Effect of Soil Compaction on Leaf Number and Area, and Tuber Yield of White Lisbon Yam

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The effect of soil compaction in root and tuber zones on the growth and yield of White Lisbon yams (*Dioscorea alata L.*) was examined using specially designed boxes. Soil compaction reduced leaf number, leaf area, and yield. A close positive linear relationship was observed between leaf number and yield. It is suggested that the growing tuber contributes substantially to the development of the plant by assisting in the absorption of moisture and essential nutrients. Compaction in the tuber zone had no effect on tuber number, tuber length, and tuber width. However, tubers growing in compacted soil penetrated the soil to a lesser depth, tended to develop above the original level of the soil to a greater extent, and had a larger number of growing points (or toes).

The edible portion of the yam (*Dioscorea* spp.) is the underground tuber. Tubers can be very large, and sometimes weigh more than 80 kg. In commercial production, however, tubers are usually very much smaller and range from less than 1 kg to about 10 kg depending on cultivar and growing conditions. White Lisbon (*D. alata* L.) is the major cultivar of Trinidad, Barbados, and other islands in the Eastern Caribbean; it normally produces tubers of 1–5 kg in weight. It is the object of this study to examine the relative effect of soil compaction in root and tuber zones on growth and yield of the White Lisbon yam.

Methods

The yams were grown in specially designed boxes (Fig. 1) in which the tubers and roots of the same plant developed in different compartments. Each compartment was 55.9 cm high, 22.9 cm wide, and 61.0 cm long. The partitions between the root and tuber compartments were about 5 cm lower than the outer edge of the box. The boxes were constructed from 2.5 cm thick wood.

There were six treatments in a 2 × 3 factorial with four replications. The initial bulk densities of the soil in the root and tuber compartments for each of the treatments are given in Table 1. A plot consisted of a single box in which one plant was grown.

The experiment was conducted at the University Field Station, Valsayn, Trinidad and the soil, classified as Fluventic Eutropepts by Smith (1974), was the River Estate Loam (coarse sand 5%, fine sand 45%, silt 23%, clay 26%, and organic mater 1% oven dry weight). The boxes were placed in the field and then packed with topsoil to the required bulk density (D_b). The soil was taken from the top 30 cm and sieved through a 6.3 mm mesh and then allowed to dry to about 10% moisture before packing in the boxes. The soil required no compaction to achieve a D_b of 1.1 g/cm^3; this was therefore the lowest possible D_b for this soil under existing conditions. To achieve a D_b of 1.3 g/cm^3 the soil was compacted in 8 cm depth intervals by packing the calculated weight of soil to the required depth with a broad wooden hammer, and for a D_b of 1.6 g/cm^3 the packing was done for an additional 4 cm of soil. All boxes were filled to about 5 cm below the upper edge of the box, and therefore, to the top of the partitions separating the root and tuber compartments.

Black plastic (2 mm gauge) was doubled and placed on top of the soil in the tuber (or middle) compartment with about 10 cm of plastic overhanging on one side of the box as illustrated in Fig. 1. The overhang of plastic was necessary to facilitate the removal of the

Table 1. Initial bulk densities (g/cm^3) in the tuber and root compartments.

Treatment code	Bulk densities: Tuber compartment	Root compartment
11	1.1	1.1
12	1.1	1.3
21	1.3	1.1
22	1.3	1.3
13	1.1	1.6
23	1.3	1.6

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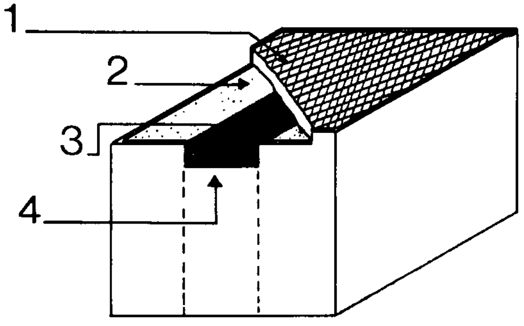

Fig. 1. Cut-away of upper 5 cm of soil to show the position of the plastic: (1) loose soil; (2) compact/uncompacted soil of root compartment; (3) black plastic over tuber compartment; and (4) black plastic overhang.

plastic at a later stage. The plastic was 8 cm wider than the middle compartment; 4 cm on each side was folded over the separating partitions to prevent roots from entering the tuber compartment. A 5 cm depth of loose soil was added to bring the soil in all three compartments to the level of the outer edge of the box.

