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THE EFFECT OF SOME SOIL PHYSICAL FACTORS ON THE YIELD OF WHITE LISBON YAMS (*DIOSCOREA ALATA* L.)

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SUMMARY

Tuber yield of yam is reduced if either the roots or the tubers grow in soils that are compacted to moderately low bulk densities. From these studies several factors have been suggested as possible reasons for the reduction in tuber yield. Tillage methods were used to produce different soil physical properties in the River Estate Loam soil. Rotovating the soil after ploughing and harrowing produces a soil with the lowest penetration resistance but this treatment does not change the stability of the soil to wetting. This treatment produced the highest tuber yields. The effect of this method of tillage on the physical properties of other soil types and on yield needs to be investigated before a general recommendation can be made.

INTRODUCTION

The growth of roots, tubers and other underground plant organs can be restricted by the penetration resistance of the soil. Since it is difficult to measure the force exerted by these underground organs during growth in different soils, the resistance the soil offers to a penetrometer is used as a measure of soil impedance to growth. The penetration resistance measured with penetrometers is not numerically equal to the resistance roots or tubers would experience because of differences in mechanical advantage, rate of penetration, and lubrication. Penetrometers are however useful for comparing soil resistances and can be calibrated against actual root pressures (Eavis and Payne, 1968). The calibration has only limited application because penetrometer readings are affected not only by bulk density and water content but by soil particle size (Barley and Greacen, 1967).

Researchers have attempted to define bulk densities that are critical for root growth (Veihmeyer and Hendrickson, 1948; Bertrand and Kohnke, 1957; Zimmerman and Kardos, 1961). Reported values vary for different soils and plant species and are difficult to interpret because environmental conditions are not comparable. Critical bulk densities can only serve as guides because bulk density is not the only factor affecting soil impedance.

Roots grow in soils by pushing their tips into soil pores that are large enough to allow the tip to enter and then exerting radial pressure as the root thickens. The resistance of the pore walls to shear is therefore an important factor in root growth. The tubers of yams occupy a large volume in the soil. There is therefore considerable soil movement or displacement during tuber growth. The shear strength of the soil will influence tuber growth and yield. When yams are grown in soils in which the resistance to downward penetration by the yam tuber is too great then the tuber grows upward and the yam emerges from the ground. The authors have seen yam tubers with as much as a third of its length protruding above the soil surface.

The bulk density of soils in the West Indies vary from a low value of less than 1 g cm^{-3} in some of the allophanic soils to about 2 g cm^{-3} in some subsurface clay soils and the total pore space varies from over 65 per cent to less than 20 per cent. At the low extremes of bulk density the soils are loose and have low shear strength and penetration resistance. These soils are however not extensively distributed in the West Indies and have the disadvantage of retaining large quantities of water at high energies. The extremely dense clay soils have high penetration resistance and high shear strength and low available water for plant growth. There are however large areas of agricultural, potential agricultural, soils which vary in texture from a sand to a clay and have intermediate values of bulk density. Some of the soils in this group can profitably be ameliorated to provide the soil physical conditions suitable for good growth and yield of root crops.

Soil tillage breaks up dense soil and produces a soil with low penetration resistance. Tillage is still largely an art hence it is not possible to predict the kind of soil physical conditions a mechanical implement or a series of mechanical implements will produce on a given soil type at a given soil water content. Even when a suitable soil physical condition is produced there is still the problem of stabilizing this structure against water or mechanical load. Most of the soils in the West Indies lose their structure fairly soon after tillage and particularly if there has been heavy rainfall. The soil aggregates created by tillage coalesce to form a dense mass because the factors responsible for producing stable soil aggregates e.g. organic matter, iron, calcium, are often present only in low concentrations.

Besides the problem of being able to predict the soil physical properties which will be created by a particular tillage operation there is also the need to know the rate of growth and final yield which will result from a known soil physical condition.

In this study the effect of compaction of the soil in which roots and tubers grew on leaf area, leaf number and tuber yield were investigated. The effect of methods of land preparation on the yield of yam was also studied and some of the physical changes created by the method of land preparation were measured.

MATERIALS AND METHODS

Soil

The soil used for the studies in growth boxes and for the field trial was River Estate Loam of Trinidad (Fluventic Eutropepts, Smith 1974). The soil was crushed with a wooden hammer, sieved through 6.35 mm sieve before packing the soil in the growth boxes.

