THE EFFECT OF VARIOUS METHODS OF LAND PREPARATION ON SOIL RESISTANCE TO PENETRATION AND YIELDS OF CORN (*Zea mays* L.), CASSAVA (*Manihot esculenta* CRANTZ) AND SWEET POTATO (*Ipomoea batatas* L.) IN ASSOCIATION. I. EFFECT OF CROPPING SYSTEMS AND LAND PREPARATION ON THE SOIL[1] /

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Resumen

La resistencia del suelo a la penetración se midió cuando un suelo Typic Dystropept fue arado durante la estación seca (abril 1975) y la estación húmeda (junio), utilizando un tractor de oruga Caterpillar D4 de 60 kW (75 caballos) para subsolar y un tractor de llantas Massey Ferguson 175S de 50 kW (67 caballos). Además se hicieron mediciones cuando el suelo fue preparado desyerbando y limpiando sin usar maquinaria. Cada tipo de preparación de terreno tuvo subtratamientos tales como suelo descubierto, suelo con cobertura vegetal muerta de caña de azúcar, suelo sembrado con maíz y un suelo sembrado con yuca y camote en asociación. El experimento se llevó a cabo en CATIE, Turrialba, Costa Rica, con un promedio anual de lluvia de 2682mm y una temperatura promedio anual de 23.3°C.

El maíz se sembró en mayo y junio y se cosechó en octubre y la yuca asociada con camote se sembró al mismo tiempo y se cosechó 10 meses después en marzo y abril, 1976.

La resistencia del suelo se redujo en forma significativa hasta 0.1 m de profundidad arando y hasta 0.3 m subsolando. El suelo preparado durante la estación seca experimentaba una humedad significativamente inferior a aquella del suelo preparado durante la estación húmeda y la humedad superior se atribuyó al fangeo (puddling). Estas diferencias eran notables hasta 14 semanas después de preparar el suelo seco y 6 semanas después de preparar el suelo húmedo. Después de estos lapsos límites de tiempo, los efectos eran residuales. Durante el desarrollo de los cultivos, la resistencia de suelo se aumentó debido a 1. El secamiento del suelo durante la estación seca que provocó un aumento hasta 5 veces. 2. El tráfico humano que ocurrió en el maíz, y yuca con camote, hasta 0.2 m de profundidad. 3. El tiempo de sedimentación, tal como fue observado en las parcelas sin tráfico humano durante la estación húmeda.

Introduction

Corn, casava and sweet potato are crops commonly used by small farmers of tropical Latin America and the Caribbean. Cassava and sweet potato in association has been considered a promising combination (12). Land preparation for these crops follow various local traditions, and in many cases small farmers do not have the resources to mechanically prepare the land or carry out irrigation. The relationship between land preparation and crop yields depends on the initial values and subsequent changes in the physical, chemical and biological conditions of the soil. It is therefore convenient to include in a soil diagnosis such properties wich can decide on ploughing needs. This paper reports on studies on the effect of different methods of land preparation on the physical properties of a soil.

Materials and methods

The experiment was carried out in the experimental fields of CATIE in Turrialba, Costa Rica (9°

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53 N and 83° 39 W) at an elevation of 602 m The area has a mean monthly temperature of 23 3°C (maximum 27 1°C and minimum 17°C), a mean annual rainfall of 2682 mm and an annual mean of 251 rainy days. There are 4.5 hours of daily average sunshine hours, and the average daily relative humidity is 88%. The average atmospheric water balance which is approximately 50% reliable, (rainfall - A pan evaporation) shows 11 months of moisture excess which varies between 9 and 269 mm with a monthly average of 137 mm (6) On the average there is 1 month of deficit of 44 mm, this being generally in March. The 75% reliable atmospheric water balance (75% reliable rainfall* - A pan evaporation) shows 9 months of moisture excess which varies between 21 and 130 mm with a monthly average of 86 mm. At the level of 75% reliable rain, there are deficits in February, March and April, which average 67 mm. The probability of a deficit in February is 37.8%, March 74.8%, and April 46.3%.

With a design of hierarchal classification with 4 replications, 6 methods of land preparation were evaluated Each preparation method had a block of 8 x 130 m containing 4 subtreatments with a plot size of 7 x 8 m, replicated 4 times, as follows:

Treatment 1 (S_1):
Preparation with a 60 k W (75 h.p.) D. 4 caterpillar track tractor at 0.1 m depth during the dry season.

Treatment 2 (S_2):
Preparation with the track tractor at 0.1 m durming the wet season.

Treatment 3 (S_3):
Preparation with a 50 k W (67 h p.) Massey Ferguson tire tractor at 0 1 m during the dry season.

Treatment 4 (S_4):
Preparation with the tire tractor at 0.1 m during the wet season.

Treatment 5 (S_5):
Preparation with the track tractor with a subsoiler at 0.25 m during the dry season.

Treatment 6 (S_6):
No mechanical prepatation. Hand weeded and cleaned

Subtreatments:

Subtreatment 1 (CS_1):
Bare soil

Subtreatment 2 (CS_2):
Soil covered with mulch (sugarcane trash).

Subtreatment 3 (CS_3):
Soil planted with corn.

Subtreatment 4 (CS_4):
Soil planted with cassava in association with sweet potato.

Land preparation included 1 ploughing and 3 harrowings with either a D-4 Caterpillar track tractor of special application or a Massey Ferguson 175s tire tractor The subsoiling was done with a subsoiler (Rome 1J3944R crowder) and ploughing and harrowing were done with discs. Land preparation in the dry season occured during 10-15 April, 1975 when the gravimetric soil moisture between 0-0.2 m was 29.1% ± 1.6, and in the wet season occured during 10-11 June, 1975, with a soil moisture of 39.5% ± 1.5.

The soil is Institute clay loam (normal phase) which is classified as a Typic Dystropept with average field capacity values (33 k Pa suction or 0.33 bars suction) for the 0-0.1 m layer of 37.8% (gravietric) for disturbed soil and 41.3% for undisturbed soil; a 15 bar (x 10^2 k Pa) suction value of 28.3% for distirbed and 29.1% for undisturbed soil; a lower plastic limit of 36.4% and a sticky point of 47.8%. In the 0-0.2 m layer the soil has 29% sand, 43% silt and 29% clay (US classification) and in the 0-0.1 m layer available water is 11.5% (volumetric), bulk density 1.09 mg/m^3 (g/cc) and total porosity 57.2%. In the 0-0.15 m layer the soil (5 months after planting) had an average pH (H_2O) of 4.9, pH(KCl) of 4.1, total nitrogen 0.33%, organic matter 5.7%; base exchange capacity 296 m mol (+)/kg, (29.6 me/100g), base saturation 24% and Al saturation 4%.

Subtreatment CS_1 was maintained free of weeds with Gramoxone, with prescribed paths within the plot (7 x 8 m) for human traffic. CS_2 was covered with trash from sugarcane (*Saccharum officinarum*) in sufficient amount so that no soil could be seen from above, and had prescribed paths within the plot for human traffic in order to control weeds. Subtreatment CS_3 was planted between 8-15 June, 1975 with the Tuxpeño 1 variety of corn (*Zea mays* L.) after sprinkling the soil with 2.5% Aldrin and treating the seed with 2.5% Aldrin and 50% Orthocide. Planting was manual using a metal pointed digging stick (espeque) to make holes in the ground and placing 4 seeds in each hole. Planting spacing was 1 m between

* Rainfall with a 75% probability of being surpassed

rows and 0.5 m between plants giving a planting density of 80 000/ha (without thinning). Fertilizer was applied in bands on planting and 35 days afterwards. Total fertilizer application was 125, 120, 40 and 20 kg/ha of N, P_2O_5, K_2O and Mg O respectively. There were three weedings and two applications of Furadan granules around each corn plant to control *Anomala cinta*.

