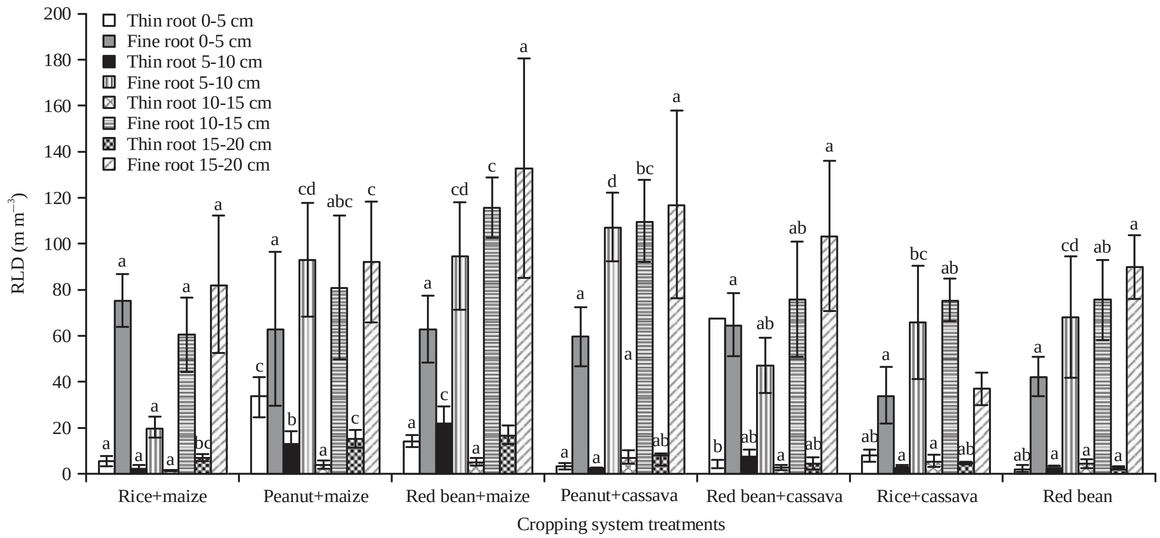


Fig. 5: Effect of cropping system treatments on root length density at 60 days after planting. The same letters in each root parameters indicated no significant differences between treatments by DMRT (α= 5%)