Growth Boxes

The boxes were made from 2.5 cm thick wood and each box consisted of three compartments as illustrated in Fig. 1. Each compartment had a volume of 78.09 dm^3 and was 5.59 dm high, 2.29 dm wide and 6.10 dm long. The tubers were made to develop in the centre compartment and the roots in the two outer compartments. The partitions between the root and tuber compartments were about 5 cm lower than the outer edge of the box.

The growth boxes used for the soil compaction studies had the three compartments packed with soil to the required bulk density up to the level of the inner partitions. A sheet of black plastic, which overhung the edges of the central compartment and which was pulled away when the tubers started to develop, was spread over the centre compartment and the box filled to the outer edge with 5 cm of loose soil (Fig. 2). Setts of White Lisbon yam (*Dioscorea alata* L.) weighing about 100 gms were planted in the centre of the tuber compartments.

Growth boxes which were used for the studies on the effect of exposure of tubers to daylight did not have soil in the centre compartment. The outer walls of the centre compartments had either sliding windows to allow the tubers to be exposed to light or were walls without windows. The top of the centre compartment was covered with wire mesh and black plastic and 5 cm of loose soil. A hole was cut in the centre of the wire mesh and black plastic before applying the 5 cm of loose soil. Yam setts were planted in the centre of the centre compartment. When tubers developed they grew through the hole in the top of the centre compartment.

Head setts were always used as the planting material and all setts had sprouted at planting. They were pruned to one sprout per sett piece, leaving strong sprouts of about the same size. 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 to prevent crusting of the soil surface.

The compound fertilizer 13:13:20 was applied at the rate of 24 gms per compartment. Sixteen (16) gms were applied to each before planting (8 gms were incorporated at a depth of about 30 cm and 8 gms applied to the soil surface). The final 8 gms was applied to the soil surface at 7 weeks after planting.

The plants were staked using bamboo poles 4.14 m tall. The black plastic was removed by pulling on the over-hang at 9 weeks after planting.

Packing the soil to known bulk densities

The weights of soil required to give the required bulk densities in the compartments of the growth boxes were calculated. The soil required no compaction to achieve a bulk density of 1.1 gm/cm^3. To achieve bulk densities of 2, 1.3 and 1.4 gm/cm^3, the soil was compacted with a wooden hammer by 8 cm depth increments and for a bulk density of 1.6 gm/cm^3, the depth increment was 4 cm.

Measurement of bulk density

Bulk density was measured one week before harvest by removing a core of soil 3.8 cm in diameter and 38 cm long. This core was cut into three equal sections and bulk density calculated for each depth interval from dry weight and volume of each soil segment. The bulk density of the entire 38 cm depth was also found as a mean of the three segments.

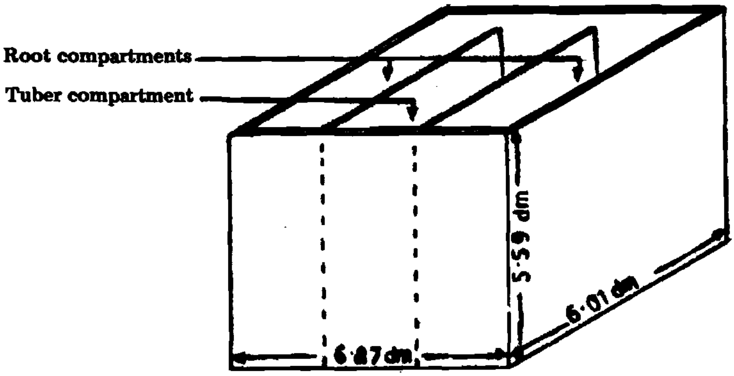

Fig. 1. Overall view of box to show the relative position of root and tuber compartments (From Ferguson and Gumbs, 1975).

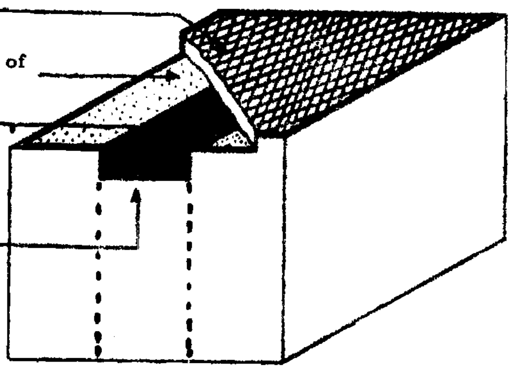

Fig. 2. Cut-away of upper 5 cm of soil to show the position of the plastic (From Ferguson and Gumbs, 1975).

Measurement of Penetration Resistance

This was done using the Proctor Penetrometer supplied by Soil Test Inc. of the USA.

