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WATER STATUS AND GROWTH OF PLANTS IN PVC CYLINDERS INSTALLED VERTICALLY IN THE FIELD

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ABSTRACT: Increasing the efficiency of irrigation water use is critical in water-scarce countries such as Barbados. Planting in pots can ensure that most of the applied irrigation water is available exclusively to the target plant, but plant growth may be restricted due to large fluctuations in soil moisture availability and temperature, reduced rooting volume and pot drainage issues. Planting in open-ended PVC cylinders installed vertically in the field should help to ensure that applied water remains largely within the root zone of the target plant, while avoiding many of the problems associated with potted plants above the soil surface. This study assessed the effects of planting in buried PVC cylinders on water status and growth of two crop species (sweet pepper and bean) in a heavy clay soil. A split-plot experimental design was used with two main plot (height of cylinder protruding above the soil: 0 and 3 cm) and three sub-plot (buried depth of cylinder: 0, 15 and 30 cm) treatments. Cylinders (internal diameter: 16cm) were hammered into loose dry soil. Irrigation was applied as needed to supplement rainfall by manual sprinkling with a garden hose. Soil moisture status and plant growth were not significantly affected by the height of cylinder above the soil surface. As the length of buried cylinder increased, moisture content in the top 5 cm of soil within the cylinder also increased and ponding was often observed in the 30 cm cylinders. Plant growth was not significantly affected in the 15 cm cylinders but was reduced for both crops in the 30 cm cylinders. Excessive rainfall during the study period resulted in supra-optimal soil moisture conditions within the buried cylinders. Significant effects on soil penetration resistance suggested that there was soil compaction within the PVC cylinders, which was likely due to hammering during the installation process and/or swelling of soil within the cylinders on re-wetting. This approach appears to have some potential for increasing the efficiency of irrigation water use and is likely to be beneficial under low rainfall conditions with more precise water application.

Keywords: tissue moisture content, water potential, dry mass ratio, greenness index

INTRODUCTION

Barbados is listed as a water-scarce country and strategies have been outlined to enhance the management of existing water resources and increase the efficiency of water use (Government of Barbados 2007). Although Barbados is an extreme example, the majority of Caribbean territories suffer varying degrees of water stress and scarcity on both a seasonal and inter-annual basis. Agricultural enterprises are the largest consumers of water and there is a need to increase water use efficiency in agriculture as developmental needs compete for fresh water supplies (FAO 2007). As populations increase, programs to encourage urban and peri-urban horticulture (UPH) are advocated in many developing countries (FAO 2010). An important option in UPH is the growing of plants in containers, which can potentially impact water requirements.

Planting in pots can improve water use efficiency by ensuring that water is applied to the target plant while reducing or eliminating losses due to surface run off and the watering of weeds and non-crop areas. Decreased plant growth and transpiration are associated with reduced container size for potted plants, although the relationship between transpiration and available soil moisture content appears to be unaffected (Ray and Sinclair 1998). Restrictions in rooting volume due to container size can result in several physiological and morphological changes, including effects on plant biomass production, partitioning, plant water relations, nutrient uptake, leaf chlorophyll content, branching, flowering and yield (NeSmith and Duval 1998).

Apart from pot size, container geometry, growing media selection and the length of time the plant stays in the container have been identified as factors that can affect plant growth and development (NeSmith and Duval 1998). A reduction in the flexibility of irrigation scheduling is expected as container size becomes smaller and the porosity of the growing media increases. Excessive root zone fluctuations in soil moisture and temperature and root growth problems in relation to the presence of a perched water table at the base of the pots are abiotic features commonly associated with container-grown plants (Mathers et al. 2007). The perched water table is a water-saturated zone at the base of the container, which further reduces rooting volume in container-grown plants. The impact of the perched water table is reduced as the depth of the container increases.

Negative effects of abiotic factors on container-grown plants can be reduced by planting in open-ended PVC containers (cylinders) which are buried in the ground. Fluctuations in root zone moisture and temperature will be reduced because of the buffering capacity of the surrounding soil, and the presence of a perched water table can be minimized by controlling the interface between the growing medium in the container and field soil. In this study, the effects of planting in buried PVC cylinders on water status and growth of two-crop species (sweet pepper and bean) were assessed on a heavy clay soil in Barbados. The effects of container depth below and above the surface of the soil were investigated with the aim of identifying possible effects of this technique on soil-water availability and plant growth.

