Soil compaction effects on early plant growth of squash

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Abstract

Attempts to grow squash in minimum tilled soil have resulted in poorer establishment and plant growth compared with plants sown into conventional tilled soil. The possibility that the higher bulk density of the top soil in minimum tilled soils affects root development and seedling growth was examined in a glasshouse experiment. Pots were prepared with soil bulk densities of 0.9, 1.1, 1.3 and 1.5 g/cm^3. Seedling weights and leaf area decreased with increasing bulk density, and this was associated with decreased root growth and root length densities.

***Additional key words*:** *Cucurbita maxima*, root length density, leaf area

Introduction

Squash (*Cucurbita maxima* L.) is a widely grown vegetable crop worth *c.* $60 M annually in exports. It is generally grown in rotation with maize, sweet corn or other crops and there is increasing concern about the deterioration of soil quality due to tillage on many soils in which squash is grown. This has led to an interest in the adoption of minimum tillage techniques to help minimise soil problems (Pearson and Wilson, 2002).

However, while maize and sweet corn crop yields do not appear to be reduced by minimum tillage practices (Pearson *et al.*, 2000), grower observations indicate that squash yields on minimum tilled soils may be lower compared to conventionally cultivated soils. Early plant growth in particular seems affected, with plants grown in minimum tilled soils having poorer establishment and being smaller than plants grown in conventionally cultivated soils (Wilson L.R. pers.comm.).

Minimum tillage practices for squash involve preparing a strip of tilled soil using an adapted rotary hoe. This strip often has very defined sides with soil smearing on the surface and bottom of the strip, which could form compaction layers in the soil. To determine the importance of these compaction layers, a glasshouse study was conducted to evaluate soil compaction effects on root and plant growth of squash seedlings.

Methods and Materials

The experiment was performed in a glasshouse in a cool-temperate climate at Hastings, New Zealand (lat. 39.47°S, long. 176.64°E).

The soil used in the experiment was a Mangateretere silt loam. After tilling with a rotary harrow, the top 15 cm. of the soil was collected, air dried and sieved. Aggregates of 4-8 mm only were used for the experiment, and the soil was kept at 50 % field capacity for 2 weeks before pots were prepared.

The pots used were made out of PVC pipe, with an internal diameter of 15 cm and a height of 14 cm. Measured volumes of soil were packed into each pot to achieve soil bulk densities of 0.9, 1.1, 1.3, and 1.5 g dry soil/cm^3. For the 0.9 and 1.1 g/cm^3 treatments, the soil was maintained at 50 % field capacity while packing, and for the 1.3 and 1.5 g/cm^3 treatments, the soil was maintained at 75 % field capacity while packing. Each soil bulk density level was replicated 4 times, giving a total of 16 pots. Once all the treatments were prepared, water was added to ensure that field capacity was 75 % in all pots. Pots were placed on sawdust in a four-replicate randomised block design and left for three days before planting. Three pre-sprouted seeds of *Cucurbita maxima* variety Delica were placed in each pot and covered with loose soil at 50 % field capacity on February 3, 2002. Irrigation was applied to keep the soil moist. Initially irrigation was applied every two days, but this proved insufficient to maintain soil moisture, so after the first week, irrigation was applied daily.

Emergence and leaf tip appearance were recorded daily. Minimum and maximum temperatures in the glasshouse for the previous 24 hours was recorded daily at 9:00 am. during the experiment. A data logger was used to record hourly air temperature and soil temperature at a 2 cm depth in all pots of 3 replicates.

Plants were harvested 45 days after planting when the tip of the fourth leaf had appeared on all plants. At harvest, plants were cut off at soil level. Total leaf fresh mass per pot was recorded before measuring leaf area using a LICOR-3100 leaf area meter. Leaf dry mass was obtained after drying in an oven for 48 hours at 70 °C.

The soil was then removed from each pot as a core and separated into the top 7 cm layer and the bottom 7 cm layer. Roots were washed from each soil layer and stored in ethanol at 4 °C prior to measuring lengths. Root lengths were measured by counting root intersections on a 2 cm × 2 cm grid following the method of Tennant (1975) and are reported as root length density (RLD – cm root per cm^3 soil). Fresh mass of roots was then recorded, before drying in an oven for 48 hours at 70 °C before measurement of dry mass. All data were analysed by ANOVA using GenStat Ver. 6.1.