Mean Weight Diameter (MWD) analysis by dry sieve and wet sieve techniques

This was done according to the standard procedure described by Kemper and Chepil (1965).

Field Trial

This trial was located at the University Field Station on River Estate Loam soil. Four methods of land preparation were examined in a randomised block design. There were four replications. The four methods of land preparation were:

1. M_1T_1 - Air dried soil ploughed and harrowed
2. M_1T_2 - Air dried soil ploughed, harrowed and rotovated
3. M_2T_1 - Soil wet to field capacity before ploughing and harrowing
4. M_2T_2 - Soil wet to field capacity before ploughing, harrowing and rotovating

Plots were 15.24 m long and 9.10 m wide. All plots were separated from each other by a distance of 3.66 m. The treatments were randomised among plots and those to be wet to field capacity were irrigated by sprinkler irrigation for two days before tillage. Plots were ridged on the day after tillage. Ridges were 91 cm apart and there were 10 ridges per plot. White Lisbon yam setts of about 113 gm were planted 46 cm apart and to a depth of about 7 cm along the ridges. The plants were staked using the trellis system described by Haynes (1967). The plants were sprayed regularly with Dithane M45 and Miltox at a rate of 2.8 kg/ha.

RESULTS

Soil Compaction and Tuber Yield

Three methods of land preparation which are adopted for the growing of yams in the West Indies are (1) tillage of the entire field by one or more tillage implements followed by the planting of yam setts in rows, (2) tillage as in (1) but the field is put into alternating rows of ridges or banks (about 30 cm high) and furrows and the yam setts are planted in the ridges, and (3) the digging of trenches which are back-filled with organic material or organic material mixed with soil before planting the setts in the trenches. In (2) above, and particularly in (3), the yam tuber and roots may grow in soil with a different degree of compaction.

In a study conducted by Ferguson and Gumbs (1975), yam tubers and roots were made to grow in separate compartments in growth boxes and with the soil in the compartments at different bulk densities. The authors found that compaction of the soil in the compartments in which roots or tubers grew significantly reduced tuber yield. Table 1 shows the effect of level of compaction in root and tuber compartments in the growth boxes on tuber yield per plant.

TABLE 1. The effect of level of soil compaction in root and tuber compartments on tuber yield per plant (kg); 1973 studies (From Ferguson and Gumbs, 1975).

			Root	Compartment		Mean
Level of Compaction			0	1	2	
Bulk Density			1.1	1.3	1.6	
				Kg/plant		
Tuber	0, 1.1 g/cm^3		3.09	2.11	2.21	2.47
Compartment		% reduction	(0)	(32)	(29)	(0)
	1, 1.3 g/cm^3		2.26	2.17	1.60	2.01
		% reduction	(27)	(30)	(48)	(19)
	Mean		2.67	2.14	1.90	
			(0)	(20)	(29)	

	S.E.	Probability Level (%)
Mean Tuber Compartments (TC)	0.15	98.2
Mean Root Compartments (RC)	0.12	99.3
TC x RC	0.21	87.5
CV = 18.9%		

Compacting the soil in the root compartment to an initial bulk density of 1.3 g/cm^3 (level 1) decreased yield from 2.67 kg to 2.14 kg or a decrease of about 20% from the non-compacted (1.1 g/cm^3) bulk density (level 0). At an initial soil bulk density of 1.6 g/cm^3 (level 2) yield was decreased by 29%. Compacting the soil in the tuber compartment to a bulk density of 1.3 g/cm^3 decreased yield from 2.47 kg to 2.01 kg or about 19%.

The interaction between compaction levels in the root and tuber compartments was significant at the 97.5% probability level. Yield was highest (3.09 kg) in the treatments (00) where the soil was not compacted in either the root or tuber compartment, and lowest (1.60 kg) in the treatment (12) having the highest compaction levels. There was therefore a reduction in yield of 48% when the soil in the tuber and root compartments was compacted to levels 1 and 2 respectively. Compaction to level 1 in the tuber compartment with the root compartments at level 0 reduced yield by 27% while compaction to level 1 in the root compartments with the tuber compartment at level 0 reduced yield by 32%.

The study also showed that compacting the soil in the root compartments significantly reduced leaf number and leaf area measured at 3, 4, 8 and 25 weeks after planting but soil compaction in the tuber compartments significantly reduced leaf number and leaf area only at 25 weeks. Reduction in the total photosynthetic surface and therefore the total amount of carbohydrates available to the developing tubers seemed to have contributed to the reduction in yield. The reduction in leaf number, leaf area and tuber yield caused by soil compaction in the tuber compartment indicates that the growing tuber contributes substantially to the growth of the plant. It seems likely that the tubers absorb nutrients and water through the numerous roots which occur on the tubers or through the tubers themselves and therefore play a major role in promoting plant growth.

