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SUBSOIL GRAVEL HORIZON AND MAIZE ROOT GROWTH

II. EFFECTS OF GRAVEL SIZE, INTER-GRAVEL TEXTURE AND NATURAL GRAVEL HORIZON

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SUMMARY

The effect of gravel concentration, size of gravel and inter-gravel texture on root growth and development of maize seedlings was investigated in a greenhouse study. The adverse effect of naturally compacted gravel horizon of an alfisol on maize root growth was also studied in a field experiment. Gravel concentration of above 10 to 20 per cent by weight significantly reduced rate of root elongation and produced symptoms typical of mechanical impedance. The inhibitory effect of gravels was more pronounced for small rather than large gravels and for coarse rather than fine inter-gravel texture. The natural gravel horizon of an alfisol definitely inhibited rate of root elongation, total root volume, number of roots and depth of root penetration.

INTRODUCTION

Soils with pediment gravels at shallow depth are widespread in West Africa in areas where the underlying country rock is Pre-Cambrian granite and metamorphic: mainly paragneisse, quartzite and quartzschist. Gravel horizon occurs in most soil profiles of middle and upper slopes [4]. The thickness of this horizon as well as concentration and size of the coarse fragments vary even for short distances. Moreover, the texture of the fine earth fraction ranges from coarse loamy sand to sandy clay, although a sandy clay loam texture predominates [3].

The interaction of gravel size and matrix-texture on plant growth in general and root growth in particular is not well understood. Takijima and Sakuma [5] found a concentration of coarse sand and gravel in equal proportions critical for rice root elongation. Vine [6] reported that although rooting depth was significantly affected by gravel concentration and gravel size, total root length was not. Penetrometer readings were closely correlated with primary seminal diameters of roots and rooting depth.

The adverse effect of gravel concentration on root growth of maize seedlings were described in an earlier report [2]. This report describes some effects of gravel size and concentration and inter-gravel soil texture on root growth of maize seedlings. An experiment to evaluate the relative effect of a natural field gravel horizon on root development of maize is also reported.

MATERIALS AND METHOD

Experiment I

A 3-factorial experiment was established in the greenhouse by using a 38.5-litre capacity container described in the earlier report [2]. These containers were filled with gravel-soil mixtures. There were three gravel sizes: 4-8 mm, 8–15 mm and 15–40 mm, and three textures of the fine earth: sand, sandy loam, and clay. There were also five gravel concentrations of 0, 10, 25, 50, 75 per cent by weight. The inter-gravel bulk density was maintained at 1.2 g/cm^3 for all the treatments. Treatments were replicated thrice. Five-pre-germinated maize seedlings were transplanted in each container and were grown for seven days. Soil moisture content was monitored by using gypsum blocks and was adjusted daily to 0.3 bar at 15-cm depth. A 1-cm thick gravel mulch on the soil surface reduced evaporation losses. Root number, total root length, depth of root penetration, fresh and dry shoot and root weight and shoot height were taken at harvest.

Experiment II

Field experiments were conducted on the IITA experimental farm near Ibadan, Nigeria. The surface soil, 15 cm deep was scraped off to expose the gravel horizon. The following treatments were then imposed:

(i) gravel horizon maintained at natural bulk density.
(ii) gravel horizon loosened to simulate deep tillage.
(iii) inter-gravel soil sieved free of gravels and packed at initial inter-gravel bulk density, and
(iv) replacement of subsoil with surface soil.

In the first treatment, a rectangular block of the gravel horizon, 50 $\times$ 50 $\times$ 50 cm, was isolated by cutting trenches around it. In the second treatment, the soil from a volume, 50 $\times$ 50 $\times$ 50 cm was carefully dug out and replaced layer by layer. In the third and fourth treatments, the natural soil was removed from the block and the holes created were filled with sieved ($<$ 2 mm) inter-gravel soil and surface soil, respectively. A uniform bulk density of 1.4 g cm^{-3} was maintained in the latter treatments. The treatments were completely randomized and replicated thrice. Ten seeds of maize $TXBC_3$ were sown on each plot after thorough irrigation and subsequent drainage. Plants were later thinned to six at emergence and grown for seven days. Plots were mulched with rice straw to minimise soil temperature fluctuations and evaporation losses. Plant heights were measured at harvest and the observations on root development were made by digging 50-cm deep trenches through the middle of two adjacent plots. Root observations made were: depth of root penetration, number of seminal and secondary roots, root spread, mean root length and fresb and dry root weight.

The soil physical characteristics of bulk density, porosity and moisture retention characteristics were determined on soil cores. Particle size analysis was done by hydrometer method.

