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Journal of Agronomy RSS

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Source: Journal of Agronomy 5 (1): 111-117, 2006

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Journal of Agronomy 5 (1): 111-117, 2006
ISSN 1812-5379

The Influence of N-P-K Fertilizer Rates and Cropping Systems on Root Biomass and Some Root Morphological Variables of Sweet Corn and Vegetable Soybean

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Abstract: A field experiment using 1.2×0.5×0.5 m rhizoboxes with 280 kg soil was carried out to investigate the effect of three N-P-K fertilizer rates (50, 100 and 150% of the recommended fertilizer rate) and cropping systems (mono-crop corn or soybean, intercrop corn and soybean without root separation, with plastic and with geotextile root separation) on root biomass, volume surface area and total root length. Mono-crop corn and intercropped corn under plastic sheet root separation had significantly higher total root length than intercropped corn without root separation and with geotextile root separation, but soybean higher root volume was noticed in intercropped soybean without root separation and with geotextile root separation. Increasing fertility level from 50% of recommended rate (RFR) to 100 and 150% RFR significantly increased root dry weight of corn and soybean, as well as root volume, surface area and total root length of corn. In soybean increasing fertility level from 50 to 100% RFR increased total root length and root surface area, but further increase to 150% of recommended rate decreased both variables.

Key words: Cropping systems, fertilizer rates, root biomass, surface area, Length, volume, corn, soybean

INTRODUCTION

Roots are the primary sites for the uptake of all mineral elements and water required for crop growth. Due to this fact, root growth and development are highly plastic (Neumann and Martinoia, 2002) and depend much on many soil factors like water content, nutrient availability, aeration, pH, bulky density and soil temperature (Glinski and Lipiec, 1990). Moreover, plants allocate much of their photosynthates to root production and maintenance; for instance, Jackson *et al.* (1997) estimated that 33% of global annual net primary production is used for finer root production and the growth and maintenance of fine roots may use up to 50% of daily photosynthetic in crop plants (Lambers, 1987).

When plants are grown together, there is both above and below ground interaction which determine resource use, this indicates the importance of roots in crop production. However, detailed root studies are undertaken less compared to shoot studies, because root sample acquisition and analysis are tedious and time consuming (Zoon and Van Tienderen, 1990), some of the research findings indicate that root competition has a greater effect than shoot competition on the relative performance of associated species (Peach *et al.*, 2000). Under conditions, where light and water are not limiting, nutrient is the major source of competition of associated species if rooting depth is the same. Nevertheless, nutrient supply is not uniform down the soil profile and crop plants differ in their ability to obtain nutrients from different soil profiles (Genney *et al.*, 2002). For instance mono-crop *Achillea millefolium* plant obtained more nitrogen when nutrient was injected at 5 cm rather than 20 cm. But, when this plant was intercropped with *Festuca ovina, Achillea* acquired more nitrogen in lower depth (Jumpponen *et al.*, 2002). The interesting point is that, roots can distinguish potentially competing roots of the same or different species (Falik *et al.*, 2003) and as a result plants may avoid resource competition by using root system plasticity (Fitter *et al.*, 2002). Additionally root mass which is easier to measure than total root length and surface area has been used to compare root systems (Murphy and Smucker, 1995), but root mass measurements are not indicative of the total absorptive area of the root system and alteration of root system architecture can happen without a change in total root biomass (Hodge, 2004).

Mineral nutrient supply greatly affects both size and morphology of root systems (Durieux *et al.*, 1994), among nutrients nitrogen (Sattelmacher *et al.*, 1993; Durieux *et al.*, 1994; Zhang and Forde, 1998) and phosphorus (Kuang *et al.*, 2005) are said to have greater influence on root growth, while potassium effect is no well documented (Robinson and van Vuuren, 1998).