MATERIALS AND METHODS

This study was conducted under field conditions at the University of the West Indies, Cave Hill Campus, Barbados, on a heavy clay (black) soil with planting in raised beds. Two crops were grown:

1. Sweet pepper (*Capsicum annuum*, 'King Arthur'), planted 26th November 2010 and harvested 8th February 2011.
2. Bean (*Phaseolus vulgaris*, 'Green Crop') was planted 15th February and harvested 25th March 2011.

The soil was cultivated manually to obtain a fine tilt and beds (90 cm wide) separated by furrows (30 cm wide) were prepared. PVC cylinders (16 mm inner diameter, 3 mm thick wall) were cut to the required lengths (3, 15, 18, 30, 33 cm) and hammered vertically into dry soil on 25 November 2010. A split-plot experimental design was used with four replications (blocks). There were two main plot treatments (height of PVC above the soil):

1. 0 cm PVC above soil
2. 3 cm PVC above soil

Within each main-plot treatment, three subplot treatments (depth of PVC below the soil) were applied:

1. 0 cm PVC below soil
2. 15 cm PVC below soil
3. 30 cm PVC below soil

Each sub-plot consisted of six plants, with a spacing of 30 cm between plants within a sub-plot, 45 cm between sub-plots in the same bed, and 60 cm between plants on adjacent beds. One plant was planted within each buried PVC cylinder and in the corresponding bare soil area for the Control treatment (0 cm PVC above and below soil surface). Plants were irrigated by using a garden hose daily mornings, and a soluble fertilizer (NPK 20:20:20) was applied weekly at the recommended rate using a watering can. Seedlings were sprayed with pesticides in the early growth stages as needed to reduce pest damage. For sweet pepper, the experimental area was covered with bird netting (25% shade) to reduce bird damage during the fruiting stage. After termination of the sweet pepper crop, all crop residues were removed and the area was replanted with bean after one week, using the same experimental design.

Plant height and number of leaves were determined weekly from 9th January to 4th February 2011 for sweet pepper, and from 8th March to 22nd March 2011 for bean. Soil moisture content (v/v, %) was determined by using a soil moisture probe (Model EC5, Decagon Devices Inc., USA). The 5-cm-length probe was inserted vertically into the soil within and just outside the area bounded by the PVC cylinder and at corresponding locations in control plots. Soil moisture determinations (two replications per sub-plot) were made in the afternoons (4:00 pm) on 27th January and 4th February 2011 for sweet pepper, and on 8th, 16th and 22nd March 2011 for beans. Leaf greenness index was determined periodically using a chlorophyll index meter (Field Scout CM1000, Spectrum Technologies Inc., USA). Measurements were made on the topmost fully expanded leaf between midday and 2:00 pm afternoons with bright sunshine. Five readings were taken per leaf with the instrument held 5-10 cm from the leaf, and two leaves were sampled per sub-plot. Greenness index is calculated as a dimensionless number between 0 and 999 based on leaf reflection of red and infrared light wavelengths.

At the termination of each crop, shoots were harvested by cutting at the base of each plant and dry mass components were determined after drying plant parts in an oven at 80°C for one week. Both fresh and dry mass were determined for leaves of the harvested bean plants. Leaf water potential was determined for bean plants at the time of harvesting using a pressure chamber (Model 3005, Soil Moisture Equipment Corporation, USA). The terminal leaflet of the topmost fully expanded leaf was used, and two plants were sampled per plot between 4.00 and 4.30 pm. Soil penetration resistance (0- to 20-cm depth) was determined using a penetrometer (SC900, Spectrum Technologies, Inc., USA) a few days after harvesting the bean plants. Measurements were made at 8 cm from the remaining root stubble (within the PVC cylinder zone) with the soil at field capacity following overnight rainfall, and two determinations were done in each sub-plot. Data were analyzed using statistical analysis software (GenStat Discovery Edition 3, VSN International, UK).