Subtreatment CS_4 was planted simultaneously with the Japonesa variety of cassava (*Manihot esculanta* Crantz) and the C-15 Salvador B-4906 variety of sweet potato (*Ipomoea batatas* L.) during the same period as CS_3. The cassava was planted, using a shovel to place inclined cuttings 20-30 cm long in the ground at a spacing of 1.0 m x 1.0 m giving a population of 10 000/ha. Two rows of sweet potato slips were planted between the rows of cassava with a shovel, to give a spacing of 0.5 m x 0.4 m and a population of 50 000/ha. There was one weeding and fertilizer application was similar to that of CS_3. Applications of 80% Sevin were made three times to control *Diabrotica* sp and *Megastes grandalis*.

Soil resistance to a 5 mm diameter circular stainless steel piston pushed 5 mm into the soil was measured by a John Chatillon push - pull guage Cat. No 719-40 MRPFR, which measured the maximum thrust applied for penetration. Moisture of the corresponding soil was measured (7). Measurements were made 0.1 m from the planting rows in two areas within a subtreatment at depths of 0, 0.1, 0.2 and 0.3 m. Sampling was done during 4 periods: P-1, 15th July-10th August, 1975; P-2, 10 September-10 October, 1975; P-3, 2-18 December, 1975; P-4, 9–25 March, 1976. The bulk density of each subtreatment in the 0-0.1 m layer was measured 6 months after planting by the constant volume cylinder method (7) after two days of rain. Soil moisture retention curves of indisturbed samples stored at field moisture, were taken from 6 subtreatments with human traffic and 6 without traffic, at 0, 0.1 m, 0.1 - 0.2 m and 0.2 - 0.3 m (7)

Chemical analyses were done approximately 5 months after planting. Two samples from 0 - 0.15 m and 0.15 m to 0.3 m were taken from each plot and combined. All plots of S_5 and S_6 and 4 plots of S_1, S_2, S_3 and S_4 were sampled. Samples were mixed and conserved at field moisture before analysing for moisture, pH (water), pH (1M KCl), organic matter (Walkley-Black), total N, available phosphorous (Olsen-Hunter), extractable sulphur, exchangeable bases, cation exchange capacity, exchangeable aluminium, exchangeable Cu, Zn, Mn and Fe (13).

Table 1. Climate and operations during the experimental period.

Year	Month	Av. Temp. °C	Reliable Rainfall mm*	Rainfall mm	Rainfall Probability % **	Operations	Atmospheric Water balance mm ***	Gravimetric soil moisture %, 0-0.2 m for C_4
1975	Jan	19.8	118	131	29.7		54	
	Feb	19.9	54	20	9.4		–75	
	Mar	21.4	38	28	18.3		–108	
	Apr	21.1	54	33	15.8	1	–85	29
	May	22.2	166	112	9.9		–8	
	June	21.4	236	227	21.6	2,3	140	39
	July	20.9	203	327	67.5	4	238	43
	Aug	21.1	186	330	80.7		244	
	Sept	23.5	204	418	94.7	5,6,7	313	47
	Oct	21.5	200	326	79.5		234	
	Nov	21.4	195	420	80.2	8	336	
	Dec	19.4	183	570	77.4	9,10	496	47
1976	Jan	19.2	118	259	76.1		180	
	Feb	19.3	54	105	38.5		11	
	Mar	20.4	38	13	8.3	11	–121	29
	Apr	20.5	54	134	48.9	12	3	

* Rainfall with a 75% probability of being exceeded. (1944-1974), ** Probability of occurence between 0 mm and the observed rainfall. (1944-1974); *** Rainfall - Type A pan Evaporation (PET). Operations: 1. dry season land preparation; 2. wet season land preparation (10-11 June); 3. planting C_3 and C_4 8-15 June; 4. P-1 resistance sampling (15 July - 10 August; 5. P-2 resistance sampling (10 Sept - 7 Oct); 6. bending corn stalks (19 Sept - 10 Oct; 7. reaping corn (30 Sept - 30 Oct); 8. sampling for chemical analysis (15 Nov); 9. sampling for bulk density (15 Dec); 10. P-3 resistance sampling (2-18 Dec); 11. P-4 resistance sampling (9-25 March); 12. reaping of cassava and sweet potato (8 April).

Results and discussion

Table 1 shows the climate and operations during the experimental period. During the periods of negative atmospheric water balance the soil was dry (29%) whereas during periods of positive atmospheric water balance the soil was at or above field capacity (39-47%).

Effect of the cropping systems (subtreatments) on the soil

Figures 1 to 4 show the relationship between percent of gravimetric soil moisture and penetration resistance for different subtreatments. Soil drying has caused up to a 5 fold increase in soil penetration resistance. Subtreatments CS_3 and CS_4 which involve human traffic cause the resistance to rise more

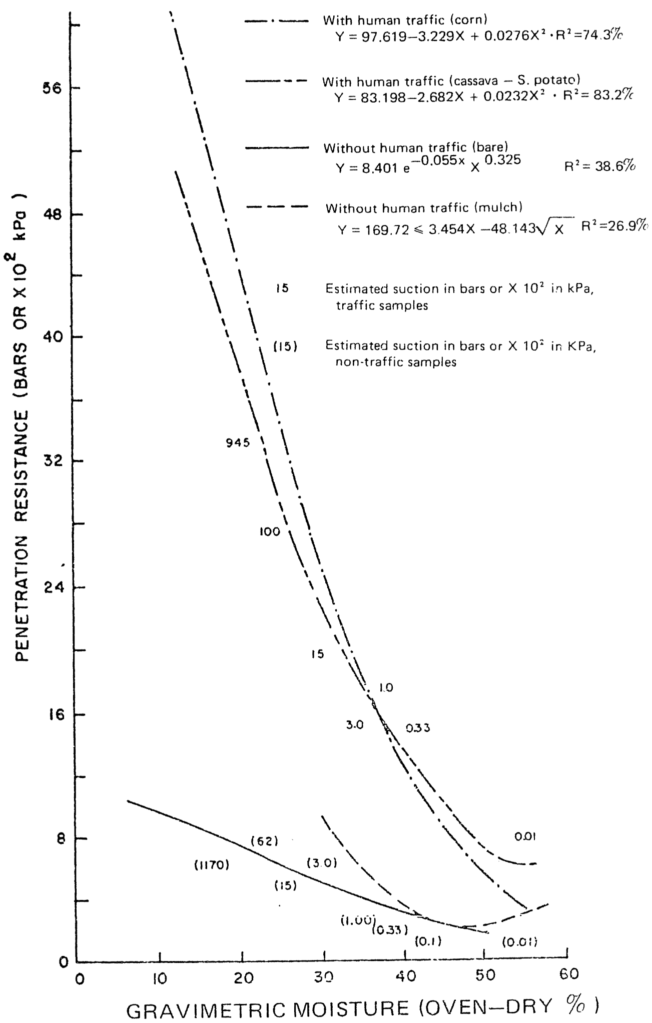

Fig. 1. Changes of penetration resistance with gravimetric moisture for cropping system subtreatments at 0 m depth (192 observations) R > 16% significant at 1% level.