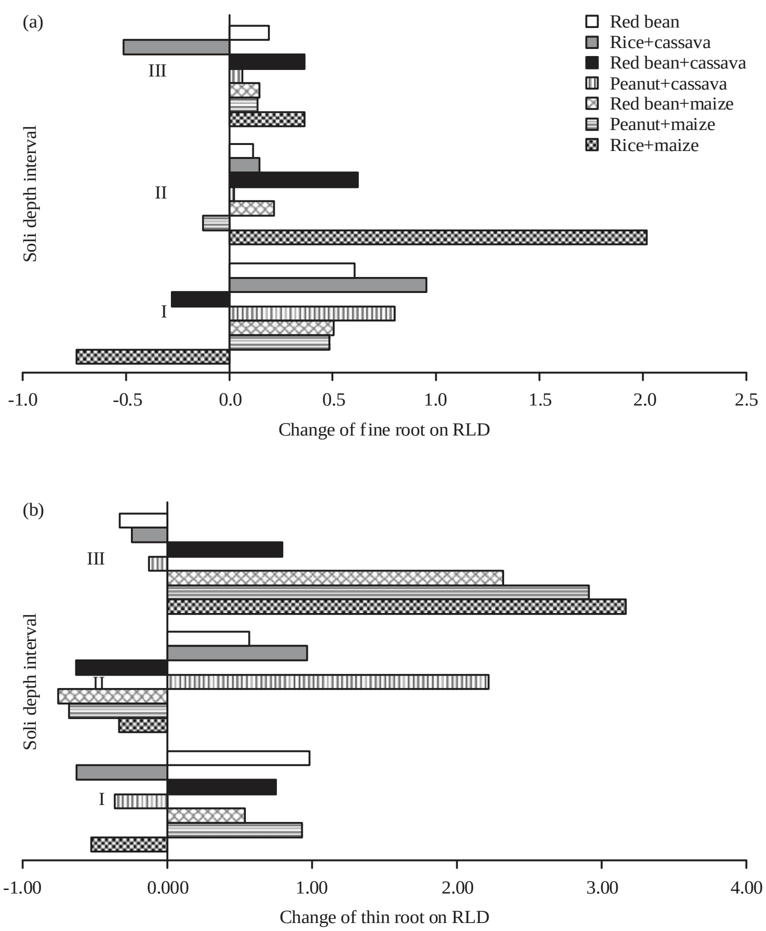


Fig. 6(a-b): Change of root length density on annual crops at 60 days after planting (a) Fine root and (b) Thin root. I: Soil depth interval 0-5 to 5-10 cm, II: Soil depth interval 5-10 to 10-15 cm, III: Soil depth interval 10-15 to 15-20 cm

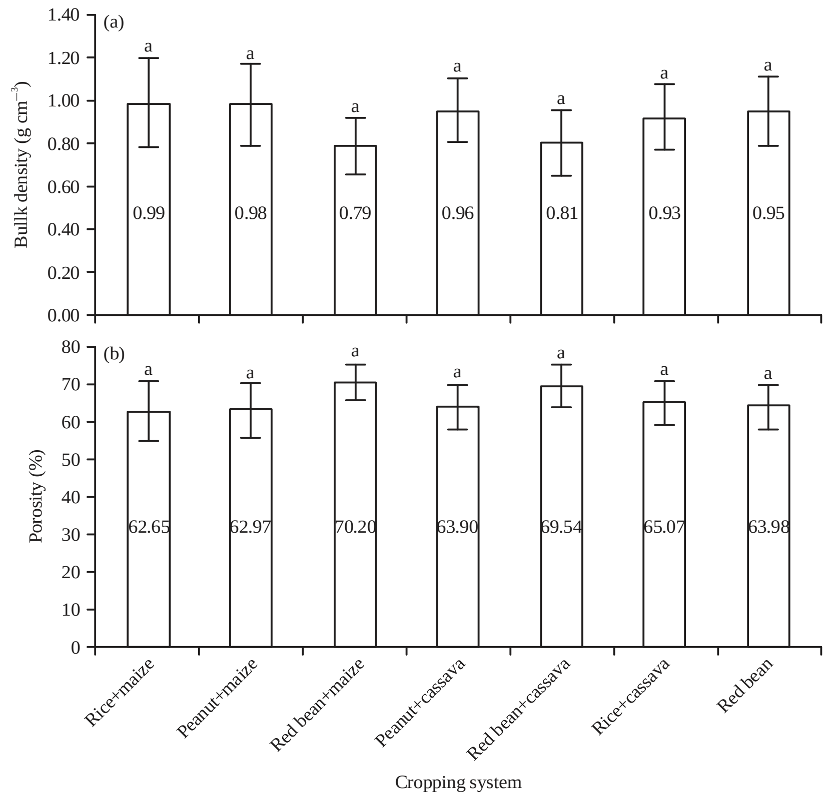


Fig. 7(a-b): Effect of cropping system on bulk density and soil porosity at 60 days after planting. The same letters in each treatments indicated no significant differences between treatments by DMRT ($\alpha$= 5%)

**Root interaction and soil physical conditions:** There were no significant difference in bulk density and soil porosity among all combinations of annual crops. Nevertheless, the combination of "Red bean+maize" resulted in the lowest bulk density (0.79 g $cm^{-3}$) and the highest soil porosity (70.20 %) (Fig. 7).

The combination of annual crops resulted in decreased bulk density and increase in soil porosity as measured by comparing those parameters before soil tillage and at 60 DAPS. The lowest decrease was found in "Rice+maize" (0.24 times) and the highest decrease was found in "Red bean+maize" (0.39 times) (Fig. 8). Meanwhile, the lowest increase was found in "Rice+maize" (0.23 times) and the highest increase was found in "Red bean+maize" (0.38 times).

The interaction between parameters of root (24 items) and soil physics (1 item) across all crop combinations revealed using Principal Component Analysis (PCA) showed that there were five components with the initial eigen value of more than 1.00. Component 1 and 2 are the principal components with the highest initial eigenvalues of 9.776 and 5.979, respectively. Both of these components can explain variance of 25 items in the amount of 63.017%.