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Meanwhile, though corn and soybean are grown together little is known about their root interactions (Hayashi and Shigenaga, 1993) and how fertility levels influence the root morphology. It was reported that application of 160 kg P/ha as triple super phosphate increased root dry weight, but decreased total root length and root surface area of soybean (Kuang *et al.*, 2005). Moreover, Kuang *et al.* (2005), also reported that both N and P content correlated with root morphological traits of soybean, which may imply that N taken up by the roots may contribute more to the plant N status than biological N fixation in their experiment. Furthermore, Durieux *et al.* (1994) noticed that increasing nitrogen fertilizer rate from 0 to 140 kg N ha^{-1} increased total root length of corn while further fertilizer rate increase to 224 kg N ha^{-1} reduced total root length of corn.

Root length and root surface area correlated highly to the to the phosphorus uptake by the plants under low P soil situation (Vance *et al.*, 2003; Yan *et al.*, 2004). Hence, total root length, surface area and root volume might be better root characters which can indicate the effect of nutrient and cropping systems.

Hence, this study was conducted to investigate how fertility levels and cropping systems influence root morphology and biomass of sweet corn and vegetable.

MATERIALS AND METHODS

The field study was conducted from August to November 2004 at the experimental farm (field two) of the Department of Crop Science, Faculty of Agriculture, University Putra Malaysia (3°00′N, 101°42′E, with an altitude of 30 m above mean sea level). The experimental design was factorial in RCBD; with two factors replicated thrice. The two factors were. Factor A: comprised four cropping systems, namely: mono-crop sweet corn (Cs_1), mono-crop vegetable soybean (Cs_2), intercropped sweet corn and vegetable soybean without root separation (Cs_3), intercropped sweet corn and vegetable soybean with plastic sheet root separation (Cs_4), intercropped sweet corn and vegetable soybean with geotextile root separation (Cs_5). Factor B: consists of three fertility levels of 50% (F_1), 100% (F_2) and 150% (F_3) of the recommended fertilizer rate (120: 60:90, $N:P_2O_5:K_2O$ for sweet corn and 34: 56:56, $N:P_2O_5:K_2O$ for vegetable soybean).

Rhizoboxes having dimensions of 1.2×0.5×0.5 m were prepared from ply wood and plastic sheets. Three sides of the rhizobex were covered with plastic sheet, while the fourth side had acrylic sheet for root observation and then covered with ply wood door. Based on the treatments plastic sheet and geotextile were used for root separation. Plastic mesh and wooden sticks were placed at the bottom of the boxes to facilitate better drainage; in addition clay bricks were put below the boxes to raise the boxes from the ground level. Boxes were arranged in the field with a distance of 3 m between treatments and 4 m between replications.

Muchong soil series (Very fine, kaolinitic, isohyperthermic (Paramananthan, 2000) from field ten (Universiti Putra Malaysia) were cut up to one meter (cutting first the upper 20 cm separately followed by the sub soil 80 cm). The sub soil was filled in the boxes up to 80 cm and after two days the remaining 20 cm surface soil was filled. Soil pH was measured and based on the result lime was applied and made the pH 6.

After the harvest of above ground plant parts of sweet corn and vegetable soybean, the door and the acrylic sheet of the rhizoboxes were carefully removed with out disturbing the soil. Then the roots were obtained by gradually loosening the soil and taking the roots out layer by layer. The very dense roots of the upper soil layer were first taken and followed by lower layers. Roots were placed on container with sieves of several mesh sizes to prevent loss of fine roots during washing, following the method of Costa *et al.* (2000). Roots were immediately taken to the laboratory and kept in the refrigerator set at 4°C, till analysis. Roots length, volume and surface area were analyzed using Whin Rhizo scanner (a, b, c 2000) an interactive scanner-based image analysis that controls scanning, digitizing AND analysis of root samples. Roots were placed in the plexiglass trays (150×250 mm) with 5 to 10 mm deep water layer, depending on root size. Roots were spread on the tray before scanning to minimize overlapping. For root dry weight measurement, roots were dried in an oven at 80°C for 72 h at and weighed using sensitive balance.

The data was subjected to analysis of variance (ANOVA) for factorial RCBD with the help of SAS soft ware (SAS Inst., 2004), treatment means were compared at $p<0.05$, using Least Significant Difference (LSD) (Gomez and Gomez, 1984). Interaction was not significant, hence main factors are presented.