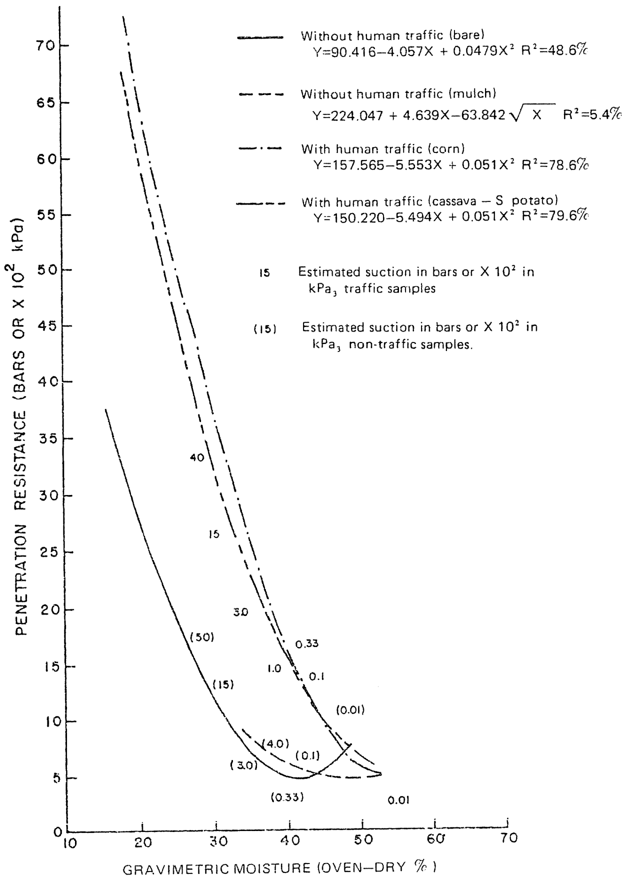

Fig. 2. Changes of penetration resistance with gravimetric moisture for cropping system subtreatments at 0.1 m depth.

steeply on drying at 0 m depth and the effect diminishes with depth until where no difference is noted at 0.3 m. Based on experience with the penetrometer used in the experiment, resistance readings (at field capacity) are rated as follows: 0 to 600 k Pa, excellent; 700 to 1 200 k Pa acceptable; 1 300-2 500 k Pa not acceptable, and greater than 2 500 k Pa root growth inhibited. Resistances at 40% gravimetric moisture (approximately field capacity) for subtreatments CS_1 and CS_2 have acceptable values at 0 and 0.1 m depth. The higher moisture regime of CS_2 shows the moisture conservation due to the mulch.

Figures 5 to 8 show the progress of the penetration resistance during the growing season. The compacting effect of the human traffic in subtreatments CS_3 and CS_4 are observed for 0 to 0.2 m depths. The soil resistance increase during P-1 to P-4 is due to a combination of compaction as seen in the higher resistance values of CS_3 and CS_4, hardening with time as seen by the increase of resistance in CS_1 and CS_2 between and P-1 and P-2, and drying as seen

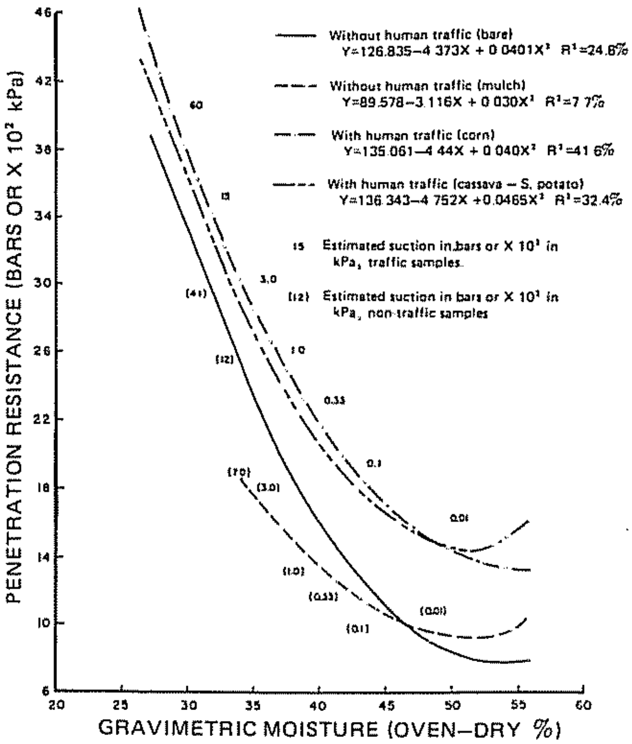

Fig. 3. Changes of penetration resistance with gravimetric moisture for cropping system subtreatments at 0.2 m depth.

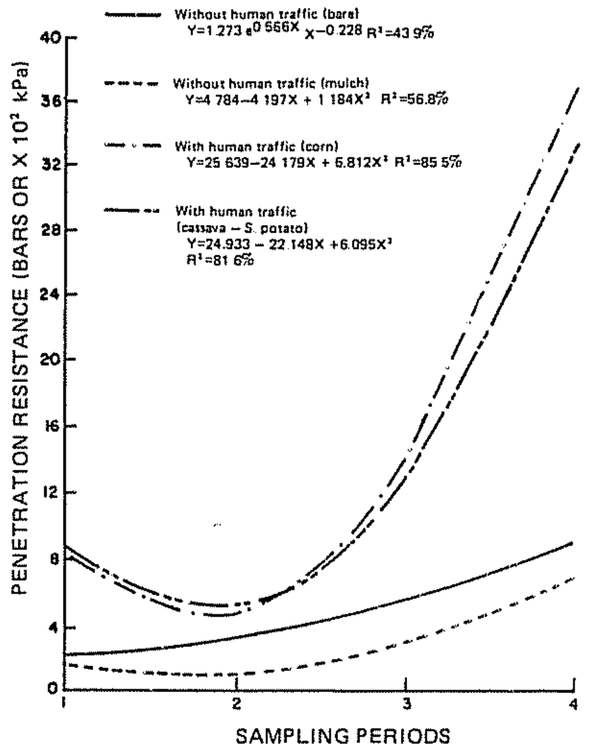

Fig. 5. Changes of penetration resistance with the sampling periods for cropping system subtreatments at 0 m depth (192 observations).

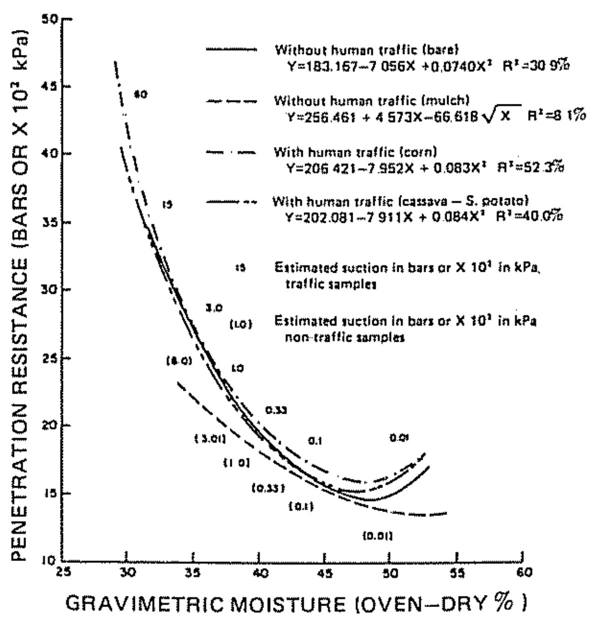

Fig. 4. Changes of penetration resistance with gravimetric moisture for cropping system subtreatments at 0.3 m depth.

by the increase of resistance in all subtreatments from P-2 to P-4. Figures 9 to 11 show an increase of resistance adjusted to the 40% moisture value to eliminate the moisture effect and demonstrate the contribution of hardening or settling with time on the resistance, as well as the effect of the compaction of the human traffic of cropping systems CS_3 and CS_4. In CS_3 the corn was on the average trampled just over twice and in CS_4 over 6 times (2x for the cassava operations and 4x for the sweet potato operations). The similarity of the curves for CS_3 and CS_4 in Figures 1 to 11 suggest that trampling 6 times has a similar effect to trampling twice.

