SOIL COMPACTION EFFECT ON RUNOFF AND INFILTRATION IN AERABLE SOIL (LUVISOL)

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ABSTRACT

Field experiments were carried out to study the effect of soil compaction on runoff and infiltration in aerable soil (Luvisol). Various farm operations for growing maize (zea mays) were induced using a Massey Ferguson (MF 290 tractor). The processes were repeated several times and each time tractor passes, infiltration and runoff were measured. On analysis, it was found that water infiltration into the soil decreased while runoff increased with increase in the frequency of tractor passes on the jform. On sub-soiling the land with 60cm rigid tine, linfltration increased rapidly, thus reducing runoff considerably. Therefore, sub-soiling was recommended for restoring the physical properties of soil damaged by compaction during farm operations.

Key Words: Soil, Compaction, Runoff, Mechanization.

Effect of Soil Compaction on Runoff

INTRODUCTION

In an attempt to equitably match the rapidly growing world's population with food production, agricultural mechanization has been adopted by most countries of the world. Mechanization in itself poses a number of problems. One of these is soil compaction, a process of mechanically pressing soil particles together. Compaction could be natural or induced. Natural compaction is due to the impact of rain drops, splash and settlement of soil after cultivation. Induced compaction is consequent to the movement and trafficking of farm mechinery over soil surface. The rate and degree of compaction on the soil is affected by the climate, soil type, soil moisture, tractor axle weight, wheel type and size, and frequency of machinery on the farm.

The mechanics of soil compaction can be explained by the principles of rolling resistance and sinkage. Bekker (1966) developed a soil pressure-sinkage relationship of the form

$$p = \frac{KC}{b} + KQ\, z^n \quad \text{---} \quad 1$$

where p = ground pressure
b = the smaller dimension of contact area (e.g. wheel width)
z = sinkage
n , KC and KQ are constants for a particular soil.

Other common methods of measuring soil compaction include the soil bulk density technique (which inovolves measuring the dry weight of a known volume of soil) and the use of soil penetrometer (which is a direct measurement of the force it takes to drive a rod with a cone-shaped point through the soil).

Compaction could lead to poor internal drainage of soil, poor aeration, excessive runoff, soil erosion and consequently reduction in crop yield. The frequency of machinery on the farm depends on the number of operations needed in the growth of crops from land clearing to harvesting. Reed (1986) observed that on a sloping land, compaction could lead to increased runoff which would cause erosion of the upper reach of the land and deposition of the soil on the fertile land down the slope. He also reported that wheel compaction and plough pan development restricted soil moisture infiltration. In effect, the wetness of the soil was limited only to the plough depth. Ebert et al. (1985) discovered that in compacted soil, root system development was confined to the upper few centimeters of the soil profile as the compacted layer offered resistance to root penetration. This lowers evapotranspiration, weakens plants anchorage in the soil, hinders plant growth and finally reduces yield. Raghavan et al. (1979) showed that although the number of days for corn (zea mays L.) emergence on uncompacted soil was reduced due to the wetness of upper horizon, crop yield was reduced in heavily compacted soil by over 35% of the yield on uncompacted soil.

The severity of compaction is dependent upon the soil type, number of tractor passes, rate of water infiltration and type of crop.

The problems of compaction in agricultural soils are seriously threatening increased food production through mechanization. Investigations are needed to determine the levels of compaction at which soils cannot support optimum production of crops. This paper focusses on how water infiltration, runoff and erosion of farm land are affected by different levels of induced compaction.

MATERIALS AND METHOD

This study was carried out in 1988 in Makurdi, Benue State of Nigferia. Benue State lies within Longitudes 6° 30'E and 9° 40'E and Latitudes 6o 30'N and 8° 15'N. It has two major seasons in a year - the rainy season which starts from April and ends in October and the dry season which starts from Novermber and ends in March. The average annual rainfall and temperature are 1200.7mm and 28.3oC respectively (Soil Survey Report, 1984). The soils of Benue State are made up of a total of seven soil types, namely, Lithosols, Acrisols, Luvisols, Fluvisols, Nitosols, Cambisols and Regosols (Soil Survey Report, 1984).