The first principal component (circle with long dash dot dot), which accounted 39.102% of the total variance was named as vertical root distribution (Fig. 9). The component consisted of Bm5_10fr (-0.971), Bm5_10tr (0.971), Bm0_5fr (-0.955), Bm0_5tr (0.955), RAR0_5fr (-0.852), RAR0_5tr (0.807), RLD15_20fr (0.791), RLD0_5fr (0.745), RLD5_10tr (0.674), RLD15_20tr (0.663) and RAR15_20tr (-0.577). Based on the distribution of eigen values, it can imply that vertical root distribution is restricted if biomass of fine root is concentrated at the layer 0-5 and at 5-10 cm and if RAR of fine root is concentrated at the layer 0-5 cm and if RAR of thin root is concentrated at the layer 15-20 cm.

The second principal component (circle with long dash), which accounted 23.914% of the total variation was named as horizontal root distribution. The component consisted of RAR5_10fr (0.953), RAR15_20fr (0.947), (Bm10_15tr (0.901), Bm10_15fr (-0.891), RAR10_15tr (0.858), RAR10_15fr (0.851), Bm15_20fr (0.741) and Bm15_20tr (-0.741). Based on the distribution of eigen values, it can imply that horizontal root

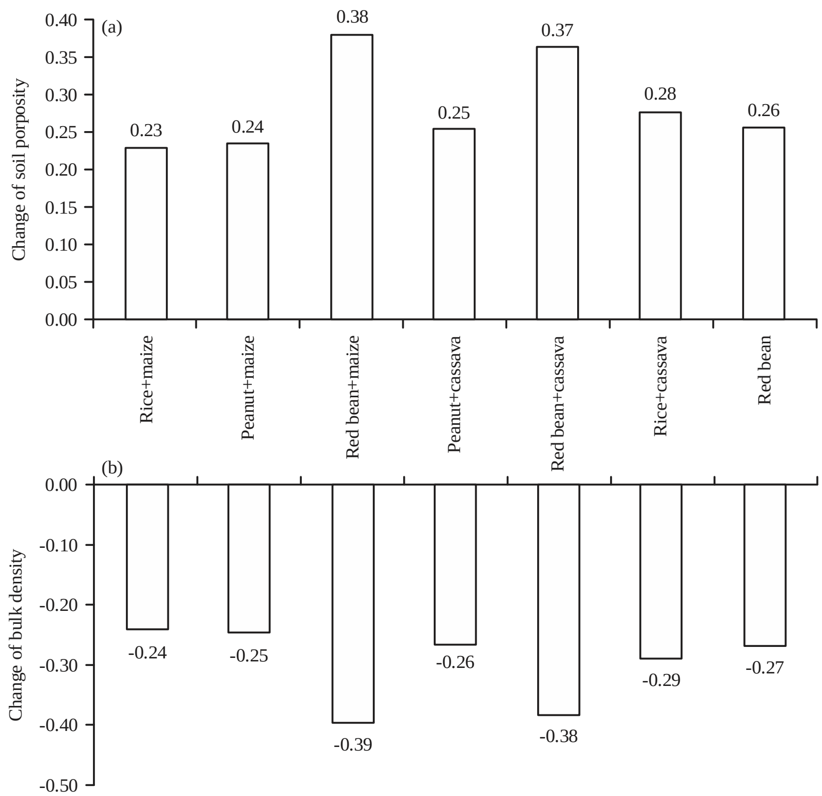


Fig. 8(a-b): Change of bulk density and soil porosity at 60 days after planting

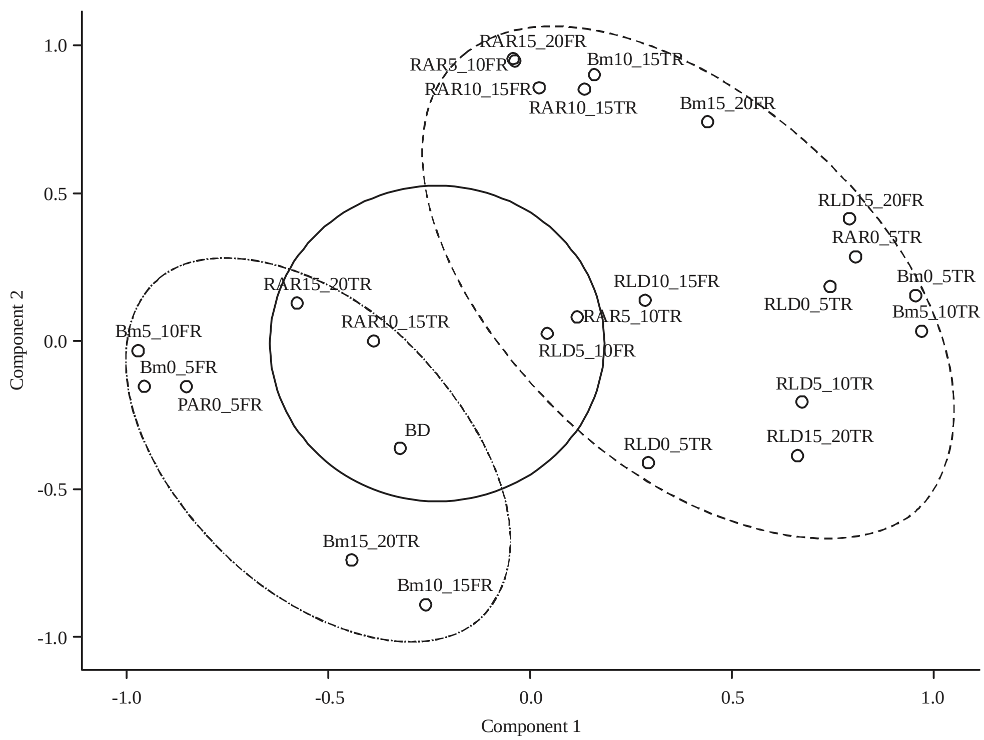


Fig. 9: Effect root interaction on soil physics conditions. Bm: Root biomass, RAR: Root area ratio, RLD: Root length density, FR: Fine root, TR: Thin root, 0_5: Soil layer of 0-5 cm, 5_10: Soil layer of 5-10 cm, 10_15: Soil layer of 10-15 cm, 15_20: Soil layer of 15-20 cm, BD: Bulk density

distribution is restricted if biomass of fine root is concentrated at the layer 10-15 cm and if biomass of thin root is concentrated at the layer 15-20 cm. Nevertheless, parameters of RLD10_15tr, RAR15_20tr, RAR5-10tr and RLD5_10fr (circle with solid line) are closely related to the bulk density.