Figures 12-15 show the moisture changes during P-1 to P-4 for different depths. Drying occurs in a period of negative atmospheric water balance and contributes to the increase in soil resistance The moisture conserving effect of the mulch is seen in the curves for CS_2. The average bulk density between 0-0.1 m for CS_1 (1.06 Mg/m^3) was significantly lower (5% level) than for trampled soils, CS_3 (1.10) and CS_4 (1.12). CS_2 (1.08) was not significantly different from the other subtreatments. Penetration resistance

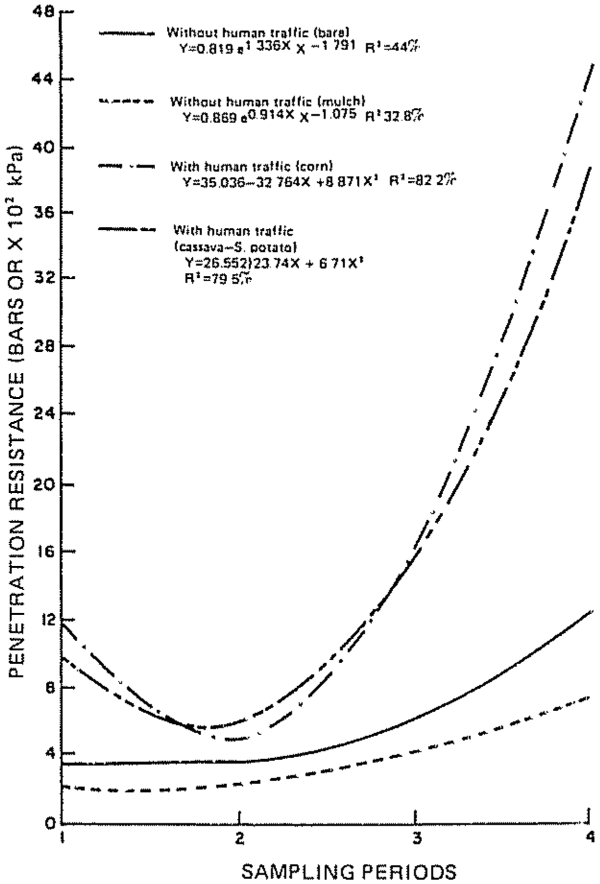

Fig. 6. Changes of penetration resistance with the sampling periods for cropping system subtreatments at 0.1 m depth.

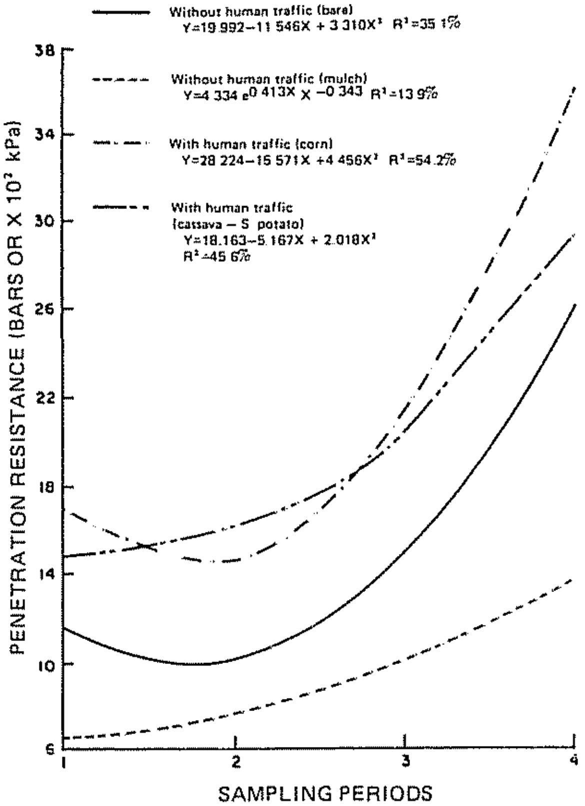

Fig. 7. Changes of penetration resistance with the sampling periods for cropping system subtreatments at 0.2 m depth.

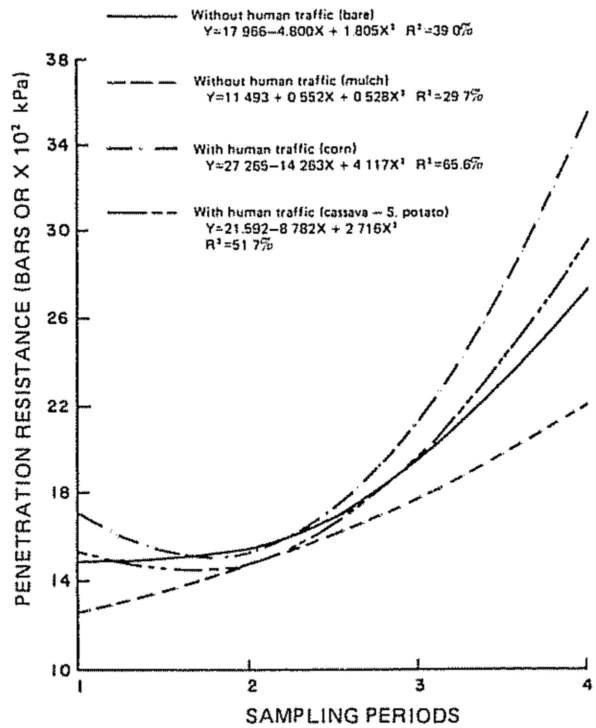

Fig. 8. Changes of penetration resistance with the sampling periods for cropping system subtreatments at 0.3 m depth.

was much more sensitive to compaction effects than bulk density. Percent air space in CS_1 (16%) was significantly greater than for CS_2 (9.4%), CS_3 (10.8%) and CS_4 (8.1%) due to the lower water content of CS_1, probably due to a lower infiltration of rainfall on the bare surface (5, 10).

Effect of land preparation methods on the soil

Tables 2 to 5 show average values of penetration resistance adjusted to 40% moisture by covariance analysis, for different periods and soil preparation methods for a given cropping system. The adjusted values allow a comparison by eliminating the soil moisture effect, and considering a resistance value equivalent to field capacity. The values of subtreatments CS_1 and CS_2 are lower than those of CS_3 and CS_4 and this reflects the compaction effect of the latter treatments, as was previously shown in Figures 9 to 12. CS_2 S_6 serves as a control to compare the other treatments, since it represents the undisturbed soil without surface compaction and the

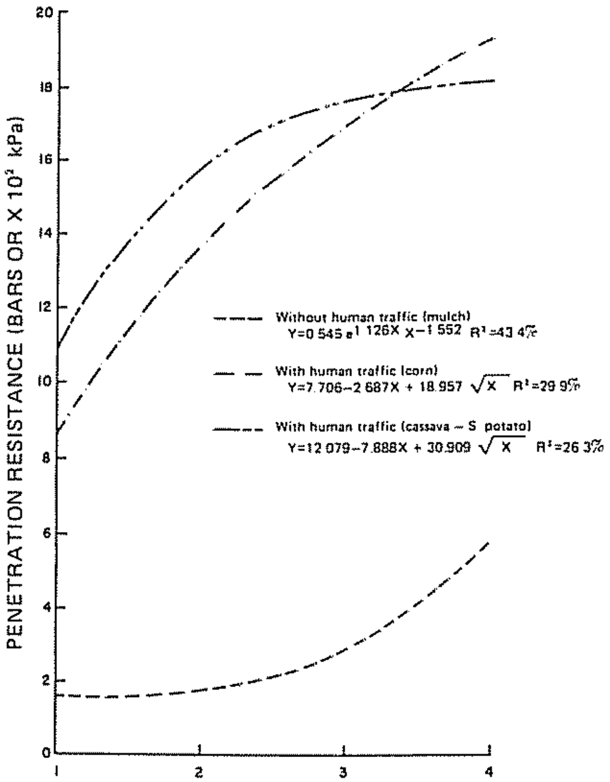

Fig. 9. Changes of penetration resistance (adjusted to 40% gravimetric moisture) with the sampling periods for cropping system subtreatments of 0 m depth.