RESULTS AND DISCUSSION

Excessive rainfall during the sweet pepper crop reduced the number of observations made compared to those made during the bean crop. Height of PVC cylinder above the soil surface did not significantly affect any of the parameters measured in this study, and data were pooled for the two main-plot treatments (0- and 3-cm height of PVC cylinder above soil surface). The presence of the 3-cm height of PVC cylinder above the soil surface was expected to trap and retain more water within the PVC cylinder because of reduced runoff losses. Results for both bean and sweet pepper crops suggest that there was no particular advantage of having the PVC cylinders extend above the soil surface under the conditions of this study. Irrigation water applied in this study appears to have been sufficiently uniform and of mild intensity to avoid excessive runoff on plots, or greater ponding within the raised PVC cylinders. Plant canopies were also observed to cover the diameter of the PVC cylinder, reducing any direct entry of irrigation water to the soil surface at the base of the plant.

For measurements within the PVC cylinder zone, moisture content of the top 5 cm of soil increased as the depth (length) of the PVC cylinder below the soil surface increased (Figure 1). Soil water content within the 30 cm PVC cylinder was about 28% higher than that in soil where no PVC cylinders were present. There was a tendency for soil moisture content to also increase as PVC cylinder depth increased for measurements outside the PVC cylinder zone; however, the effects were not significant (Figure 1). It is likely that water conserved within the PVC cylinders can slowly become available outside the PVC cylinders. This is comparable to the traditional technique of applying irrigation water within earthen pots buried in the field, where water seeps slowly into the surrounding soil and plant water use efficiency is increased (Bainbridge 2002).

Shoot dry mass was not significantly affected by planting in the 15 cm PVC cylinders for sweet pepper or bean compared to the corresponding control treatments (Figure 2). Plant growth of bean was greater than that of sweet pepper in 0 cm (control treatments) and 15-cm PVC cylinder. Growth of both bean and sweet pepper was severely reduced by planting in the 30-cm PVC cylinders, and shoot dry mass was reduced by 56% for bean and 36% for sweet pepper compared to the controls (Figure 2). Shoot dry mass was similar for bean and sweet pepper when grown in the 30-cm PVC cylinders. There was a strong negative correlation between shoot mass of bean and soil moisture content in the top 5 cm soil (Table 1). Soil moisture retention within the 30-cm PVC cylinders was most likely supra-optimal for plant growth. Excessive root zone moisture is likely to reduce soil aeration, which can have adverse effects on root respiration, water and nutrient transport, and soil nitrogen (Scott and Renaud 2007).

In comparison with the control treatment, plant height and number of leaves for bean were not significantly affected by planting in the 15 cm PVC cylinders, but were reduced in the 30 cm PVC cylinders (Figures 3, 4). The effect on number of leaves per plant was more severe and occurred earlier than the effect on plant height. No significant effects of the treatments were observed in leaf greenness index (data not shown); however, this is based on a limited number of observations made over the period. It may also have been useful to sample leaves at different points in the canopy (not only the topmost fully expanded leaf). Periodic root flooding has been shown to reduce plant height, leaf production and leaf chlorophyll content in field bean (Pociecha, Kościelniak, and Filek 2008).

Leaf moisture content of the bean plants was not significantly affected by height of PVC cylinder above the soil surface or by growing in the 15-cm PVC cylinder, but was reduced for plants growing in the 30-cm PVC cylinders compared to the control plants (Table 2). Reduced root water absorption and transport to the shoot system can lead to wilting under flooded soil conditions (Scott and Renaud 2007). Results of leaf moisture content determinations support the conclusion that the soil moisture content was supra-optimal for plant growth in the 30-cm PVC cylinders. However, no significant effects of the treatments on leaf water potential were observed (data not shown), which may be related to the time of sampling of leaflets for water potential determinations. The ratio of reproductive parts to shoot mass ratio (pods/shoot mass ratio) was negatively correlated with leaf water potential in bean and positively correlated with soil moisture content in the top 5 cm soil (Table 1). Earlier partitioning of shoot dry mass into reproductive structures may have been caused by stress conditions in the 30-cm PVC cylinders.