RESULTS

Interaction was not significant and hence in this paper the result of cropping systems and fertility levels are presented.

Root dry weight: Fertility levels significantly ($p<0.05$) influenced root dry weight of both sweet corn and vegetable soybean, while cropping systems did not affect root biomass (Fig. 1a and b). Hundred and fifty percent of the recommended fertility level recorded heaviest root dry

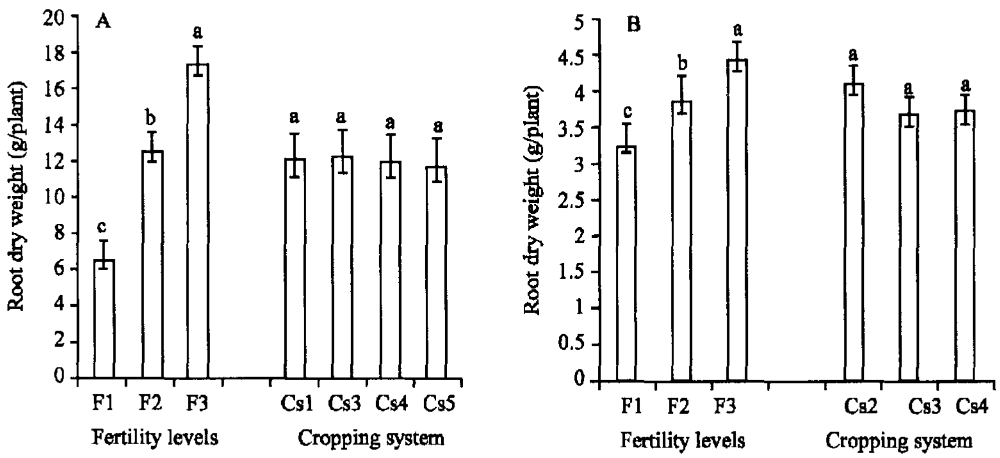

Fig. 1: Effect of fertility levels and cropping systems on root dry weight per plant of sweet corn (A) and vegetable soybean (B)

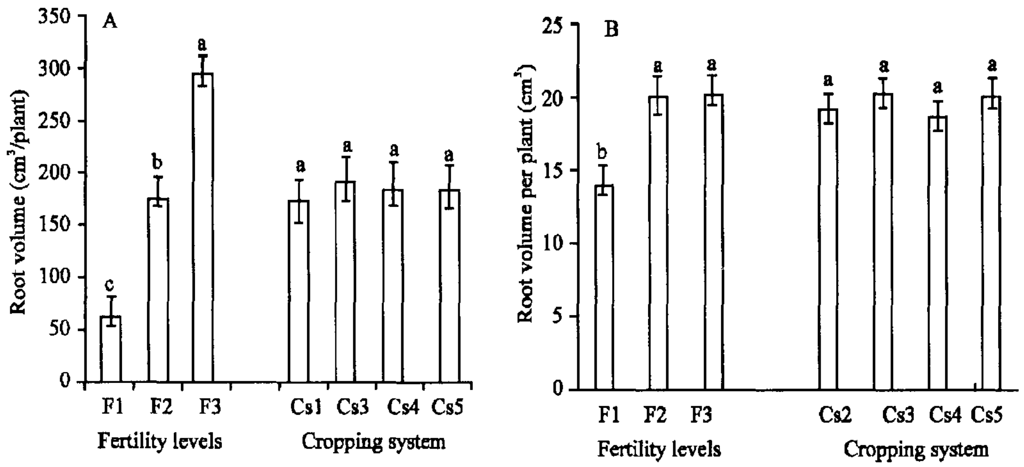

Fig. 2: Effect of fertility levels and cropping systems on root volume of sweet corn (A) and vegetable soybean (B)