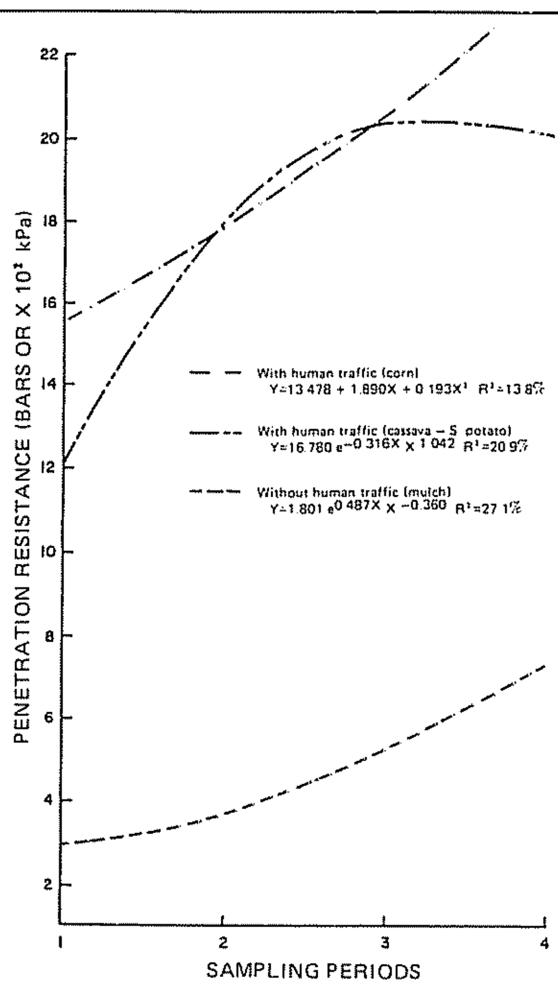

Fig. 10. Changes of penetration resistance (adjusted to 40% gravimetric moisture) with the sampling periods for cropping system subtreatments at 0.1 m depth.

lowest moisture change during the experimental period. This treatment shows an increase of soil resistance with depth and probably reflects the residual effect of a previous history of tillage.

For CS_1–CS_4 in general, the effect of tillage is noted where for depths of 0 and 0.1 m resistances for treatments S_1–S_4 are significantly lower than for S_6 but are significantly equivalent at 0.2 and 0.3 m depth. The subsoiling treatment for dry soil S_5 shows in all subtreatments significantly lower resistance values than S_6 for depths up to 0.3 m indicating a deeper and more through effect of subsoiling.

Comparing the various tillage methods S_2-S_5 for the subtreatments CS_1–CS_4, soil prepared when dry in treatments S_1, S_3 and S_5 have significantly lower water contents than soils prepared when wet in treatments S_2 and S_4 as well as the no tillage treatment S_6. The higher water contents of S_2 and S_4 may be attributed to a combination of the puddling effect (2, 4, 8) and poorer drainage (3, 9) and the higher water content of S_6 maybe attributed to its greater compaction in the natural state (8) as is supported by a higher 0.33 bars (x 10^2 k Pa) suction moisture value determined for the undisturbed naturally compacted soil.

With the exception of S_3, all the treatments of soil prepared when dry, which gave lower moisture contents also have significantly lower penetration resistances (S_1 and S_5). The resistance in S_3 was no different from S_2 and S_4, presumably due to the greater compaction effect of the tire tractor on the dry soil. The higher resistance of S_2 and S_4 are attributed to puddling, and these values were often similar to those of S_6.

The differences mentioned in the proceeding paragraphs are most pronounced in period P-1. However the pattern is residual and not consistent during

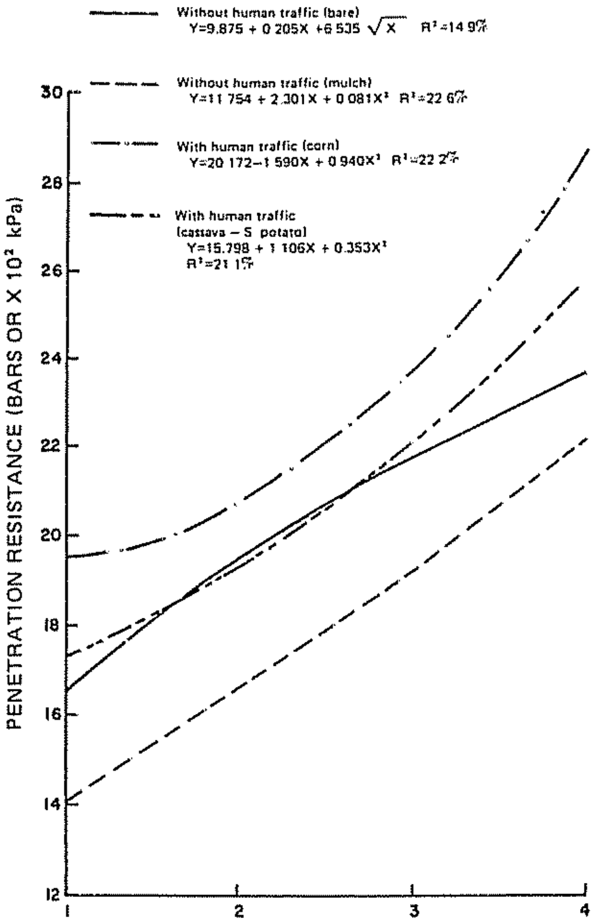

Fig. 11. Changes of penetration resistance (adjusted to 40% gravimetric moisture) with the sampling periods for cropping system subtreatments at 0.3 m depth

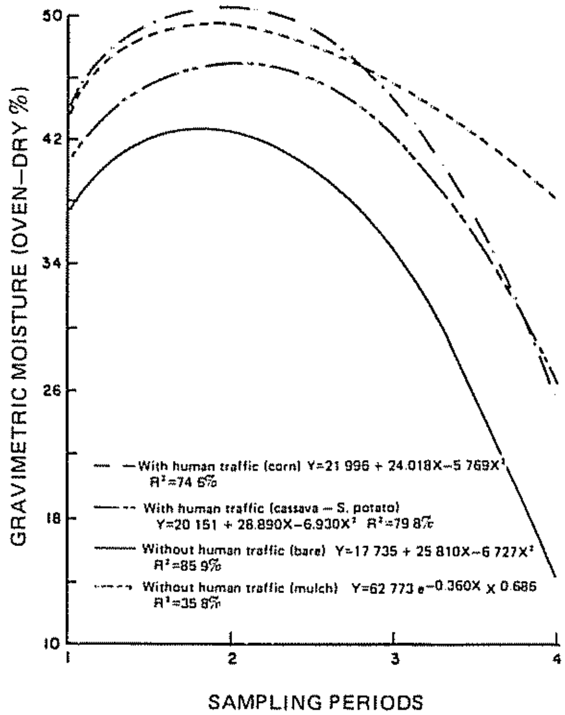

Fig. 12. Changes in gravimetric moisture with the sampling periods for cropping system subtreatments at 0 m depth.

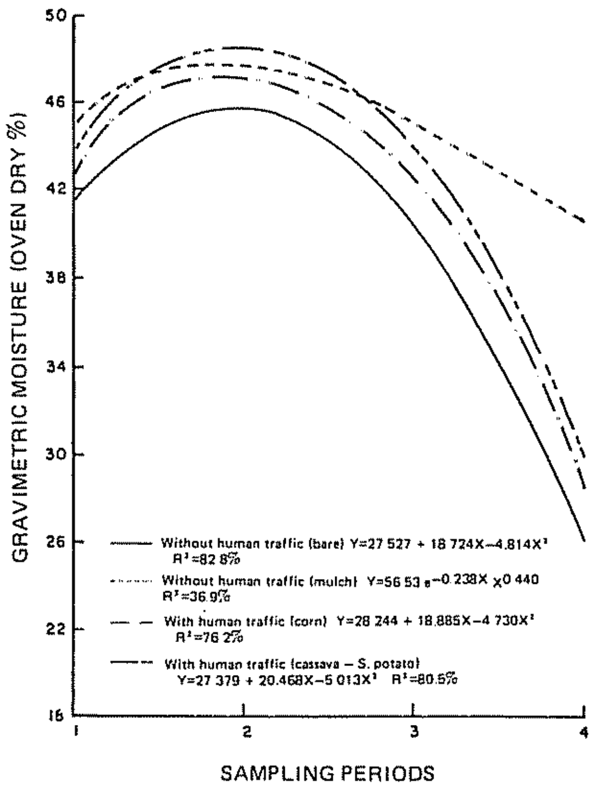

Fig. 13. Changes in gravimetric moisture with the sampling periods for cropping system subtreatments at 0.1 m depth.