Soil penetration resistance measured within the PVC cylinder zone increased with soil depth for all treatments with values within the 15- and 30-cm PVC cylinders being significantly greater than those for the control treatment except at the 2.5-cm soil depth (Figure 5). These results suggest that there was significant soil compaction within the PVC cylinders (15- and 30-cm depth). Soil penetration resistance was highest within the 15-cm PVC cylinders, over the 10.0 to 12.5 cm soil depth range and within the 30-cm PVC cylinders over the 17.5 to 20.0 cm soil depth range (Figure 5). Soil compaction within the PVC cylinders may have been caused by the process of hammering the cylinders into the dry soil and/or by soil expansion within the cylinders on watering. There was a strong positive correlation between the penetration resistance in lower soil layers (at and beyond 15.0-cm depth) and soil moisture content in the top 5 cm soil (Table 3), suggesting that compaction contributed to impeded drainage within the PVC cylinders. Correlations between soil penetration resistance and shoot dry mass, leaf/shoot dry mass ratio and pod/shoot dry mass ratio were also consistent with the suggestion that plant stress within the PVC cylinders could have been caused by soil compaction (Table 3).

CONCLUSION

Soil moisture content increased within PVC cylinders that were inserted vertically in the soil, and the effect was greater for longer PVC cylinders that reached greater depths. Effects of height of the PVC cylinder above the soil surface were not significant. Plant growth of bean and sweet pepper was negatively associated with soil moisture content in the top 5 cm soil. Soil compaction within the PVC cylinders could have restricted drainage leading to supra-optimal soil moisture conditions in the root zone. This technique (tube-culture) may be useful for increasing the efficiency of irrigation in very dry areas or seasons. Further studies are needed to optimize cylinder size and walls, installation procedures and rooting media so as to obtain the maximum benefits.

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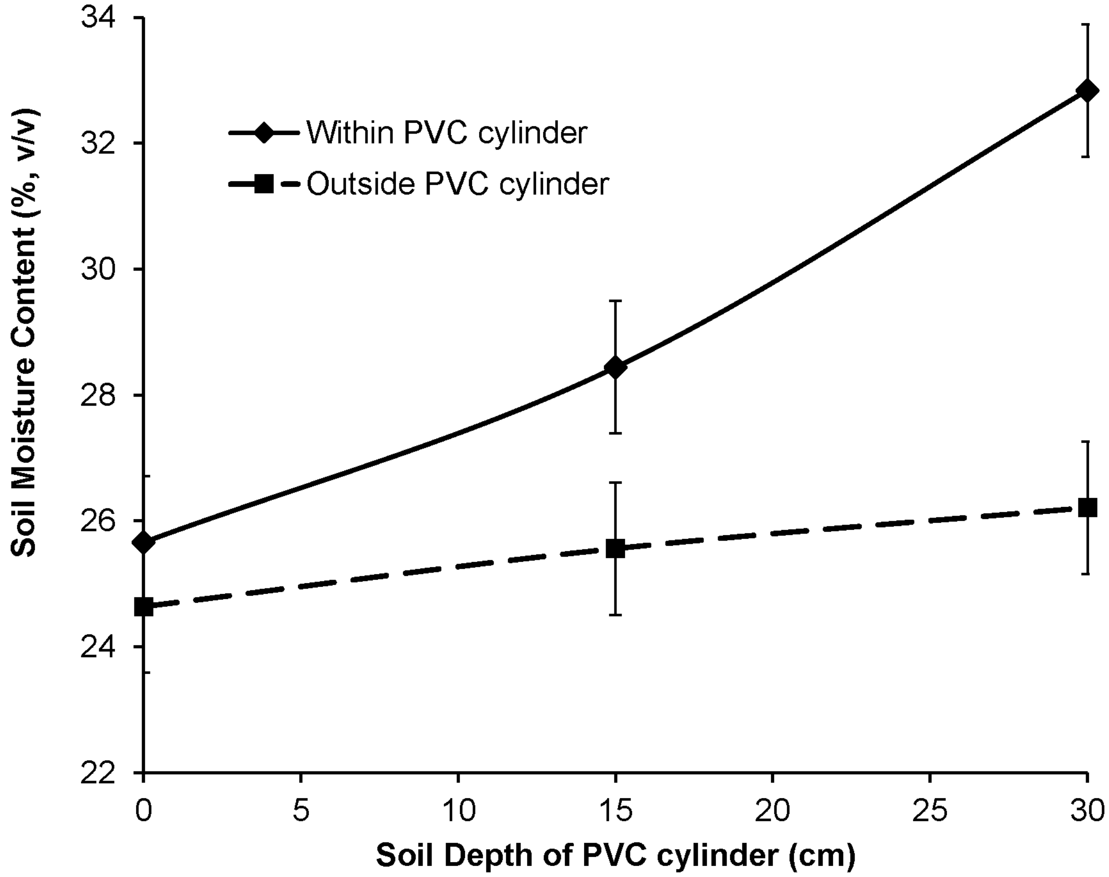