The experimental plot which is constructed on the Luvisols of Benue State is 60m x 50m, has a slope of 3% and can be located on Latitude 7° 41' and Longitude 8° 31'N of equator. Luvisols are connotative of alluvial accumulation of clay. There are eight subdivisons of luvisols comprising of arthic, chronic, calcic, vertic, ferric, albic, gleyic and plinthic luvisols. They account for over 65% of the soils (land area) of Benue State (Soil Survey Report, 1984).

The characteristics of the luvisols on which the plot was constructed is decribed on Table 1.

Table 1: Characteristics of Luvisols

Characteristics	Luvisols
% Clay	20 - 25%
pH	4.5 - 7.5
Organic Matter	5 - 10%
Carbon: Nitrogen	12:18
Cation exchange	20 - 25%

In order to shorten the period necessary to obtain useful information on cummulative effect of compaction on runoff and erosion and also eliminate numerous problems associated with farm management in developing countries, the experiments were designed to be comparable to and not typical of mechnized maize production. A total of seven experiments were carried out on the same plot. Compaction comparable to that which could be obtained within a year of actual mechanized maize production has to be induced for each experiment. It is expedient that all the seven experienments be performed on one plot in order to quantify several years of accumulated soil compaction on the plot.

A Massey Ferguson MF 290 tractor was used to induce compaction on the soil. Tractor passes were made to simulate mechanized farm operations, namely, ploughing, harrowing, ridging, planting, fertilizer application, weeding and harvesting in maize production. Land clearing operation with heavy machinery is not a routine annual farming activity and therefore was not accounted for in the operations listed above.

The direction of tractor pass for each simulated operation is shown in Fig. 1. A penetrometer was used to measure compaction. Compaction tests were carried out at 1m interval, on the experimental plot. Double ring infiltrometers were used to measure water infiltration into the soil after seven tractor passes that simulate one year of mechanized operations for maize production have been completed. The initial moisture content of the soil (before each compaction) was determined by the gravimetric method. Infiltration was measured at 5 minutes interval for the first 50 minutes and at 10 minutes interval for the subsequent 70 minutes. At terminal infiltration the water remaining in the infiltrometer was used to calculate runoff, using the rainfall-runoff model:

$$P = Q \pm \Delta s + E_t + L \quad \ldots\ldots 2$$

where P = volume of rainfall in a specific time

Q = volume of runoff in the same time

ΔS = change in soil moisture content during the specific time

L = deep percolation losses

E_t = evapotranspiration

Here E_t is negligible in 120 minutes of infiltration test. L was evaluated by subtracting infiltration at soil saturation point from the total infiltration at the end of test. Change in soil moisture was measured using the gravimetric method.

Runoff was finally evaluated using equation 3

$$Q = P \pm \Delta s - L \quad \ldots\ldots 3$$

For control, an infiltration test was conducted on the soil before the experiments commenced. A total of one control and seven experiments were car-

ried out. Seven tractor passes, representing seven mechanized operations needed to produce maize were used to induce compaction for each experiment.

At the end of the seventh (last) experiment when a compaction force of 1.35kg/m^2 was achieved, subsoiling of the plot to a depth of 60cm was carried out with 60cm rigid time to loosen and break any soil pan that might restrict infiltration.

RESULTS

The summary of the data collected are shown in Table 2. The estimated runoff for each of the experiments is shown in Table 3.

Table 2 shows the values of compaction and infiltration after 120 minutes vis-a-vis the frequency of tractor passes on the plot. In all the experiments accumulated infiltration at 120 minutes decreased and runoff increased as compaction increased; that is, as the number of tractor passes increased. It can also be observed that in experiment 2 an additional increment of 0.37kg/cm^2 over 0.60kg/m^2 in experiment one led to a drastic reduction of 8mm in infiltration (Table 3). In experiments 6 and 7, increment of 0.01kg/m^2 also led to a severe reduction of 13mm and 19mm respectively, in infiltration. From the above, it is clear that after a certain level of compaction is attained, a small increase in compaction can greatly restrict infiltration of soil moisture and therefore leads to excessive runoff and consequently erosion. Fig. 2 shows the differences in the amount of infiltration at the end of 120 minutes for each of the seven experiments. Fig. 3 shows the variation of soil compaction (resistance to penetration) with number of tractor passes.