P-2 to P-4. The differences were therefore discernable up until 14 weeks after preparation of the dry soil and 6 weeks after preparation of the wet soil.

The average percent air space between 0-0.1 m for S_5 (16.3%) was greater than for the other treatments S_1 (12.4%), S_2 (9.6%), S_3 (12.5%), S_4 (8.5%), and S_6 (8.2%). The value for S_5 was significantly greater (5% level) than for S_2, S_4 and S_6. The higher values of air space for S_1, S_3 and S_5 can be attributed to the lower moisture contents.

The interaction of % moisture and penetration resistance with the yields of corn, sweet potato and cassava will be discussed in a following paper.

Table 2. Average values of penetration resistance in k Pa (value shown x 10^2) or bars (value alone) adjusted to 40% gravimetric moisture, for 6 land preparation methods during 4 sampling periods (P), followed by the associated average gravimetric moisture %, for subtreatment Cs_1

	Bare soil (C_1) at 0 m depth P – 1 (15/Jul-10/Aug/75)		P – 2 (10/Sept-7/Oct/75)		P – 3 (2-18/Dec/75)		P – 4 (9-25/Mar/76)	
♦								
S_1	0.7 c	35.7 cd	3.0 b	41.2 a	3.2 b	40.5 a	2.0 b	13.7 b
S_2	2.4 b	43.9 a	3.6 b	40.5 a	3.2 b	38.4 c	1.3 c	15.0 a
S_3	1.3 b	36.6 c	2.8 b	40.2 a	3.5 b	37.3 cd	1.9 bc	9.3 f
S_4	2.4 b	42.2 b	3.7 b	41.2 a	2.7 b	36.0 e	0.0 d	12.4 c
S_5	0.7 c	35.3 d	4.1 b	38.8 d	3.9 b	36.4 cd	0.0 d	12.0 cd
S_6	6.5 a	34.3 e	7.2 a	31.7 e	13.1 a	40.2 a	17.4 a	10.6 e
$\bar{x}$	2.3 (bars)	38.0 (%)	4.1	38.9	4.9	38.1	4.1	12.2
			0.1 m depth					
S_1	0.8 d	38.3 e	6.1 b	44.3 bcd	6.5 b	42.7 b	8.6 b	28.7 a
S_2	6.0 bc	45.6 a	6.9 b	44.4 bc	4.3 b	42.9 b	3.2 d	23.6 c
S_3	3.9 c	41.5 c	6.6 b	43.7 cd	5.5 b	40.0 e	4.2 cd	23.0 c
S_4	7.9 b	46.3 a	8.5 b	45.5 ab	6.8 b	42.1 b	6.5 bc	27.3 a
S_5	2.7 d	39.8 d	3.2 c	39.8 e	3.6 b	39.2 e	0.0 e	24.3 b
S_6	11.9 a	40.6 cd	15.9 a	46.0 a	19.0 a	45.9 a	32.6 a	22.0 c
$\bar{x}$	5.5	42.0	7.9	43.9	7.6	42.1	9.2	24.8
			0.2 m depth					
S_1	3.6 c	40.0 d	15.4 bd	44.4 ab	10.8 d	43.4 b	25.9 b	36.1 ab
S_2	17.8 b	46.4 a	12.0 d	44.7 a	15.1 cd	44.8 b	20.3 c	35.3 abc
S_3	15.9 b	41.0 c	17.7 ab	41.8 e	24.6 ab	40.1 d	21.7 bc	32.5 e
S_4	22.9 b	42.9 b	18.1 ab	42.8 bc	16.4 c	41.5 d	23.9 bc	35.0 bc
S_5	5.4 c	40.8 d	10.6 e	44.2 abc	7.8 e	41.3 d	0.6 e	33.0 e
S_6	17.4 b	42.4 bc	21.3 a	43.0 bc	27.7 a	47.3 a	34.8 a	36.8 a
$\bar{x}$	13.8	42.2	15.8	43.5	17.1	43.1	21.2	34.8
			0.3 m depth					
S_1	16.1 b	38.7 c	25.1 a	44.0 ab	26.0 a	41.8 c	28.6 a	36.8 bc
S_2	22.2 a	45.2 a	23.6 a	45.1 a	20.7 b	44.2 a	27.4 ac	37.0 b
S_3	13.1 c	41.7 b	17.4 bc	42.1 c	19.1 b	40.0 c	21.0 d	34.4 e
S_4	18.3 ab	42.3 b	19.4 b	42.5 b	17.2 b	40.1 c	24.4 cd	35.3 c
S_5	12.1 c	40.6 b	16.3 c	41.6 c	14.6 c	41.0 c	13.2 e	34.8 e
S_6	16.2 b	42.2 b	21.0 ab	43.9 ab	25.8 a	45.6 a	30.9 a	39.6 a
$\bar{x}$	16.4	41.8	20.5	43.2	20.6	42.1	24.5	36.3

Values compared within columns with the same letter are not significantly different at the 5% level (Duncan). Preparation methods: S_1 dry soil track tractor, S_2 wet soil track tractor, S_3 dry soil tire tractor, S_4 wet soil tire tractor, S_5 dry soil subsoiles track tractor, S_6 weeding no tillage.

Table 3. Average values of penetration resistance in k Pa (value shown x 10^2) or bars (value alone) adjusted to 40% gravimetric moisture, for 6 land preparation methods during 4 sampling periods (P); followed by the associated average gravimetric moisture %, for subtreatment CS_2.

	P – 1 (15/Jul-10/Aug/75)		P – 2 (10/Sept-7/Oct/75)		P – 3 (2-18/Dec/75)		P – 4 (9-25/Mar/76)	
Sugar cane trash mulch (CS_2) at 0 m depth								
S_1	1.2 b	39.1 e	1.4 c	45.0 d	1.8 b	44.5 c	6.2 b	37.8 bc
S_2	1.6 b	45.8 c	1.8 b	46.3 d	1.6 b	47.5 b	7.0 b	39.3 b
S_3	1.2 b	42.6 d	2.1 b	50.1 b	2.2 b	45.4 b	5.6 c	36.2 c
S_4	2.0 b	49.8 a	2.6 b	50.6 b	1.9 b	45.1 b	6.0 b	37.4 bc
S_5	1.0 b	40.0 d	1.4 e	42.6 e	1.8 b	42.7	6.1 b	34.1 d
S_6	4.4 a	48.5 a	7.5 a	54.7 a	6.8 a	58.2 a	11.4 a	44.9 a
$\bar{x}$	1.9	44.3	2.8	48.2	2.7	47.2	7.0	38.3
0.1 m depth								
S_1	1.7 c	40.9 e	2.3 d	46.7 c	3.0 c	45.1 c	7.6 b	39.0 b
S_2	2.0 c	45.1 b	2.8 d	46.9 bc	3.1 c	48.7 a	7.1 b	40.3 b
S_3	3.3 b	44.6 b	5.4 b	48.7 ab	3.4 b	44.0 c	7.4 b	40.0 b
S_4	3.6 b	49.9 a	4.9 bc	48.5 abc	4.7 b	44.8 c	8.3 b	39.8 b
S_5	1.8 c	42.6 c	3.5 c	43.3 e	3.7 b	42.2 b	7.6 b	36.2 c
S_6	9.3 a	45.8 b	13.1 a	49.3 a	13.1 a	49.8 a	16.1 a	45.1 a
$\bar{x}$	3.6	44.8	5.3	47.2	5.2	45.8	9.0	40.1
0.2 m depth								
S_1	4.8 b	42.2 c	9.2 b	46.8 a	9.5 c	45.6 b	17.3 bc	38.8 cd
S_2	7.2 b	47.0 a	8.8 b	46.4 a	9.9 c	46.1 b	14.0 c	40.8 b
S_3	14.7 a	44.5 b	20.3 a	45.8 ab	15.9 b	44.6 b	15.9 c	39.6 bc
S_4	16.4 a	45.2 b	19.9 a	44.4 b	21.0 a	42.0 c	22.5 a	37.2 d
S_5	5.2 b	40.9 c	6.2 b	42.6 c	7.3 c	42.3 c	6.3 d	36.9 e
S_6	16.1 a	45.2 b	18.7 a	45.7 ab	18.4 ab	48.1 a	19.8 ab	45.8 a
$\bar{x}$	10.7	44.2	13.9	45.3	13.7	44.8	16.0	39.8
0.3 m depth								
S_1	13.2 b	41.3 b	21.9 a	46.3 a	22.5 a	45.1 c	28.8 a	41.3 b
S_2	18.2 a	44.8 a	16.1 b	41.4 b	13.9 c	48.7 a	23.7 b	39.5 bc
S_3	15.8 ab	43.6 a	18.2 ab	45.9 a	18.0 b	44.0 c	20.4 b	40.6 bc
S_4	15.5 ab	43.8 a	21.0 a	41.9 b	20.3 ab	44.8 c	23.1 b	38.3 e
S_5	7.1 c	42.7 a	11.6 c	41.6 b	11.7 c	42.2 b	17.9 c	37.1 d
S_6	13.0 b	44.0 a	20.1 a	47.1 a	20.8 ab	49.8 a	22.6 b	44.2 a
$\bar{x}$	13.8	43.4	18.2	44.0	17.9	45.8	22.7	40.2