Results and Discussion

Air temperature averaged 22.4 °C and soil temperature averaged 17.2 °C during the experiment, which were not limiting to growth based on the work of Buwalda and Freeman (1986). There were no differences in soil temperatures between the different treatments. Emergence did not vary between treatments but was delayed, possibly due to drying out of the soil in the early stages of the experiment, and occurred 15 days after sowing. The average phyllochron for leaf tip appearance was 45 growing degree days above a base temperature of 8 °C.

The total root length density (RLD) in the 0-14 cm core of soil decreased ($P<0.001$) with soil compaction from 0.872 cm/cm^3 to 0.172 cm/cm^3 as soil bulk density increased from 0.9 to 1.5 g/cm^3 (Figure 1). For every 0.1 g/cm^3 increase in soil bulk density, RLD decreased by 0.12 cm/cm^3. RLD was higher in the 7-14 cm layer of soil compared to the 0-7 cm layer of soil when soil bulk density was < 1.1 g/cm^3 (Figure 1), but as soil bulk density increased to 1.5 g/cm^3, RLD in the 7-14 cm layer decreased markedly to 0.01 cm/cm^3. This trend was also evident in the percentage distribution of roots in the different layers of soil (Figure 2), where the proportion of roots in the top 7 cm of soil was significantly ($P<0.01$) higher at bulk densities greater than 1.3 g/cm^3. At a bulk density of 1.5 g/cm^3, almost all the roots (97 %) were in the top 0-7 cm layer of soil. Similar effects of soil compaction have been observed on the root length densities of other plant species (see Clark *et al.*, 2003: Roselem *et al.*, 2002).

While the proportion of root length at different depths of the soil varied with bulk density, there was no consistent effect of soil bulk density on root dry mass per plant (Figure 3). Root dry mass decreased from 0.12 g to 0.02 g as bulk density increased, but it was not significant ($P<0.14$), due to large variations in root dry mass per plant. This is evidenced by the large standard errors in Figure 3. Also there was no significant effect of soil bulk density on root dry mass when each depth was considered separately ($P<0.30$ for the 0-7 cm layer, $P<0.12$ for the 7-14 cm layer).

Increasing soil bulk density also had no significant effect ($P<0.15$) on total (roots + tops) dry mass per plant (Figure 4), and the response of plant fresh mass was similar (not shown). Experiments with grass crops have shown that soil compaction can affect RLD, but have little effect on biomass of seedlings (Rosolem *et al.*, 2002).

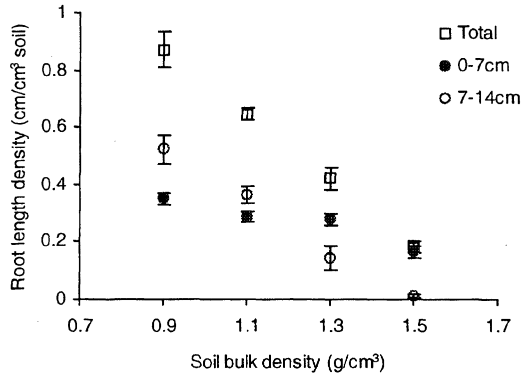

Figure 1. Root length density of squash seedlings as affected by soil bulk density. Vertical bars show the standard error of the mean.

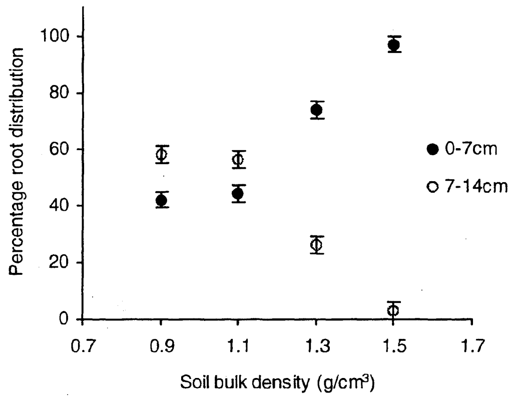

Figure 2. Percentage root distribution in the top and bottom 7 cm of soil at different bulk densities