On subsoiling the plot to a depth of 60cm at the end of the seventh experiment when a compaction force of 1.35kg/m^2 was obtained, it was observed that infiltration rapidly rose above the rate of the control experiment. Fig. 2).

DISCUSSIONS

The ideal approach to this experiment would be to undertake actual mechanized maize production for 7 to 8 years and quantify the effect of compaction on water infiltration, runoff and erosion. Therefore considering the circumstances and conditions under which these experiments were performed, the results may not, precisely be equated to the operations under actual farming conditions. Compaction could have been more or less estimated. Nevertheless, the prime objective of this study which is to quantify compaction and its effects on runoff and infiltration has been positively achieved.

This study has established that a compaction force of 1.35kg/m2, can seriously limit soil moisture infiltration and lead to increased runoff and erosion. Since we cannot conveniently dispense with mechanization in the bid to increase agricultural production, there is urgent need to find solutions to the adverse consequences of soil compaction due to mechanization. The basis of management of soil compaction is traffic control over the field. To this end, a crop production system in which the traffic lanes and the cropping areas are distinctly and permanently separated is ideal.

The high soil Iresistance observed on the control experiment as compared with the 7 tractor passes is due to the initial hard surface crust which has been fallow over a long period. Taylor (1986) observed that if tractors and implements are used on the farm such that wheel tracks on the farm remain permanent from year to year other areas of the farm which do not experience wheel traffic will have less compaction. Jasa et al. (1985) recommended that where field operations necessitate a great deal of trafficking, subsoiling of the farm should be carried out as frequently as necessary to repair the damage. To achieve maximum soil tilth (soil lossening) and prevent further compaction, deep tillage should be performed when the soil is relatively dry.

It was observed in this study that subsoiling restored infiltration rate above the rate at the beginning of the first experiment. In order to determine how often the sub-soiling should be carried out as suggested by Jasa et al (1985) it is recommended that local experiments be carried out to quantify compaction and its effects on different soils. This is expedient since variables such as soil type, soil moisture and implements influence compaction. It has been established here that compaction reduces infiltration and accelerates runoff. The solution to the above must be in restoring or improving the physical properties of the soil. One way of doing this is by subsoiling since sub-soiling loosens the soil and improves water infiltration.

CONCLUSIONS

From the results obtained in this study, the following conclusions can be made:

1. Five years of continuous mechanized maize production on luvisols of Benue State may lead to a level of soil compaction with significant reduction in infiltration.

2. Runoff increases directly as compaction

increases.

3. Subsoiling of the land after five years of continuous mechanized maize production on luvisols of Benue State of Nigeria will help in restoring the infiltration capacity of the soil and consequently reduce runoff and erosion on the farm

4. It is therefore recommended that subsoiling be carried out on luvisols of Middle Belt of Nigeria as soon as a total compaction force of 1.35kg/m2 which must include soil resistance, is obtained or every five years of continuous mechanized farming.

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Table 2: EFFECT OF COMPACTION OF SOIL ON WATER INFILTRATION

Experiments	Initial Moisture (mm)	Compaction kg/m^2	No. of Tractor Passes	0	5	10	15	20	25	30	35	40	45	50	60	70	80	85	90	100	110	120
				Time (min) →																		
				INFILTRATION (mm)																		
Control	0.6025	0.937	-	0	30	49	62	74	84	93	102	110	117	123	135	145	154	158	162	169	175	181
1.	1.41	0.60	7	0	21	31	40	47	54	61	67	73	80	85	97	107	115	119	124	132	139	145
2.	1.35	0.97	14	0	14	23	32	39	46	54	61	67	74	79	90	100	109	114	118	125	131	137
3.	1.13	1.10	21	0	14	23	31	37	43	49	55	61	65	69	78	86	94	98	101	107	113	119
4.	0.73	1.21	28	0	10	19	28	35	41	47	53	58	63	67	75	82	89	92	96	101	106	110
5.	0.72	1.33	35	0	10	19	27	33	38	43	48	54	58	63	72	80	87	90	93	97	101	105
6.	0.71	1.34	42	0	9	16	23	28	33	38	43	47	51	54	62	68	74	77	80	84	88	92
7.	0.71	1.35	49	0	8	14	19	24	28	32	36	39	42	45	51	55	59	61	63	67	71	93