Values compared within columns with the same letter are not significantly different at the 5% (Duncan). Preparation methods: S_1 dry soil track tractor, S_2 wet soil track tractor, S_3 dry soil tire tractor, S_4 wet soil tire tractor, S_5 dry soil subsoiled track tractor, S_6 weeding no tillage.

Table 4. Average values of penetration resistance in k Pa (value shown x 10^2) or bars (value alone) adjusted to 40% gravimetric moisture, for 6 land preparation methods during 4 sampling periods (P); followed by the associated average gravimetric moisture %, for subtreatment CS_3.

	Corn (CS_3) at 0 m depth							
	P – 1 (15/Jul-10/Aug/75)		P – 2 (10/Sept-7/Oct/75)		P – 3 (2-18/Dec/75)		P – 4 (9-25/Mar/76)	
S_1	2.6c	38.0c	15.0ab	45.6ab	17.0bc	44.3cd	14.6c	27.4a
S_2	15.6a	47.3a	13.4b	43.8bc	20.1ab	48.7a	27.1a	28.2a
S_3	7.8b	41.9b	13.6b	45.0bc	14.6c	43.6d	11.7c	20.6b
S_4	10.9b	43.9b	18.6a	47.9a	17.9abc	47.2a	28.8a	28.6a
S_5	3.8c	37.9c	6.3c	39.9d	9.9d	39.4b	14 14.8c	22.5b
S_6	9.9b	38.2c	16.9ab	42.4c	20.8a	46.8ac	20.6b	21.6b
$\bar{x}$	8.4	41.2	14.0	44.1	16.7	45.0	19.6	24.8
	0.1 m depth							
S_1	5.6b	40.0d	18.2b	41.4c	18.3b	44.2b	21.5c	28.7ac
S_2	20.4a	48.4a	19.2ab	45.2b	21.8b	46.5a	32.1a	28.9a
S_3	19.3a	43.9c	19.1ab	45.9ab	18.8b	44.2b	14.9d	23.8b
S_4	18.5a	45.8b	22.4ab	47.1a	20.5b	45.7ab	35.1a	30.1a
S_5	5.8b	38.7d	9.8c	40.9c	10.9c	40.8c	14.2d	24.7b
S_6	22.5a	42.8c	22.8a	42.2c	31.5a	48.4a	27.3b	27.2c
$\bar{x}$	15.3	43.3	18.6	43.8	20.3	45.0	24.2	27.2
	0.2 m depth							
S_1	17.2c	39.0c	25.2a	45.6a	24.1b	43.4b	18.6d	32.9b
S_2	26.6a	47.2a	23.9a	43.0b	24.4ab	42.4b	30.6c	31.7bc
S_3	21.1bc	42.1b	25.5a	43.0b	29.0a	42.3b	32.7bc	30.7c
S_4	21.2bc	46.4a	23.7a	45.5a	19.4c	43.3b	35.9b	32.4b
S_5	10.5d	39.8c	12.8b	42.7b	14.0d	42.6b	9.9c	29.1d
S_6	25.3ab	45.7a	24.1a	42.7b	28.8ab	48.2a	41.3a	35.1a
$\bar{x}$	20.3	43.4	22.6	43.7	23.3	43.7	28.2	32.0
	0.3 m depth							
S_1	15.7c	40.2b	26.8a	45.0b	25.6a	44.6b	28.6b	35.5ab
S_2	26.4a	44.6a	25.6ab	45.5a	20.0c	42.3c	31.6ab	32.3d
S_3	15.7c	40.7b	22.8bc	42.2b	21.4c	41.3c	30.8ab	33.0cd
S_4	21.9b	45.3a	20.7c	41.8b	21.3c	42.1c	32.2ab	34.4bc
S_5	13.6c	39.1b	16.0d	42.5b	16.4b	42.1c	19.1c	31.1c
S_6	20.7b	44.5a	21.9bc	41.7b	29.1a	48.1a	33.9a	37.1a
$\bar{x}$	19.0	42.4	22.4	43.1	22.3	43.4	29.4	33.9

Values compared within columns with the same letter are not significantly different at the 5% level (Duncan). Preparation methods: S_1 dry soil track tractor, S_2 wet soil track tractor, S_3 dry soil tire tractor, S_4 wet soil tire tractor, S_5 dry soil subsoiled track tractor, S_6 weeding no tillage.

Table 5. Average values of penetration resistance in k Pa (value shown x 10^2) or bars (value alone) adjusted to 40% gravimetric moisture, for 6 land preparation methods during 4 sampling periods (P); followed by the associated average gravimetric moisture %, for subtreatment CS_4.