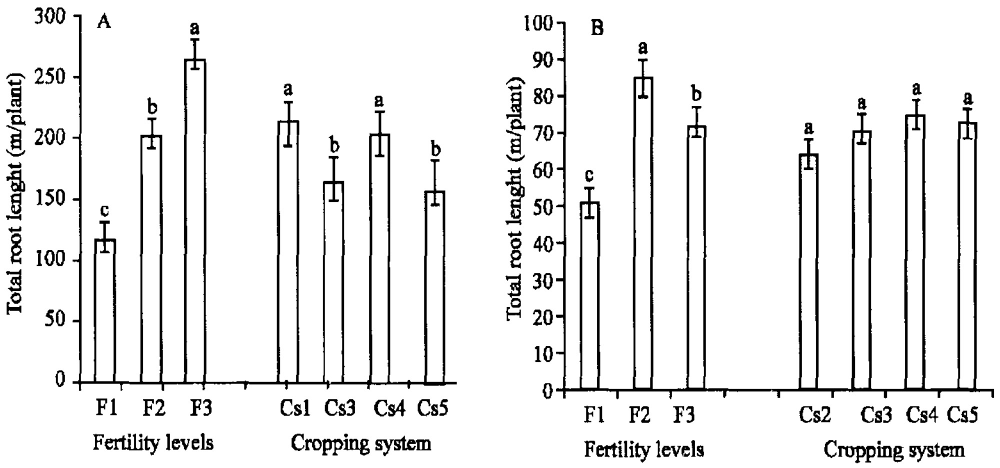

Fig. 3: Effect of fertility levels and cropping systems on total root length of sweet corn (A) and vegetable soybean (B)

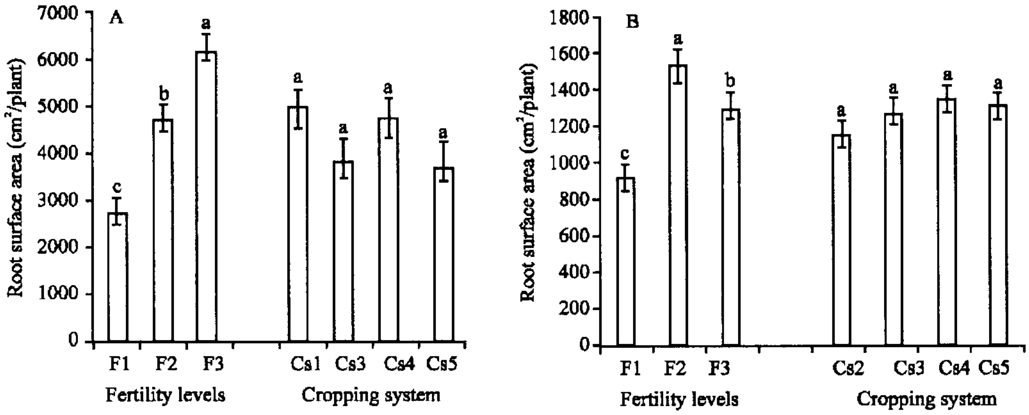

Fig. 4: Effect of fertility levels and cropping systems on root surface area of corn (A) and soybean (B)

weight of both crops, 50% of recommended rate resulted in least root dry weight, while the medium fertility level recorded average root dry weight (Fig. 1a and b).

Meanwhile, cropping systems failed to affect root dry weight significantly, though numerical differences were noticed. Mono-crop soybean had higher root dry weight compared to soybean in other treatments; intercrop corn without root separation was also had higher root dry weight than other corn in other treatments.

Root volume: Root volume of vegetable soybean was significantly ($p<0.05$) influenced by fertility levels but not cropping systems. With regard to sweet corn, significant difference among treatments was noticed due to fertility levels, but cropping systems did not affect root volume of sweet corn (Fig. 2a). Root volume of vegetable soybean increased with increasing fertility levels from fifty percent of RFR (14.1 cm^3/plant) to hundred percent of RFR (19.87 cm^3/plant) and further increase of fertility levels to 150% RFR (19.64 cm^3/plant) did not significantly affect root volume of soybean. Among the cropping systems, the most voluminous soybean root was recorded when soybean and corn were grown together without root separation and with geotextile root separation, but did not differ significantly from other systems (Fig. 2a and b)

Hundred and fifty percent of recommended fertility rate resulted in significantly voluminous corn root (296.86 cm^3/plant) compared to other fertility levels. The lowest root volume of 65.27 cm^3/plant was noticed in the lowest fertility level, medium fertility level recorded average root volume of 127.95 cm^3/plant. Different cropping systems did not either improve or retard root volume of sweet corn, but nevertheless numerically the highest root volume of corn was recorded when corn and soybean root systems intermingled.