Figure 1: Soil moisture content in the top 5 cm soil within and outside the perimeter of buried lengths of vertically-installed PVC cylinders that reach varying soil depths. Control values were obtained by corresponding measurements close to and away from the plant. Measurements were made on five occasions during the growth of sweet pepper and bean crops.

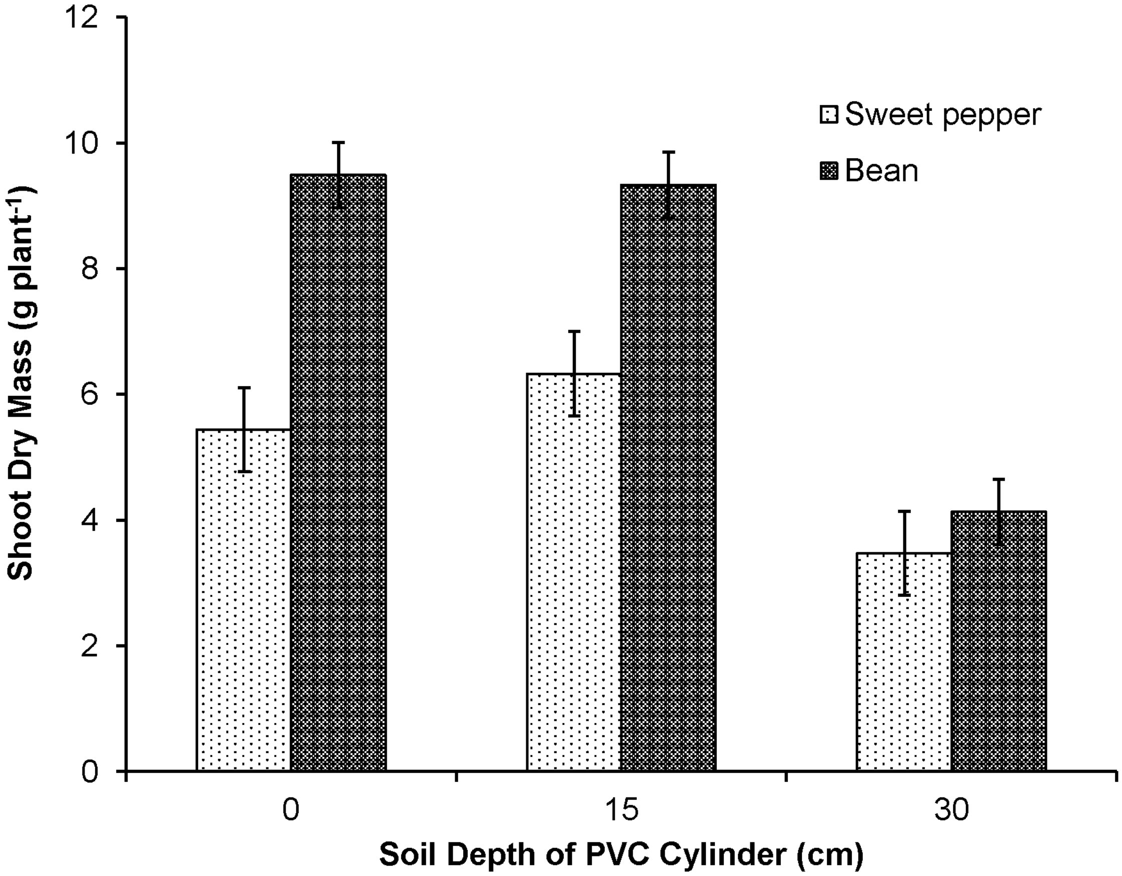

Figure 2: Shoot dry mass of sweet pepper and bean plants grown within buried lengths of vertically-installed PVC cylinders that reach varying soil depths. Control plants were grown in unenclosed soil (0-cm PVC cylinder length).