Table 3: INFILTRATION AND RUNOFF FOR EACH EXPERIMENT:

Experiments	Initial soil moisture (mm)	Δs Change in M.C (mm)	No. of tractor passes	Compaction kg/m^2	Infiltration at end of 120 minutes (mm)	Runoff at end of 120 minutes (mm)
Control	0.60	-	0	0.93	181	119.00
1.	1.41	+0.81	7	0.60	145	154.19
2.	1.35	+0.06	14	0.97	137	162.94
3.	1.13	+0.22	21	1.10	119	180.78
4.	0.73	+0.40	28	1.21	110	189.60
5.	0.72	+0.01	35	1.33	105	194.99
6.	0.71	+0.01	42	1.34	92	207.99
7.	0.71	+0.00	49	1.35	73	227.00

Note: Infiltrometer is always filled to 300 mm mark at the start of each test.

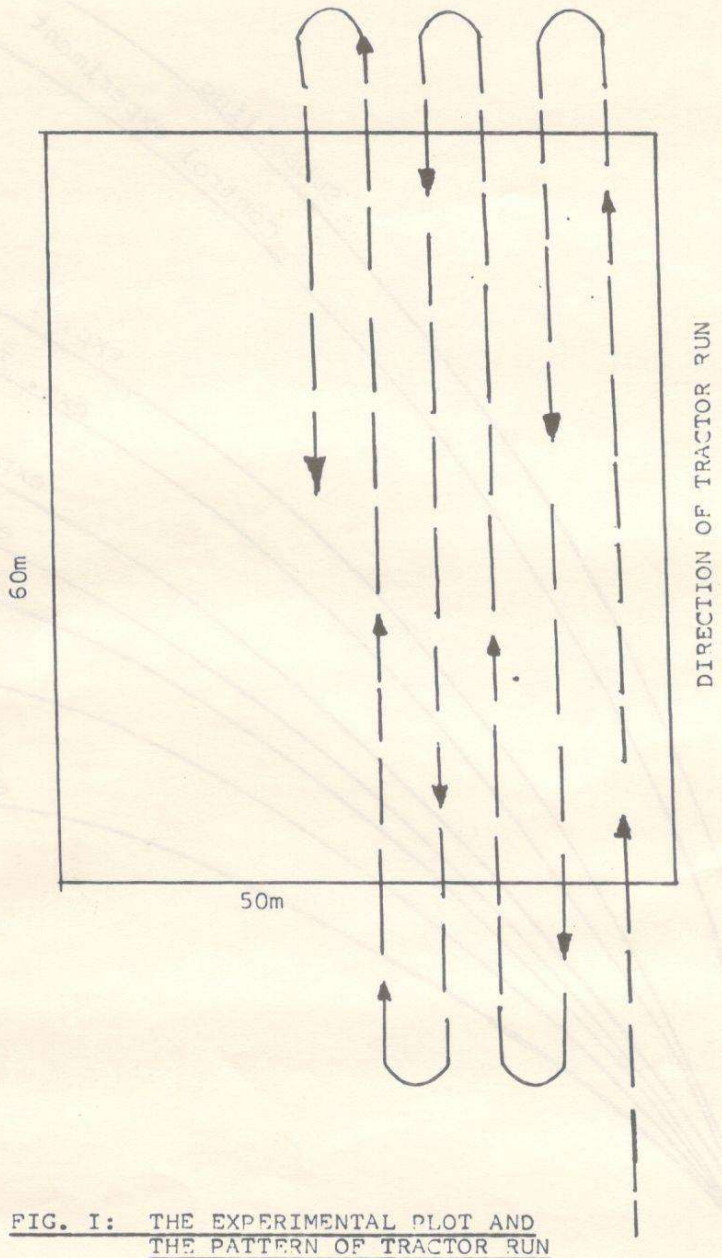


FIG. I: THE EXPERIMENTAL PLOT AND THE PATTERN OF TRACTOR RUN

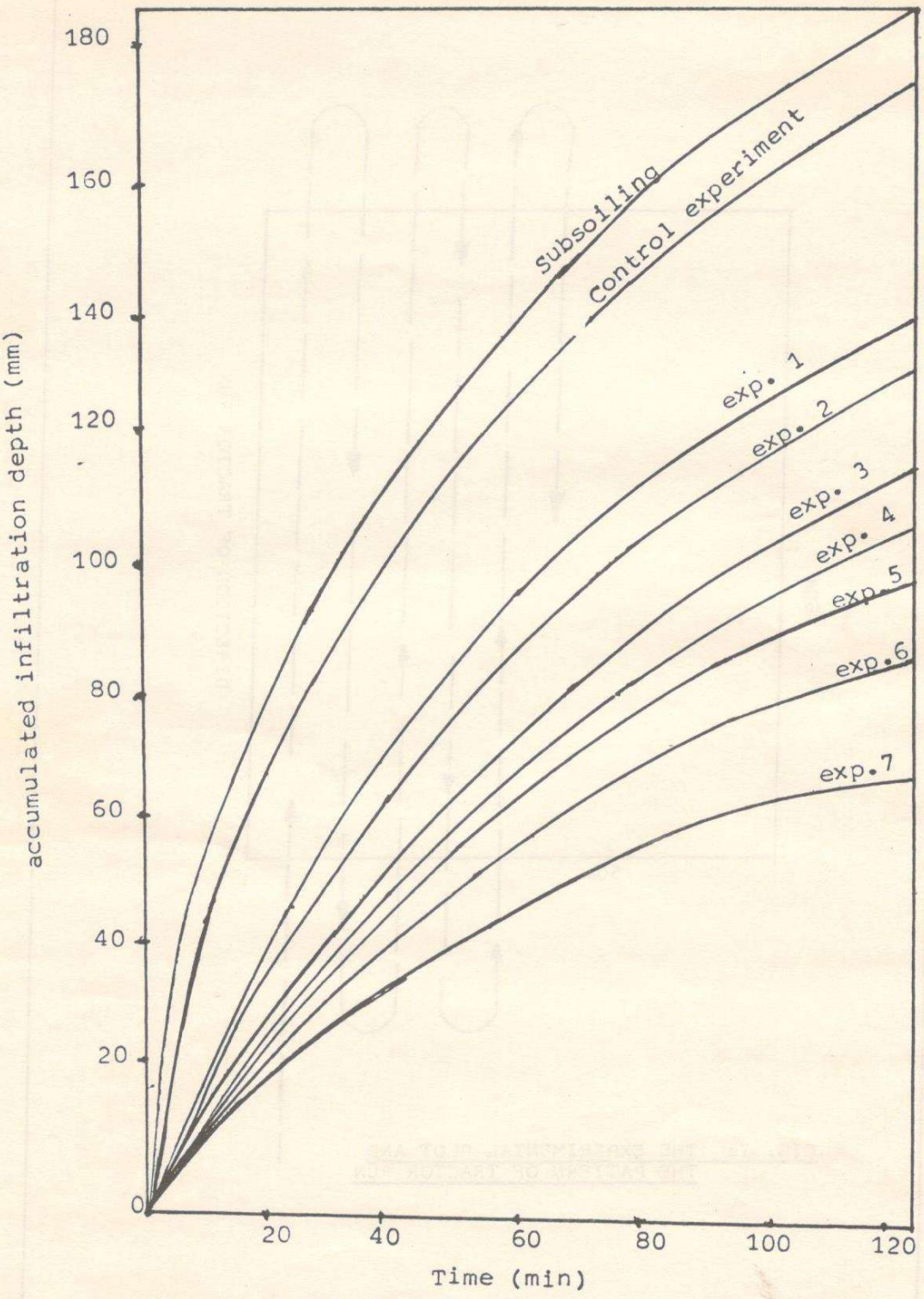


Fig. 2: Graph of accumulated infiltration depth against time.