Total root length: Increasing fertilizer rate application to vegetable soybean significantly ($p<0.05$) affected total root length. The longest roots of 82.9 m/plant was recorded for the treatments received the recommended fertilizer rate and shortest roots (49.23 m/plant) was noticed under the lowest fertilizer rate; while highest fertilizer rate reduced total root length (72.75 m/plant) compared to recommended rate. Cropping systems failed to significantly influence total root length of vegetable soybean (Fig. 3b).

On the contrary to soybean, cropping systems significantly influenced total root length of corn by which mono-crop corn and corn intercropped with soybean under plastic sheet root partitioning had significantly higher total root length compared to other cropping systems (Fig. 3a). On the other hand, there was significant increase of total root length of sweet corn from lower (116.98 m/plant), to medium (203.05 m/plant) and to the highest (272 m/plant) fertilizer rate (Fig. 3a).

Root Surface area: Increasing fertility level from 50% RFR to 100% RFR increased root surface area of vegetable soybean by 79.2%; but, increasing fertility level from 100% RFR to 150% RFR decreased root surface area of vegetable soybean by 15% (Fig. 4b).

Cropping systems had no significant effect on root surface area of vegetable soybean.

In the case of sweet corn, increasing fertility level from 50% RR, 100% RFR and 150% RFR significantly enhanced root surface area of sweet corn (Fig. 3a). On the other hand, no significant differences between the treatments were detected due to cropping systems.

DISCUSSION

Root dry weight of sweet corn and vegetable soybean increased as fertilizer rate increased (Fig. 3a and b); the magnitude of increase was 94 and 36% for corn and 18 and 14% for soybean from lowest to medium and from medium to highest fertility levels, respectively. This was attributed to fertility level, because increasing fertility level enhanced dry matter production, which partially was translocated to the roots which absorb nutrient and water, additionally heavier above ground plant parts need strong roots to anchor to the soil and hence plants allocated more dry matter to the root. Gersani and Sachs, (1992) also reported increased root biomass of pea crop as nutrient level increased. On the other hand, cropping systems did not differ with regard to dry matter accumulation to roots, this might be rooting zone difference between the two crops and we noticed that soybean and corn roots concentrate the upper 20 and 40 cm, respectively, this might resulted in better coexistence and inter-specific competition was equal with intra-specific competition with regard to root dry matter production. However, this result is in disagreement with the findings of Hayashi and Shigenaga, (1993) who reported increased root dry weight of intercropped corn compared to mono-crop, but, they did not mention the fertility management of the system and the only explanation can be given to this is that varieties may respond differently to crop-crop interference. Moreover, root dry weight might not be a good indicator of the total absorptive area of the root system and alteration of root system architecture can happen without a change in total root biomass (Hodge, 2004).

Root volume of both crops was significantly increased by fertility levels (Fig. 2a and b). Corn plants that received hundred percent of recommended fertility rate (RFR) had two fold more voluminous roots than those received 50% RFR, while further increase in fertility level from 100% RFR to 150% RFR, increased corn root volume more than two folds. With regard to soybean, increasing fertility level from 50% RFR to 100% RFR increased root volume, but further increase of fertility level did not significantly affected root volume. These results indicate that, corn plants need more nutrient than soybean and the nutrient rates applied to corn was not adequate. Hence, corn plants have to find ways to exploit large volume of soil resources and due to this fact it produced larger root volumes. In contrast, highest fertilizer rate seems to be optimum for soybean crop and no need to increase root volume. Soybean had highest root volume, when intercropped with sweet corn without root separation and with geotextile root separation; although not significantly different from other cropping systems; and this is the first time to report to such phenomenon. The root volume modification of soybean may be a sort of coexistence between the two crops. There are some findings which indicate the ability of plant roots to identify their neighboring plants (Miana *et al*., 2002, Gersani *et al*., 2001), hence, the type of neighboring plant can have a large impact on root morphological response of associated crops (Huber-Sannwald *et al*., 1997).