Head setts of White Lisbon yam (*D. alata* L.), each weighing 100 g, were planted in the centre of the tuber compartments on 27 July 1973. The setts were buried to a depth of about 2 cm in the centre of the middle compartment. The soil in all three compartments was lightly mulched with dry grass after planting. Mulching was considered necessary to prevent crusting of the soil surface. Compound fertilizer having a N:P:K ratio of 13:13:20 was applied at the rate of 24 g per compartment in a split dose. The plants were staked.

The number of leaves per plant (i.e. per plot) was recorded 3, 4, 8, and 25 weeks after planting. Leaf area was estimated at 25 weeks after planting. The bulk density was measured area, 15 leaves were selected randomly from each plant at 25 weeks and the overall length (B) was measured. The area of these leaves was then calculated using the formula: leaf area $= -76.3 + 10.0B$. The area of the whole plant was then determined, by multiplying the area per leaf by the total number of leaves per plant.

Bulk density of the top 38 cm of soil and average root density were determined 27 weeks after planting. The bulk density was measured by extracting a column of soil 38 cm long in a 5 cm diameter open slot tube sampler. The soil sections were removed, dried at 105 °C, and weighed. Bulk density was calculated as grams of dry soil per cubic centimetre. Root density was measured by taking six soil samples to a depth of 38 cm from each root compartment with the 5 cm diameter tuber sampler. Five samples were taken from the apices of an imaginary five-pointed star and the sixth from the centre of the star. Each sample was cut into 12.7 cm lengths and the six samples from each depth bulked. The soil was carefully washed from the roots on a muslin cloth sieve and the roots collected and dried at 70 °C.

The tubers were harvested on 12 February 1974, 28 weeks after planting. Data were recorded on tuber number, tuber weight, length and width of tubers, maximum depth of tubers, and the number of growing points (i.e. the number of fingers or toes). Bulk densities of the soil at the base of the tubers were measured on core samples 5 cm in diameter and 7.5 cm long, sampled by the procedure described by Blake (1965).

Results

All the main roots were confined to the root compartments indicating that the system effectively separated the roots from the tuber compartments. Tubers had a large number of fine roots (tuber roots) on their surface. These were thicker and present in greater quantities at the head than at the tail of the tubers.

Slightly higher bulk densities were recorded in the compacted tuber compartments 1 week before harvesting, but differences were not significant. The bulk densities of the soil at the base of tubers were very much higher than the initial bulk densities, indicating that the tuber itself was compacting the soil. This trend was particularly marked at compaction level 1 (1.1 g/cm^3). In the root compartment the mean bulk density of the top 38 cm of soil at compaction level 3 (D_b = 1.38 g/cm^3) was significantly higher than compaction levels 1 and 2 but very much lower than the initial bulk density of 1.6 g/cm^3. In both the root and tuber compartments the D_b of the soil at level 1 increased up to 1 week before harvesting.

Yield per plant decreased significantly with increase in initial bulk density of both the root and tuber compartments (Fig. 2). Differences in yield are shown in Table 2. The interaction between compaction levels in the root and tuber compartments was significant. Yield was

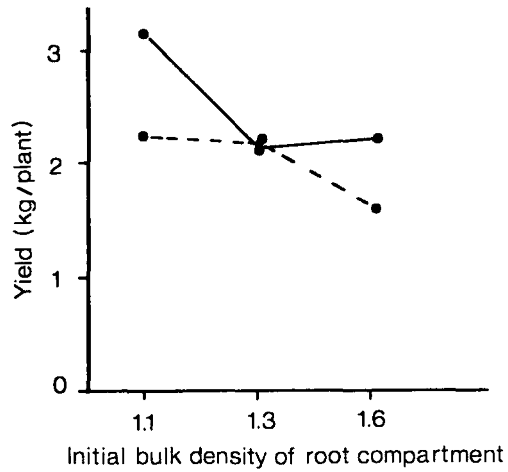

Fig. 2. Effect of initial bulk density in root and tuber compartments on yield: —— initial D_b of tuber compartment = 1.1; ---- initial D_b of tuber compartment = 1.3.