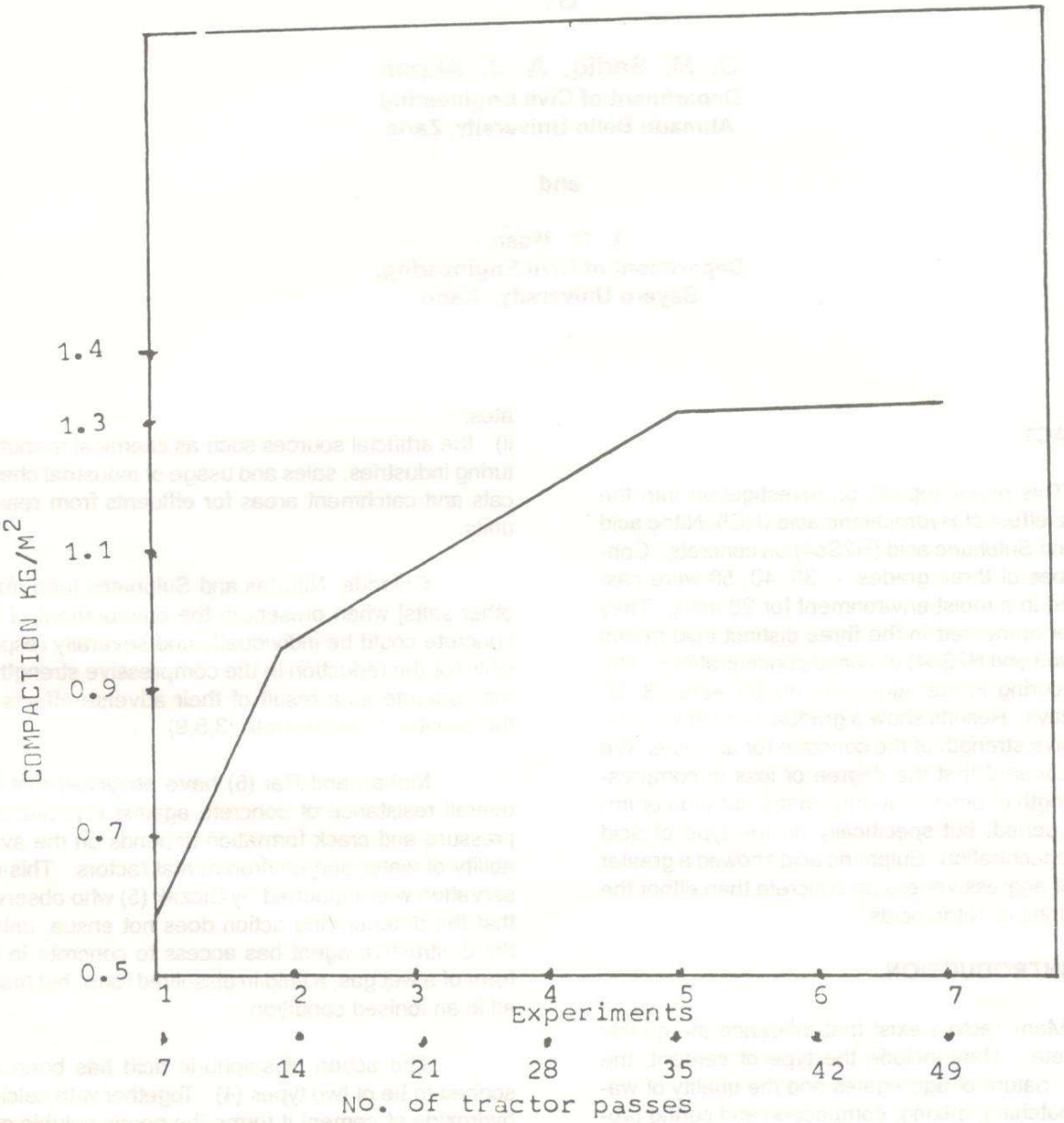


Fig. 3: Variation of soil compaction with number of tractor passes.