## DISCUSSION

The combination of annual crops resulted in varied effects on root distribution and soil physical conditions. In all treatments, the highest fine and thin root biomass across all soil depths were found in the combination of “Rice+cassava” at the soil depth of 0-5 cm with the values of 93.63% for fine root and 6.37% for thin root. Meanwhile, the highest increase in biomass between two successive soil layers was found in thin root biomass of the combination of “Red bean+maize” at the soil depth 5-10 to 10-15 cm with the increment value of 1.20 times.

High values of fine and thin root biomass were found in “Rice+cassava” and “Red bean +maize” at the soil depth 0-5 cm, eventhough there is no significant difference with others. This indicates that those crop combinations are able to occupy large area of soil surface. The ability of “Rice+cassava” and “Red bean+maize” combination to have extensive root occupation in soil surface is due to the fact that both rice and maize have fibrous root system. This is in accordance with the opinion of Lynch[9] and Malamy[15] suggesting that the spatial configuration of the root system varies depending on the plant species. Species with a fibrous root system tends to have higher root density at topsoil[16].

The concentration of fine and thin roots at the soil surface could affect the physical condition of the soil. Fine root density affects root ability to explore space in soil[3] and enhance the ability of roots to bind soil particles so that soil porosity increases. In this study, this is shown by the fact that high root biomass (fine and thin) is followed by low bulk density. The effect of concentration of root biomass at soil surface in improving soil physical condition is also supported by Mickovski *et al.*[17] arguing that the plant roots spreading horizontally can serve to increase the soil surface roughness, bind the soil particles and increase soil porosity. Furthermore, roots at soil surface can be very important for protecting the topsoil against incision by concentrated runoff[16].

