Root interactions on sole crop and intercrop give different effects of competition

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Abstract. Root interactions on sole crop and intercrop give different effects of competition. Understanding on root interactions is very challenging due to the methodology limits in root studies especially when we intercrop between tree and crop components. The objectives of this study were (1) to measure the aboveground and belowground biomass of intercropped Acacia hybrid with Beta vulgaris (red beet) and (2) to determine the rooting pattern at each rhizotron depth. This study involved three (3) types of treatments, Acacia hybrid sole crop, Beta vulgaris sole crop, and intercropping of these two species. Root intensity and root biomass were measured. Root growth of red beet was affected by the presence of Acacia hybrid while Acacia hybrid was not affected for both either in sole or intercrop. However, the root intensity of Acacia hybrid was higher in deeper soil layer when intercrop with red beet. For the root biomass, Acacia hybrid was slightly affected when intercrop with red beet. In contrast, red beet was higher when intercrop with Acacia hybrid. In terms of shoot biomass, both crops were not affected when they are in sole or intercrop. The rooting pattern showed that the root length density was dominant in the upper layer for both crops, and intercrop treatment was significantly higher compared to sole crops. In conclusion, Acacia hybrid is the competitor to the red beet in belowground interaction in terms of root growth and rooting pattern. There is no differences in terms of aboveground interactions.

1. Introduction

Studies on belowground ecosystem processes are relatively rare compared to those dealing with aboveground traits of plants whereby roots being hidden in the soil [1], their observation and study relies on deploying special methodologies that are generally time-consuming and often costly. Most plant taxa can be identified by aboveground criteria, such as flower and leaf morphology, roots show less distinctive features. Studying standing root biomass, root dynamics, and interactions belowground is essential for understanding plant functioning, plant community composition, and terrestrial biogeochemistry [2]. Because root biomass is the major plant parameter governing water and nutrient uptake [3], belowground proportions of species have to be quantified, distinguishing living and dead roots.

Studies using combination of legume and non-legume plants is wide, but limited to above ground interactions. Compared with corresponding sole crops, yield advantages have been recorded in many legume/non-legume intercropping systems, including maize/soybean [4], sorghum/soybean [5],
groundnut/pearl millet [6], maize/faba bean [7], pearl millet/cluster bean [8], groundnut/cereal fodders [9] and faba bean/barley [10]. However, the benefits from the intercropping combination are still less investigated especially using tree-crop combination.

Quantifying the beneficial or competitive effects of soil resources, particularly nutrient use in intercropping is still an important researchable issue. The legume/non-legume intercropping system has still not been understood adequately as compared to sole cropping in terms of system efficiency, more so regarding the concept of nutrient management where both plants have different growth habits and input requirements. Therefore, the objectives of this study were (i) to measure the aboveground and belowground biomass of intercropped Acacia hybrid with Beta vulgaris (red beet) and (ii) to determine the rooting pattern at each rhizotron depth.

2. Materials and Methods
The study was conducted at outside greenhouse of Forest Complex, Faculty of Science and Natural Resources, Universiti Malaysia Sabah (6°02'10.7'’ N and 116°07'34.9’’ E). The temperature was between 22 - 34°C. Completely randomized design was used. The rhizotron 1 m (150 mm × 150 mm × 1 m) was used whereby three (3) types of treatments, Acacia hybrid sole crop, Beta vulgaris sole crop, and intercropping of these two species. Each treatment had four replicates and the total of 12 experimental units. Intercropping with additive design was approached in this study. Four soil depths were divided into 0-25, 25-50, 50-75, and 75-100 cm. Four liters of water was supplied to the rhizotrons to reach field capacity. Fertilizer of AG Leader 954 was used and applied with 50 kg N ha⁻¹ or equivalent to 23 ml for each rhizotron. Root Intensity (RI), Root Length Density (RLD), Root Biomass (RB) and Shoot Biomass (SB) were measured. For RI, root images from different depths were captured every week after transplanting and counted using gridline 20 × 20 mm (intersections m⁻¹ gridline). For RB and RLD, root washing technique was applied to measure root biomass (g) and root length density (cm cm⁻³). At the same time, shoot biomass was harvested, inserted to the oven at 70 °C for 48 hrs to get dried shoot biomass.

3. Results and Discussion
Root growth of red beet was affected by the presence of Acacia hybrid, while Acacia hybrid was not affected for both either in sole or intercrop in Figure 1. However, the root intensity of Acacia hybrid was higher in deeper soil layer when intercropped with red beet. Root intensity data was also corresponded with the root length density data. The rooting pattern showed that the root length density (RLD) was dominant in the upper layer for both crops, and intercrop treatment was significantly higher compared to sole crops in Figure 2. For the root biomass, Acacia hybrid was slightly affected when intercrop with red beet as in Figure 3 and Figure 4 for belowground biomass. In contrast, red beet was higher when intercropped with Acacia hybrid. In terms of shoot biomass, both crops were not affected when they are in sole or intercrop in Figure 4.

We assume that the red beet might benefit from Acacia hybrid in intercropping as a legume tree. As in the present study, red beet was confined by the Acacia hybrid in intercropping. The root of Acacia was penetrated in the beginning and down to deeper layers. Red beet root is also fast growing crop but in this present study it was confined by tree legume. Study done by [11] found that red beet root was faster compared to clover root growth which is contradicted in the present findings. Moreover, tree-typed and fast growing species are the reasons that the higher root growth in the present study compared to red beet in intercropping [12, 13]. In the case of root length density, all the roots are higher compared to deeper soil layers due to high nutrient content and water.

It is revealed that measuring belowground such as root biomass is more meaningful than shoot biomass. This is because the competition belowground can be stronger and involve many more neighbors than aboveground competition [14]. The root interaction of these intercropping combinations could be extended in a long time or in the field intercropping, so we can see if there are any indication or benefit from tree legume to non-legume crops. The limit to perform this study is the...
lack of methods on how we can measure the root in field intercropping which is need greater intention for the future.

Figure 1. Root Intensity (intersections m\(^{-1}\) gridline) at different soil layers for each cropping types for 3 selected weeks using ANOVA followed by Tukey HSD’s post hoc Test. Statistically different values are indicated with different letters where separate tests were made for each depth (P<0.05). Bars present standard deviations of the mean, n=4.

Figure 2. Root Length Density (cm cm\(^{-3}\)) at different soil layers for only red beet sole, *Acacia* sole and mixture of them using ANOVA followed by Tukey HSD’s post hoc Test. Statistically different values are indicated with different letters where separate tests were made for each depth (P<0.05). Bars present standard deviations of the mean, n=4.
Figure 3. Root biomass (g) at different depths for four different cropping systems using ANOVA followed by Tukey HSD's post hoc Test. Statistically different values are indicated with different letters (P<0.05). Bars present standard deviations of the mean, n=4.

Figure 4. Dried Shoot and root biomass (g) for four different cropping systems using ANOVA followed by Tukey HSD's post hoc Test. Statistically different values are indicated with different letters (P<0.05). Bars present standard deviations of the mean, n=4.
4. Conclusion

In conclusion, *Acacia* hybrid is the competitor to the red beet in belowground interaction in terms of root growth and rooting pattern. There is no difference in terms of aboveground interactions. The root interaction such a combinations intercropping could be extended in the field intercropping and deeper soil layers so we can see if there is any indication or benefit from tree legume to non-legume crops. But, this is also associated with the suitable methodologies which allow individual plant root to be measured.

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