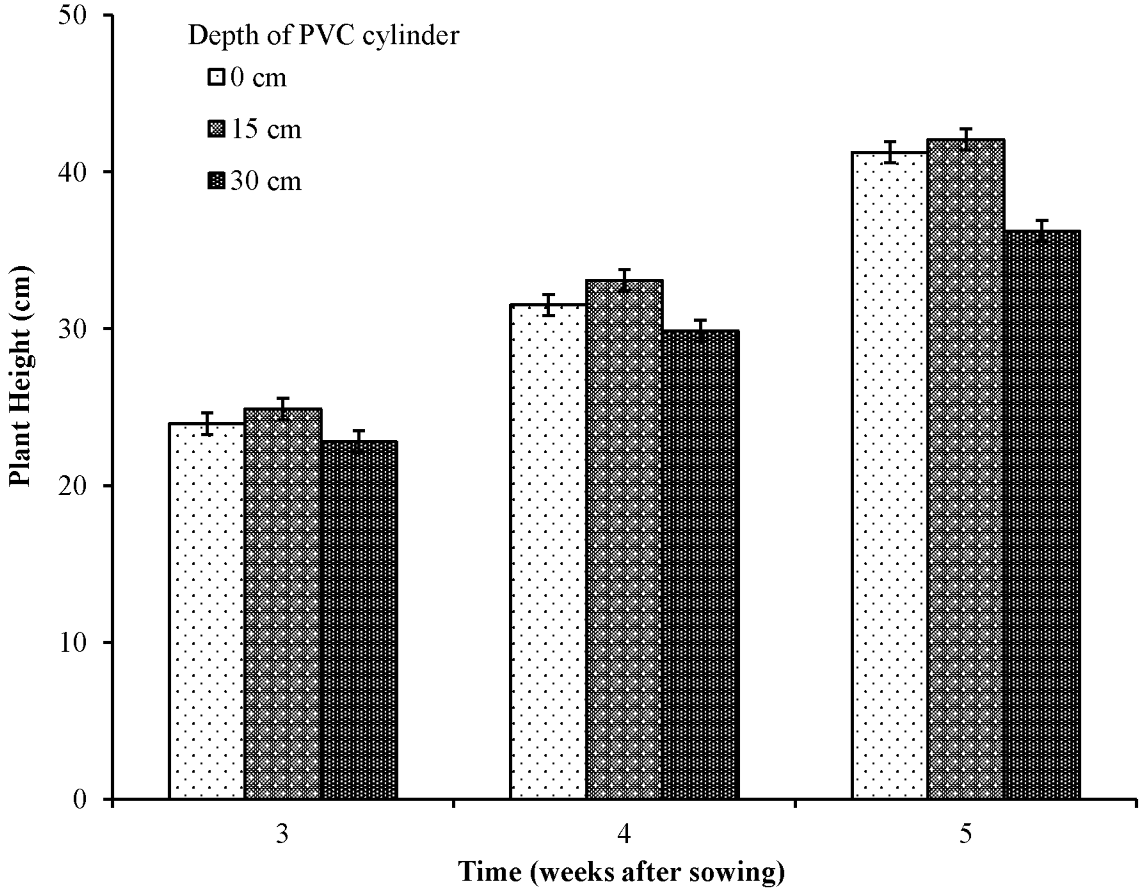

Figure 3: Plant height of bean plants 3-5 weeks after sowing within buried lengths of vertically-installed PVC cylinders that reach varying soil depths. Control plants were grown in unenclosed soil (0-cm PVC cylinder length).