highest (3.09 kg/plant) in the treatment (11) where the soil was not compacted in either the root or tuber compartment, and lowest (1.60 kg/plant) in the treatment (23) having the highest compaction level. Compaction to level 2 in the tuber compartment, with the root compartments at level 1, reduced yield by 27%, whereas compaction to level 2 in the root compartments with the tuber compartment at level 1, reduced yield by 32%.

There were no significant differences in tuber numbers per plant among treatments. The decrease in yield with increase in soil compaction in the root and tuber compartments was therefore due mainly to a decrease in tuber size. There were no significant differences in the number of growing points of tubers as a result of varying levels of compaction in the root and tuber compartments, but tubers from the higher compaction level 2 of the tuber compartment tended to have a higher number of growing points (12.7/plant) than those from low compaction level 1 (8.7/plant).

Soil compaction in the tuber compartment had no significant effect on tuber length or tuber width. There is some indication, however, that compaction resulted in slightly shorter and broader tubers, and these therefore had a lower length to width ratio than tubers grown in the soil that was not compacted. Tubers grown in soil that was not compacted penetrated the soil to a greater depth than those grown in compacted soil. Tubers in the more compacted soil tended to grow upwards above the level of the box more than tubers in the treatments in which the soil was not compacted. Mounding at the base of the plants, especially in compacted tuber compartments was very evident at harvesting. Tubers in the compacted tuber compartments (level 2) had a mean height of 18 cm above the top of the box compared to 11 cm for those with the lower compaction level 1.

Soil compaction in the tuber compartment had no effect on leaf number per plant at 3, 4, and 8 weeks after planting (Table 3). However, compacting the soil in the root compartment significantly reduced the number of leaves per plant at 3, 4, and 8 weeks. Leaf number at 25 weeks was significantly reduced by compaction in both the root and tuber compartments. Estimated leaf area at 25 weeks was

Table 2. The effect of soil compaction levels in root and tuber compartments on tuber yield (kg/plant), percentage reduction given in parentheses.

		Root compartment (RC)			
		1	2	3	Mean
Tuber compartment (TC)	1	3.09	2.11	2.21	2.47
		(0)	(32)	(29)	(0)
	2	2.26	2.17	1.60	2.01
		(27)	(30)	(48)	(19)
	Mean	2.67	2.14	1.90	—
		(0)	(20)	(29)	—
			S.E.		*p*
Mean tuber compartments (TC)			0.15		0.018
Mean root compartments (RC)			0.12		0.007
TC × RC			0.21		0.125
C.V.				18.9%	

Table 3. The effect of soil compaction in root and tuber compartments on leaf number per plant at 3, 4, 8, and 25 weeks after planting and on estimated leaf area per plant at 25 weeks after planting.

Compartment	Compaction level	Leaf number				Leaf area at 25 wks ($cm^2 \times 10^3$)
		3 wks	4 wks	8 wks	25 wks	
Root	1	7.5	16.7	90.2	207.5	11.31
	2	4.4	11.1	67.5	185.7	10.32
	3	5.2	12.9	73.5	171.2	8.85
	S.E. ±	1.1	1.8	7.7	9.7	0.97
Tuber	1	5.1	12.7	80.7	203.8	10.97
	2	6.3	14.5	73.5	172.5	9.36
	S.E. ±	0.9	1.4	6.3	7.9	0.79

also reduced by compaction in both root and tuber compartments, but differences were not as significant.

A very highly significant correlation coefficient of $+0.796$ ($p = 0.001$) was observed between leaf number at 25 weeks and yield ($y = -0.183 + 0.0129\ \ln$).

No significant differences in average root densities in the root compartments were measured among treatments.