Marshner (1986) suggested that soil compaction effects on plant growth are only noticeable when water and nutrient acquisition are impaired. In this experiment, it is unlikely that there were any differences in water or nutrient limitation between the different treatments, so there was no effect on biomass accumulation, However, in field conditions, as plants continue to grow and nutrient and water demands increase, limitations to growth could occur. Evidence from peas and soybean (Rosolem *et al.*, 2002), indicate that once roots grow through a compacted zone, there is no growth recovery of the roots. This lack of recovery appears to be because roots in compacted soils import fewer carbohydrates compared to roots in non-compacted soils, and the amount of carbohydrate required per length of root for growth appears higher in compacted soils (Atwell, 1990), resulting in a shortage of carbohydrate supply below the compacted layer. Thus, under field conditions, squash roots growing through a compacted layer may tend to be smaller and limit the supply of nutrients and water to the crop

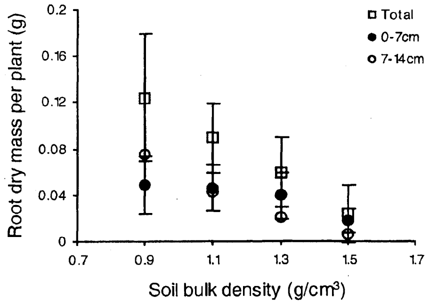

Figure 3. Changes in root dry mass per plant of squash seedlings with different levels of soil bulk density. Vertical bars are standard errors of means.

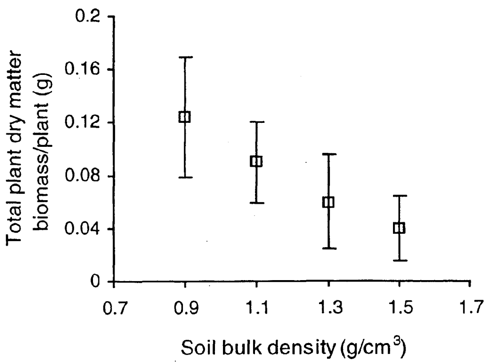

Figure 4. Response of total plant (tops+dry roots) dry matter (g/plant) of squash seedlings to soil bulk density. Vertical bars indicate standard errors of means.

Compared to plant biomass, leaf area declined significantly ($P<0.001$) from 141 cm^2/plant at the lowest bulk density to 36 cm^2/plant at the highest bulk density, a decrease of 75 % (Figure 5). Leaf area was only affected if the soil bulk density was greater than 1.1g/cm^3, and declined by 18 cm^2 per every 0.1 unit increase in bulk density. That plant biomass was not significantly impaired, while leaf area was, suggests a feedback effect of root growth on leaf area expansion, possibly through hormones (Clark *et al.*, 2003).

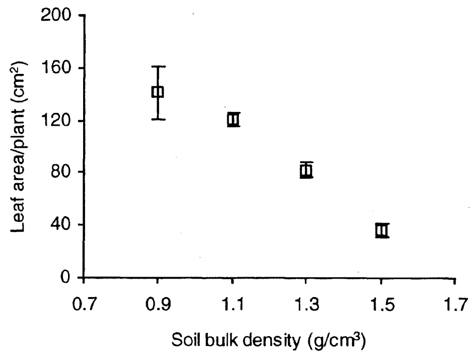

Figure 5. Response of leaf area per plant of squash seedlings to bulk density. Vertical bars are standard error of means.

Wolfe *et al.*, (1995) found that soil compaction effects on yields of cucumber, cabbage, snap bean and corn were higher in field experiments compared to the studies conducted on the same soil in greenhouse conditions. They concluded that the magnitude of the response to compaction in field conditions was worsened by plant responses to secondary effects of compaction such as reduced availability of nutrients, flooding, and increased pest pressure. While this glasshouse study indicates a possible decrease of biomass of 60 % at the highest compaction level, it is possible that field yields may be more severely curtailed where compaction severely limits nutrient supply, increases water-logging or results in increased pest pressure. The reduction in leaf area of the seedlings with soil compaction demonstrated in this experiment (Figure 4) indicates that the yield potential of the crop is already limited in the early phases of growth due to soil compaction.

Conclusions

Soil compaction reduces root length and root distribution of squash plants, and results in smaller leaf area. These effects on the plants result in poorer stand establishment and crop cover, ultimately leading to lower yields. To ensure good crop establishment and canopy cover, it is recommended that squash not be planted into soil with a bulk density greater than 1.1 g/cm^3. For squash growers, current minimum tillage practices and machinery need to be adapted to help prevent localized compaction zones in the seedbed.

Acknowledgements

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