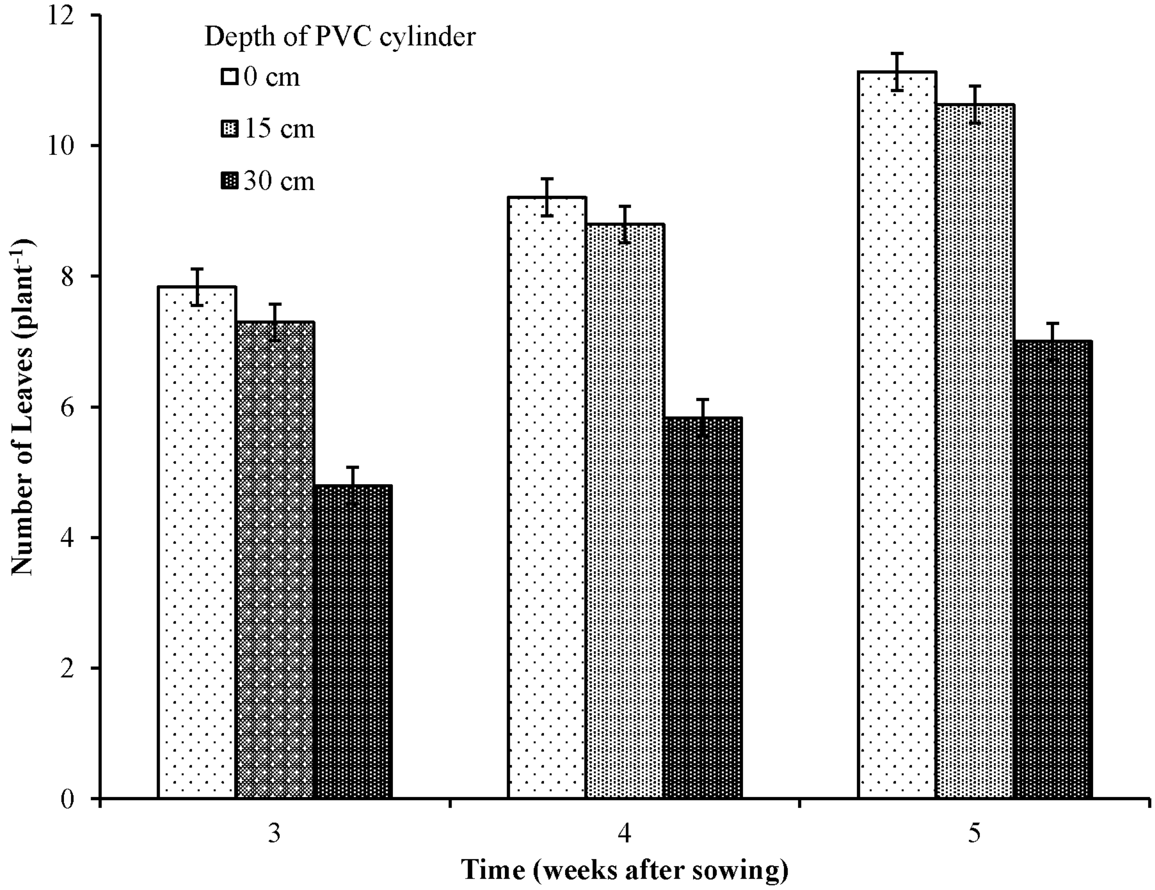

Figure 4: Number of leaves of bean plants 3-5 weeks after sowing within buried lengths of vertically-installed PVC cylinders that reach varying soil depths. Control plants were grown in unenclosed soil (0-cm PVC cylinder length).