	Cassava and sweet potato in association (CS_4) 0 m depth							
	P – 1 (15/Jul-10/Aug/75)		P – 2 (10/Sept-7/Oct/75)		P – 3 (2-18/Dec/75)		P – 4 (9-25/Mar/76)	
S_1	7.6 b	40.1 b	15.8 b	48.1 a	17.0 b	46.8 c	19.1 b	30.2 a
S_2	13.0 a	46.1 a	16.2 b	45.9 a	17.1 b	49.4 b	18.8 b	25.3 b
S_3	11.3 a	43.8 a	15.3 b	47.8 a	16.5 b	44.5 c	11.7 c	20.7 d
S_4	13.0 a	45.8 a	18.4 ab	48.5 a	15.9 b	46.5 c	24.4 a	22.6 c
S_5	6.4 b	39.1 b	11.5 c	43.5 b	14.1 b	45.2 c	18.3 b	23.6 c
S_6	13.5 a	44.2 a	20.4 a	48.2 a	22.9 a	53.4 a	18.1 b	20.1 d
$\bar{x}$	10.8	43.2	16.3	47.0	17.2	47.6	18.4	23.8
	0.1 m depth							
S_1	7.9 c	40.2 c	20.3 b	48.2 a	19.9 b	45.2 b	20.5 c	30.1 a
S_2	12.7 b	45.0 a	16.2 c	44.3 b	18.3 b	44.8 b	27.5 b	29.1 a
S_3	16.9 a	43.2 b	20.5 b	47.3 a	17.2 b	44.2 b	13.7 d	26.9 b
S_4	16.8 a	46.5 a	20.8 b	46.8 a	19.3 b	45.3 b	32.2 a	28.4 a
S_5	8.6 c	41.0 c	13.6 c	43.8 b	15.7 c	43.9 b	16.5 d	27.2 b
S_6	18.9 a	45.0 a	26.1 a	47.1 a	33.2 a	50.6 a	23.4 c	28.7 a
$\bar{x}$	13.6	43.5	19.6	46.3	20.6	45.7	22.3	28.4
	0.2 m depth							
S_1	15.5 c	39.7 d	18.0 b	46.6 a	26.3 a	44.0 b	24.6 b	37.3 b
S_2	16.8 c	44.1 b	21.7 ab	40.8 e	20.6 b	42.4 b	22.1 c	35.8 bc
S_3	21.5 a	41.9 c	24.4 a	45.5 a	27.0 a	40.8 c	27.6 ab	32.5 d
S_4	18.1 ac	44.8 ab	24.9 a	43.2 cd	20.6 b	42.9 b	29.5 a	34.1 c
S_5	10.9 b	41.4 c	13.6 c	41.9 d	14.2 c	43.0 b	22.5 c	33.8 a
S_6	22.1 a	46.1 a	25.5 a	44.9 ac	27.8 a	48.1 a	28.2 ab	39.2 a
$\bar{x}$	17.5	43.0	21.3	43.8	22.8	43.6	25.8	35.4
	0.3 m depth							
S_1	12.5 b	38.8 f	22.3 a	45.7 ab	23.6 bc	43.4 b	25.4 ab	36.1 bc
S_2	18.9 a	42.5 b	20.5 a	41.4 e	16.4 d	41.0 c	23.5 c	36.9 b
S_3	20.4 a	42.2 bc	21.6 a	46.3 a	26.0 ab	41.0 c	26.5 ab	33.6 d
S_4	18.6 a	42.4 b	21.4 a	43.6 cd	21.1 c	43.4 b	28.2 ab	35.1 c
S_5	13.6 b	40.6 c	14.4 b	42.4 d	13.4 d	41.6 c	24.4 b	34.1 d
S_6	17.7 a	44.5 a	21.7 a	44.3 bc	27.8 a	47.6 a	29.1 b	39.9 a
$\bar{x}$	17.0	41.8	20.3	44.0	21.4	43.0	26.2	35.9

Values compared within columns with the same letter are not significantly different at the 5% level (Duncan). Preparation methods: S_1 dry soil track tractor, S_2 wet soil track tractor, S_3 dry soil tire tractor, S_4 wet soil tire tractor, S_5 dry soil subsoiled track tractor, S_6 weeding no tillage.

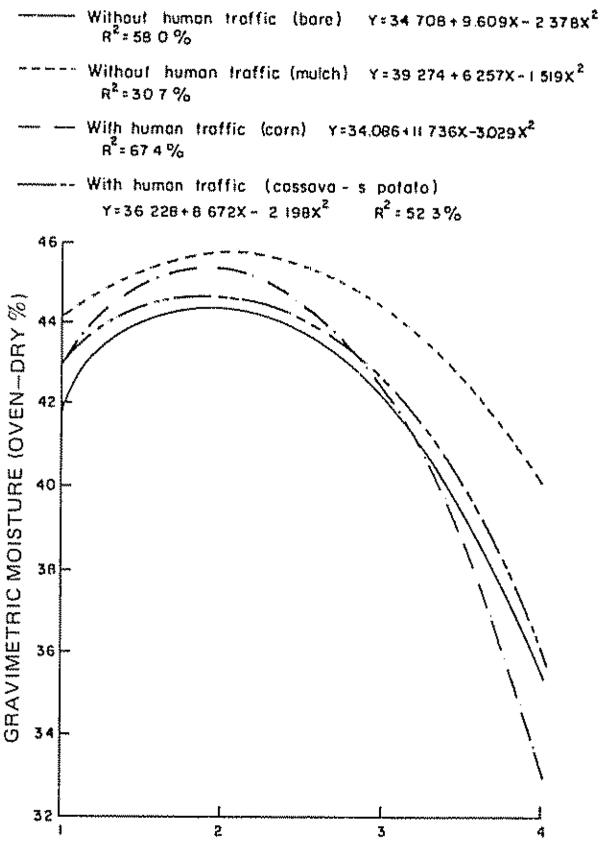

Fig. 14. Changes in gravimetric moisture with the sampling periods for cropping system subtreatments at 0.2 m depth.

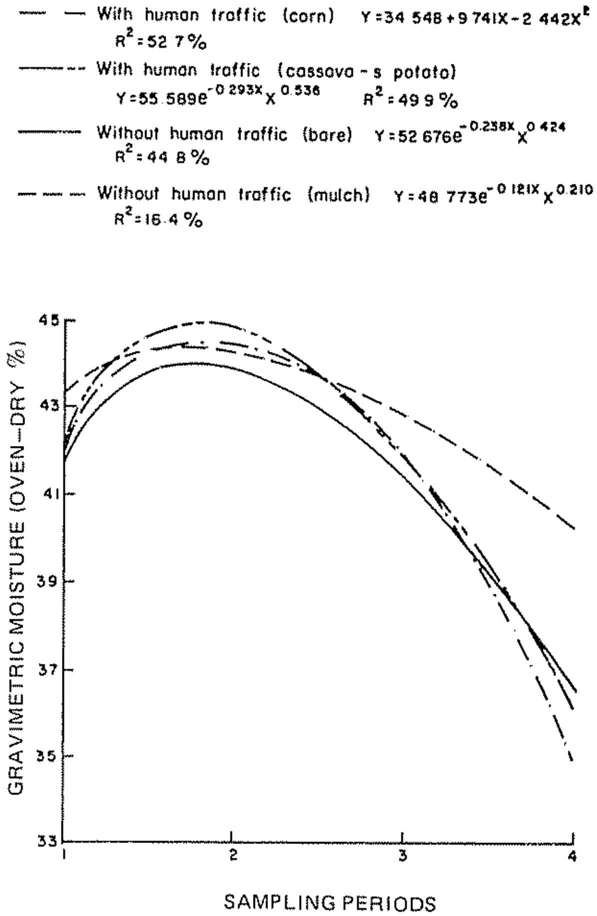

Fig. 15. Changes in gravimetric moisture with the sampling periods for cropping system subtreatments at 0.3 m depth.

Summary

Soil resistance to penetration was determined when a Typic Dystropept was ploughed during the dry season (April 1975) and the wet season (June) using a 60 k W (75 h.p.) D4 Caterpillar trac tractor to plough and subsoil and a 50 k W (67 h.p.) 175s Massey Ferguson tire tractor to plough. Determinations were also made when the soil was prepared by weeding and cleaning without the use of machinery. Each type of land preparation had subtreatments such as a bare plot, a plot covered with sugarcane trash mulch, a plot planted with corn and a plot planted with cassava and sweet potato in association. The experiment was carried out at CATIE, Turrialba, Costa Rica with a mean annual rainfall of 2682 mm and a mean annual temperature of 23.3°C.

The corn was planted in May and June and reapead in October, whereas the cassava in association with sweet potato was planted at the same time and reaped 10 months after i.e. March and April, 1976.

Soil resistance was significantly lowered by land preparation up to 0.1 m depth and by subsoiling up to 0.3 m depth. Soil prepared during the dry season had a significantly lower moisture content than soil prepared in the wet season, whose higher moisture content was attributed to puddling. These differences were discernable up until 14 weeks after preparing the dry soil and 6 weeks after preparing the wet soil. Effects were residual after these time limits. During the growing season soil resistance increased due to 1. Drying during the dry season which caused up to a 5 fold increase. The drying effect was increased by compaction due to human traffic. 2. Human traffic which occured under corn, and cassava with sweet potato, up to 0.2 m depths. 3. Settling time, as observed on the plots with no human traffic during the wet season.

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