The growth of the tubers were also restricted by the penetration resistance of the soil. Tubers from compacted soil compartments grew out of the soil surface at the top of the growth boxes indicating greater resistance to their normal geotropic growth. The emergence of tubers above the soil surface can reduce tuber yield through two effects. Firstly, the shallow depth of soil penetration means that a smaller volume of soil is exploited for nutrients and water. Secondly, the exposure of tubers to light can reduce tuber yield. Gumbs and Ferguson (1975) studied the effect of the exposure of yam tubers to light in growth boxes which allowed the tubers to develop in a soil-free compartment with windows which could be opened to expose the tubers to daylight. This study showed that exposure of the tubers to daylight for one hour each week and to continuous daylight gave lower tuber yield than tubers which developed in the absence of light but only the reduction due to continuous exposure to daylight was significant (98.6% Probability; Table 2).

TABLE 2. The effect of exposure of yam tubers to daylight on tuber yield/plant (kg), 1973 studies. (From Gumbs and Ferguson, 1975).

Treatment	Tuber Weight (kg)
Complete darkness	1.635
* Partial light	1.510
Continuous light	0.975
SE	0.132
Probability level (%)	98.6
CV (%)	20.6

* **Exposure of tubers to daylight for one hour each week.**

This soil did not maintain the initial bulk densities of 1.1, 1.3 and 1.6 g/cm^3 but bulk densities measured one week before the tubers were harvested were approximately 1.2, 1.3 and 1.4 g/cm^3 respectively. It would appear that there was consolidation of the soil at the lowest bulk density and swelling of the soil at the highest bulk density. In addition, the highest bulk density of 1.6 g/cm^3 may not have been attained because the bottom of the wooden box bulged during compaction of the soil and this bulge was first noticed only when the trial was being harvested. The bulk densities, except 1.3 g/cm^3, were not unique but varied over a range of values.

In 1974, another study was carried out to determine more precisely the effect of soil compaction in the tuber compartment alone on tuber yield. Accordingly, tubers were grown in soils at five levels of compaction (bulk densities of 1.1, 1.2, 1.3, 1.4 and 1.6 g/cm^3) while the root compartments were not compacted. The bulk densities of the tuber compartments measured one week before harvest were 1.14, 1.17, 1.27 and 1.37 g/cm^3, respectively. Table 3 shows the yield of tubers at different soil bulk densities.

TABLE 3. The effect of bulk density of the soil in the tuber compartment on tuber yield per plant (kg), 1974 studies.

Initial Bulk Density g/cm^3	Final Bulk Density g/cm^3	Mean Tuber Yield kg/plant
1.1	1.14	3.270
1.2	1.17	2.831
1.3	1.25	1.827
1.4	1.27	1.220
1.6	1.36	0.699

Yield of tubers decreased from 3.27 kg per plant for an initial bulk density of 1.1 g/cm^3 to 0.699 kg per plant for an initial bulk density of 1.6 g/cm^3 (79 % yield reduction). The greater decrease in yield (35%) occurred when the initial bulk density was increased from 1.2 to 1.2 g/cm^3. The lower tuber yield in 1974 than in 1973, for an initial bulk density of 1.6 g/cm^3, could be due to the fact that this bulk density was achieved in 1974 by compaction.

The penetration resistance of the soil at each bulk density was measured weekly throughout the growth of the crop. The resistance fluctuated with soil water content and with time and varied between 40 and 60 pounds per square inch. There was therefore not a simple relationship between penetration resistance and yield.

Tillage Trial

Most soils in the West Indies have to be tilled in order to produce soil physical conditions which are favourable for adequate root and tuber growth. The kind of tillage operation needed will depend on the soil type and the crop to be grown. In this study two methods of tillage at two soil water contents (giving four treatments) were carried out on River Estate Loam at the University Field Station. Some of the changes in soil physical properties and the tuber yields resulting from the four treatments were measured.

Tuber yields were greater when the soil was ploughed, harrowed and rotovated than when the soil was only ploughed and harrowed and greater when the tillage operations were carried out on the air dry soil than on the soil at field capacity.

TABLE 4. The effect of tillage treatment on penetration resistance of the soil and the yield of yams.