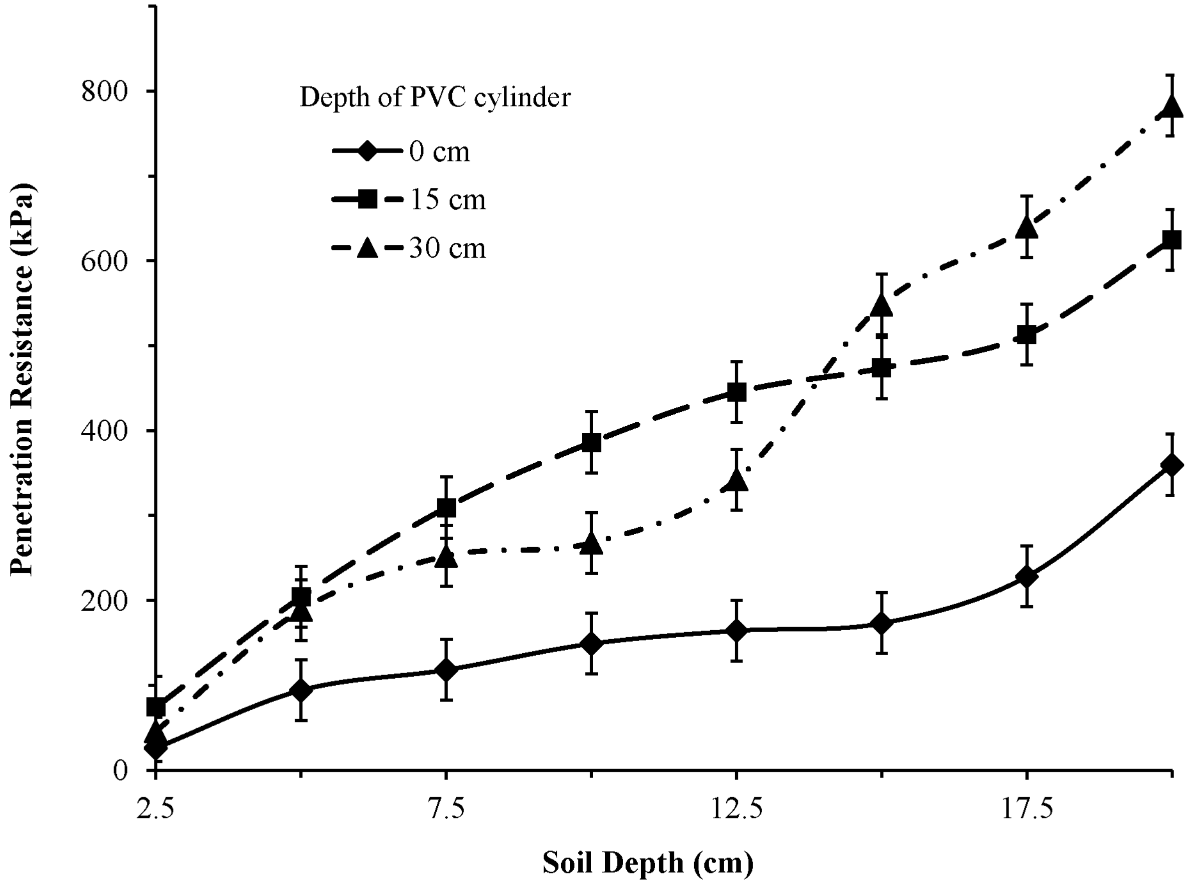

Figure 5: Soil penetration resistance vs. soil depth within buried lengths of vertically-installed PVC cylinders that reach varying soil depths. Control values were obtained in unenclosed soil (0-cm PVC cylinder length).

Table 1: Correlation matrix for shoot mass, pods/shoot mass ratio, leaf water potential and soil moisture content for the bean crop.

	Pearson's Correlation Coefficient (r)		
	Shoot mass	Pods/Shoot mass ratio	Leaf Water Potential
Pods/Shoot mass ratio	-0.56**	1	
Leaf Water Potential	0.27	-0.50*	1
Soil MC % (top 5 cm)	-0.76**	0.51*	0.18

*, ** Values significant at the 5% and 1% significance levels, respectively.

Table 2: Leaf moisture content per unit dry mass (g g^{-1}) of bean plants as affected by growth in PVC cylinders extending to varying depths below and heights above the soil surface

PVC Above soil (cm)	**PVC Below soil (cm)**			
	0 cm	15 cm	30 cm	Mean
0	6.58	6.59	5.42	6.20a
3	6.92	6.93	5.88	6.57a
Mean	6.75a	6.76a	5.65b	

*Means in the same column or row with a common attached letter are not significantly different from each other by Fischer's Protected LSD Test.

Table 3: Correlation matrix between soil penetration resistance at various soil depths and soil moisture content, shoot dry mass, leaf/shoot dry mass ratio and pods/shoot dry mass ratio for the bean crop.

Soil Depth (cm)	**Pearson's Correlation Coefficient (r)**			
	Soil MC % (top 5 cm)	**Shoot dry mass**	**Leaf/shoot mass ratio**	**Pods/shoot mass ratio**
2.5	0.18	0.09	-0.34	0.04
5.0	0.41*	-0.20	-0.22	0.25
7.5	0.22	0.00	-0.45*	0.26
10.0	0.21	0.14	-0.50*	0.12
12.5	0.35	-0.04	-0.28	0.13
15.0	0.67**	-0.47*	-0.05	0.41*
17.5	0.73**	-0.57**	-0.18	0.61**

*, ** Values significant at the 5% and 1% significance levels, respectively.