The combination of “Red bean+maize”, “Peanut+maize” and “Red bean+cassava” resulted in greater root ability to penetrate into deeper soil layer than the others. This is indicated by increases in RLD of thin root at two successive soil depths, i.e., at interval 0-5 to 5-10 cm and at interval 10-15 to 15-20 cm (Fig. 5, 6). This finding is in line with Stokes *et al.*[8] suggesting that the ability of the roots to penetrate the soil is influenced by root density, especially high RLD in deeper soil layers. Another indication that the combination of “Red bean+maize”, "Rice+maize", "Peanut+maize" and "Red bean+cassava" facilitate greater penetration to deeper soil layer is the low proportion of fine root at layer 0-5 and 5-10 cm and the low RAR of fine root at soil layer of 0-5 cm. Greater vertical penetration of roots results from the combination of “Red bean+maize”, "Rice+maize", "Peanut+maize", "Red bean+cassava" is also supported the result of PCA analysis. This is shown by the negative values of rotated component matrix of fine root biomass at the soil depth 0-5 and 5-10 cm and the negative values of rotated component matrix of RAR fine root at the soil depth 0-5 and 15-20 cm for those four crop combinations.

The root interaction of annual crops combination can improve soil physics, particularly bulk density as shown by the result of PCA. The result of PCA (Fig. 9) suggests that parameters related to bulk density are RLD of thin root at the soil depth 10-15 cm, RLD of fine root at the soil depth 5-10 cm and RAR of thin root the soil depth 5-10 and 15-20 cm. The highest improvement of soil physical condition was found in the combination of “Red bean+maize” in which bulk density decreases 0.39 times (from 1.30 g $cm^{-3}$ at before soil tillage to 0.79 g $cm^{-3}$ at 60 days after planting) and this results in an increase in soil porosity 0.38 times (from 50.94% before soil tillage to 70.20% at 60 days after planting) (Fig. 7, 8). These conditions are consistent with the results from the previous study conducted in a field experiment setting with similar treatments in that the combination of “Red bean+maize” results in a decrease in bulk density and an increase in soil porosity[1].

Given the pattern of root biomass distribution at soil surface and across soil depths, the combination of “Red bean+maize” having taproot and fibrous root results in larger vertical and horizontal root distribution than the other combinations. As a consequence, this plant combination facilitates higher improvement in soil physical conditions (bulk density and soil porosity). These results are consistent with the finding from other research[3,18-20] suggesting that plant root can improve soil physics condition. The improvement of soil physical condition mediated by the characteristics of plant roots occurs due to increasing of soil porosity caused by increasing of pore spaces by plant roots. Bengough *et al.*[21] and Datta *et al.*[22] explained that when roots penetrate soil it will cause adjacent soil particles to move a side thus creating larger pore and contributing significantly to the adhesion of the root-soil.

## CONCLUSION

The combination of "Red bean+maize" has higher ability of root penetration and it improves the physical conditions of the soil (bulk density is reduced and soil porosity increases). The combination of "Red bean+maize" also resulted in larger biomass of thin root at 0-5 cm soil layer, longer Root Length Density (RLD) of fine root at 10-15 cm soil layer and longer RLD of fine and thin root at 15-20 cm soil layer. Vertical root distribution is restricted if biomass of fine root is concentrated at 0-5 and 5-10 cm soil layers and if Root Area Ratio (RAR) of fine root is concentrated at 0-5 cm soil layer and if RAR of thin root is concentrated at 15-20 cm soil layer. Horizontal root distribution is restricted if biomass of fine root is concentrated at 10-15 cm soil layer and if biomass of thin root is concentrated at 15-20 cm soil layer. The parameters related to bulk density are RLD of thin root in soil layer 10-15 cm, RLD of fine root in soil layer 5-10 cm and RAR of thin root in soil layer 5-10 and 15-20 cm.

## ACKNOWLEDGMENTS

This study was funded by PUPT program of The Directorate General of Higher Education, Ministry of Education and Cultural of the Republic of Indonesia to Tati Suryati Syamsudin (grant number: 701/AL-J/DIPA/PN/SPK/2014) and Scholarship of Doctoral program (BPDN) to Aos.

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