Treatment	Total Yield tons/ha	% Marketable Yield	Mean Penetration Resistance lb/in^2
M_1T_1	22.1 b	93.0	40.5
M_1T_2	24.4 a	95.0	38.0
M_2T_1	21.9 b	91.7	46.5
M_2T_2	22.4 b	92.6	43.0

Correlation coefficient between and mean penetration resistance is 0.99

M_1 and M_2 are air-dried moisture content and field capacity;

T_1 is ploughed and harrowed;

T_2 is ploughed, harrowed and rotovated.

The mean penetration resistance of the soil surface and of the soil at 15 cm depth was higher when the soil was tilled at field capacity than when it was tilled at air dry water content. Rotovating the soil after it was ploughed and harrowed resulted in the soil having a lower penetration resistance than when the soil was only ploughed and harrowed (Table 4). Mean penetration resistance was very significantly correlated with yield ($r = -0.99$). Rotovating air dry soil reduced penetration resistance of the soil by 6.2 per cent and increased yields by 10.4 per cent while rotovating soil at field capacity reduced penetration resistance by 7.5 per cent and increased yields by 2.3 per cent. Rotovating air dry soil after ploughing and harrowing also gave the highest percentage of marketable yield (Table 4). Marketable yield is defined as the yam tubers greater than 100 gm weight. This treatment also produced better shaped tubers, i.e. tubers with a smaller number of sinks and fingers (Ferguson and Gumbs, 1975).

The stability of aggregates to wetting was not increased by any of the tillage methods used in this study. Mean weight diameter of aggregates was lower when the soil was rotovated, particularly if the soil was rotovated at air dry water content.

DISCUSSION

The yield of yam tubers is reduced if the roots and tubers develop in a compact soil. Although the bulk density of a soil is an indication of the degree of compactness of the soil, the penetration resistance and sheer strength are the mechanical properties that affect yield. These mechanical properties vary with changes in water content. One of the problems in quantifying the effect of bulk density on tuber yield in this study is the variation of bulk density and water content of the soil during plant growth. Yield can, however, meaningfully be related to initial bulk density because the variations of bulk density and water content can be similar for the same soil type in the field. In these studies, the penetration resistance of the soil was monitored throughout the growth of the plant but the measurements were not significantly related to yield because of the high variance.

In the 1973 study, increase in the initial bulk density of the soil from 1.1 to 1.3 g/cm^3 in which roots and tubers grew had similar effects on tuber yield. Yield was decreased by 20 per cent and 19 per cent respectively. Compacting the soil in which roots grew to a bulk density of 1.6 g/cm^3 decreased tuberyield by 29%. In the 1974 study, tuber yield decreased with each successive increment in the bulk density of the soil in which tubers grew (from a bulk density of 1.1 g/cm^3 to 1.6 g/cm^3).

The percentage decrease in tuber yield when initial soil bulk density decrease in yield (35%) for 0.1 g/cm^3 increases in bulk density between 1.1 and 1.6 g/cm^3 occurred when the initial bulk density was increased from 1.2 to 1.3 g/cm^3. This is significant because most of the clay soils in Trinidad after they have been tilled resettle to a bulk density of between 1.2 and 1.3 g/cm^3, and the bulk densities of the uncultivated surface soils are around 1.3 g/cm^3. The subsurface soil in which a large proportion of the yam tuber can develop has bulk densities that are higher than 1.3 g/cm^3. It therefore is necessary to till these soils to increase tuber yields and to stabilise the soil structure after tillage.

There may be several reasons for the reduction in tuber yield caused by soil compaction. From this study, it seems that soil compaction by reducing root and tuber growth reduces the volume of soil available for nutrient and water absorption by both roots and tubers. The resistance to tuber enlargement is another factor that may be responsible for reduced tuber yield. The energy that should be utilised to promote tuber growth is utilised in overcoming soil resistance. The emergence of tubers above the soil surface and the consequent exposure to daylight seems also to contribute to yield reduction. Another possibility is that developing tubers in the more compacted soil were smaller sinks for carbohydrates because the soil offered greater resistance to their growth thus leading 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, and Neals and Incoll, 1968). Reduced photosynthesis will result in a reduction in the supply of assimilates to the developing tuber. Reduced soil aeration, less available water and low soil water conductivity may also be important factors affecting tuber yield.

In the field study of the effect of tillage on yield and other soil physical factors, the treatment which was ploughed, harrowed and rotovated produced the highest yield, had the lowest penetration resistance and produced aggregates with the smallest mean weight diameter. The size distribution of the aggregates in this treatment may have increased the soil water available for plant growth by increasing the water retention and water conductivity.

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