Corn plants receiving 50% RFR had total root length of 116.98 m and increasing fertilizer level to 100% and 150% RFR doubled (203 m) and tripled (272 m) the total root length. This finding seems to conflict with the work of Durieux *et al.* (1994) who noticed reduced total root length of corn at higher fertilizer N rates, but the highest rate of fertilizer we applied (180 kg N ha^{-1}) was less than the amount they applied (224 kg N ha^{-1}) and hence total root length decline seems to happen at higher fertilizer rate at which plants do not need to increase root length due to adequate supply of nutrients. Conversely, increasing fertility level from 50% RFR to 100% RFR increased total root length of vegetable soybean by 76%, but further increase from 100 to 150% RFR decreased total root length by 16%. The implication of the result is that in sweet corn, fertility level was not enough and root length was increased to exploit deeper soil layers, where as in soybean at 100% RFR total root length was more, because fertilizers applied at surface layer was not enough and to get additional nutrient, root architecture was modified through increase in both total length and surface area, however at 150% RFR, nutrient might be sufficient for soybean and no need to construct new organs. Fitter *et al.* (2002) demonstrated that an increase in root length density is more important for acquisition immobile ions than mobile ones, but root length modification in response to both mobile and immobile nutrients (NPK) are also recorded (Durieux *et al*., 1994; Robinson and van Vuuren, 1998), hence increase in root length is not necessary, in general under adequate soil fertility as Grime *et al.* (1991) also noticed that at higher resource availability in fertile sites offset the cost of new organ production. Mono-crop sweet corn and sweet corn intercropped with soybean under plastic sheet root separation had the longest total root length compared to other treatments (Fig. 3a), this indicates that competition between corn roots were more than that of between corn and soybean roots as indicated by modification of corn root length and soybean root volume, because roots of different species differ in rooting zone and to avoid competition adopt morphological root plasticity. Roots of corn occupied deeper soil layers than those of soybean (our field observation), since soil fertility varies down soil profile and crops have different capacity to obtain nutrient from different depths (Genney *et al*., 2002), hence these two crops were able to coexist by concentrating their roots in different layers. The modification of total root length of corn and root volume of soybean is the first case to report; hence further work is required whether different varieties corn and soybean under intercropping will behave the same.

Increasing fertility level from 50 to 100% and then to 150% RFR; enhanced root surface area of sweet corn

(Fig. 4a). The magnitude of increase in corn root surface area from 50 to 100% RFR was 65%, while further increase of fertility to 150% increased 41%. As we said earlier, most likely up to 150% RFR is not the optimum rate for corn and due this crop increased root surface area the absorb additional nutrient from unexploited deeper soil layers. In soybean, similar to the total root length, increasing fertility level increased root surface area initially and further increase reduced. The magnitude of increase in soybean root surface area from 50 to 100% RFR was 52%, while further increase of fertility to 150% decreased 17%. In line with this result Kuang *et al.* (2005) reported that application of 160 kg P ha^{-1} as triple super phosphate increased root dry weight, but decreased root length and root surface area of soybean.

CONCLUSIONS

Highest fertility level caused vegetable soybean plant to modify root morphology by reducing total root length and surface area, due to the availability of adequate nutrient plants did not invest much on new root organ constructions. With regard to sweet corn nutrient supply was not adequate even up to the highest level and as a result of this plants increased total root length, volume and surface area to exploit more soil resources. There was adaptation of coexistence mechanism in corn and soybean intercrop to avoid competition which was root volume and total root length adjustment for vegetable soybean and sweet-corn, respectively. Moreover, root biomass might not be a good indication to indicate total absorptive area of the root system, because root morphological characters are more plastic than root biomass at least in this experiment. Hence, total root length and surface area in general and particularly in soybean may be used as an indication of fertilizer rate adequacy for crop growth. Total root length and root volume modifications as a result of intercropping needs further study, since it is the first time to report.

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