Discussion

Soil compaction in both the root and tuber compartments decreased tuber yield. Significant positive correlations were observed between leaf number at 25 weeks and yield and leaf area at 25 weeks and yield. Lower yields at the higher compaction levels therefore seem to be related to a reduction in the total photosynthetic surface and thus the total amount of carbohydrate available to the developing tubers.

The absence of any effect of soil compaction in the tuber compartments on leaf number between 3 and 8 weeks is not surprising because during that time the tubers (really only primary nodal complexes (Ferguson 1973) are present at this early stage of growth) were not in contact with the soil of differing compaction levels. The black plastic, which was removed at 9 weeks, separated the tubers from the underlying compacted or uncompacted soil. The large effect of compaction in the tuber compartment on leaf number and leaf area at 25 weeks indicates that the growing tuber may contribute substantially to the promotion of growth of the plant. The tuber is likely to be absorbing nutrients and moisture through the numerous roots that occur on the tubers, and which are more prevalent during the early period of tuber bulking. The tuber surface itself may also be absorbing nutrients and moisture. It has been observed that fibrous root (mostly nontuber) development reached a peak at 4 months after planting and declined thereafter, suggesting a reduced potential for the absorption of nutrients after 4 months (James 1953). The evidence here suggests that the tuber through its surface and/or the many fine roots on the surface may help to offset the reduced potential for absorption of nutrients and moisture resulting from the decline in the fibrous root system. The tuber itself, therefore, may be playing a major role in providing essential nutrients and moisture for plant growth.

The finding that the tuber may play an imporant role in the nutrition of the yam plant is considered significant. It may help to explain the dramatic effect the application of organic fertilizer has on increasing the yield of yams (Ferguson and Haynes 1970). Organic fertilizers when incorporated into the hill or ridge would provide not only a soil medium offering relatively low resistance to the development of tubers but also nutrients in the immediate vicinity of tubers. The effect of placement of fertilizer in the vicinity of the developing tuber on growth and yield of yams is worth investigating.

Tubers from the less compacted treatments presumably met with less resistance and penetrated the soil to a greater depth. They therefore had the opportunity of exploiting a greater volume of soil for nutrients and moisture, which may have resulted in better growth and thus higher leaf numbers. Tubers developing in the more compacted soil may also be smaller sinks for carbohydrates because the soil offered greater resistance to their growth and thus led to a build up of assimilates in the translocatory system and eventually at the sites of photosynthesis. It has been shown that photosynthesis can be inhibited by an excess of assimilation products (Humphries 1967; Neals and Incoll 1968). Reduced photosynthesis results in a smaller amount of assimilates being available for plant growth and thus results in smaller plants.

The results also suggest that the normal geotropic growth of tubers was restricted by the resistance offered by the soil in the compacted tuber compartments. Although they were smaller, tubers from compacted compartments grew higher above the top of the box than tubers from compartments that were not compacted. The slightly lower length to width ratio also suggests that tubers have the tendency to expand laterally in compacted soil. Tubers from the more compacted tuber compartments also had a slightly greater number of growing points or "toes." It is well known that soil resistance can be reduced by the incorporation of organic matter and many farmers in the Caribbean claim that tubers of White Lisbon yams develop fewer "toes" when produced in soils to which organic matter is added.

Compaction in the root compartment reduces tuber yield seemingly through a reduction of leaf numbers and leaf areas from as early as 3 weeks in the highest level of compaction. Reductions of leaf growth and tuber yield in treatments with compacted root compartments were likely to be due to the failure of roots to penetrate and exploit the soil volume for nutrients and moisture. Reduced aeration, less available water capacity, and slower soil water conductivity may also be important limiting factors.

It is not surprising that bulk densities in the tuber compartment at harvest were higher than bulk densities in the root compartment because tubers, in expanding during development, would exert physical pressure to the surrounding soil mass, resulting in increased bulk densities. The bulk densities of the soil at the base of the tubers were higher than either of the two initial bulk densities indicating that the tuber itself was compacting the soil during its growth. The ability of the soil to deform under stress may therefore be an important factor affecting the yield of yams.

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