RESULTS AND DISCUSSION

Experiment I. Effect of gravel size, concentration and inter-gravel textures

(a) Physical characteristics. Table 1 shows the data of the physical characteristics of different media used for root investiga-

TABLE 1

Some physical properties of the soils used in the investigation of the effects of gravel size, concentration and soil texture

Texture	Gravel concentration (g/100g)	Bulk density (g/cm³)	Total porosity %	Percentage pore space having pore diameters (microns)				Mechanical analysis %		
				>292	292–146	146–74	<74	Sand 2–0.02	Silt 0.02–0.002 (mm)	Clay <.0002
Sand	0	1.58	40.0	10.0	16.0	25.0	40.0	94.2	1.0	4.8
	10	1.72	34.6	19.0	11.8	37.2	27.0			
	25	1.82	31.3	22.0	10.8	36.4	30.8			
	50	1.85	30.2	39.4	16.0	23.7	20.9			
	75	1.98	25.4	44.1	15.0	16.0	24.9			
Sandy loam	0	1.52	42.0	16.0	22.0	21.8	40.2	87.2	5.0	7.8
	10	1.58	40.4	17.6	21.8	20.5	40.1			
	25	1.64	37.9	25.1	14.0	18.3	52.6			
	50	1.71	35.3	43.1	9.6	12.7	34.6			
	75	2.02	23.7	35.0	12.7	12.7	29.6			
Clay	0	1.20	54.7	12.0	15.0	8.0	65.0	56.2	13.0	30.8
	10	1.38	47.7	7.1	17.8	11.2	63.9			
	25	1.48	44.0	10.9	15.7	11.1	62.3			
	50	1.71	35.5	11.8	15.6	13.8	58.2			
	75	2.02	23.9	12.1	15.9	10.1	61.9			

tion. The clay content ranged between 30.8 per cent for the sandy clay loam to 7.8 per cent for the sandy loam and 4.8 per cent for the sand. It was difficult to maintain the desired or calculated values of bulk density when the gravel concentration was low. The bulk density values given in the table are the actual values obtained after the soil had settled.

Generally, the total porosity decreased with increasing gravel concentration and decreasing clay content of the inter-gravel material. The maximum total porosity of 54.7 per cent was obtained for the gravel-free clay soil and the minimum of 23.7 per cent for the 75 per cent gravel concentration with sandy-loam inter-gravel texture (Fig. 1). The effect of inter-gravel texture on total porosity was not significant at high gravel concentration.

The moisture retained at 60-cm suction, averaged over all gravel sizes and concentrations, was 0.041, 0.108 and 0.227 $cm^3\ cm^{-3}$ for sandy, sandy loam and clay texture, respectively. The relative reduc-

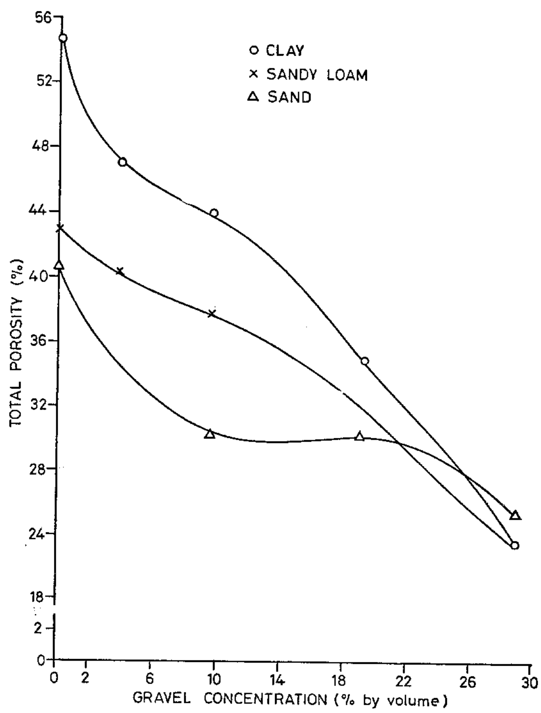


Fig. 1. Effect of gravel concentration and soil texture on total porosity.

TABLE 2

Analysis of variance table of F ratio

Variable	Plant height	Fresh shoot weight	Dry shoot weight	Fresh root weight	Dry root weight	Rooting depth	Mean root depth	Root number	*Root length* Fresh root weight	*Root length* Dry root weight
Texture (A)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Gravel size (B)	n.s.	**	n.s.	**	**	**	**	n.s.	**	**
(i) check *vs* others.	n.s.	**	n.s.	**	**	n.s.	n.s.	n.s.	**	**
(ii) Conc.-linear	*	*	n.s.	n.s.	n.s.	**	**	n.s.	**	**
(iii) Conc.-quadratic	n.s.	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
(iv) Size-linear	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	*	n.s.	**	n.s.
(v) Conc. X Size (linear)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
(vi) Conc. X Size (quadratic)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
A.X B	n.s.	*	n.s.	**	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

n.s. Not significant at 5% level of confidence.

* Significant at 5% level of confidence.
** Significant at 1% level of confidence.

tion in moisture retention averaged over the suction range from 0 to 60 cm, for 75 per cent over zero gravel treatment was 32, 41 and 55 per cent for sandy, sandy loam, and clay texture, respectively.

In Table 2 is depicted the statistical analysis of the various plant growth parameters as affected by gravel size and texture treatments.

(b) Shoot growth. Plant height and dry shoot weight was not signficantly affected by gravel size, concentration or soil texture. Fresh shoot weight, however, was significantly affected by gravel size and concentration, but not by texture.

(c) Root growth. The depth of root penetration was significantly affected by gravel size and concentration (Fig. 2). The depth of root penetration was increased for 10 per cent over zero gravely by 10, 17 and 10 per cent for sand, sandy loam and clay texture, respectively (Fig. 2). The reduction in depth of root penetration was highest for the 4–8 mm gravel size. Coarse inter-gravel texture decreased the depth of root penetration more than clayey texture. The depth of root penetration increased from zero to 10 and 25 per cent gravel concentration only for sandy loam and sandy texture

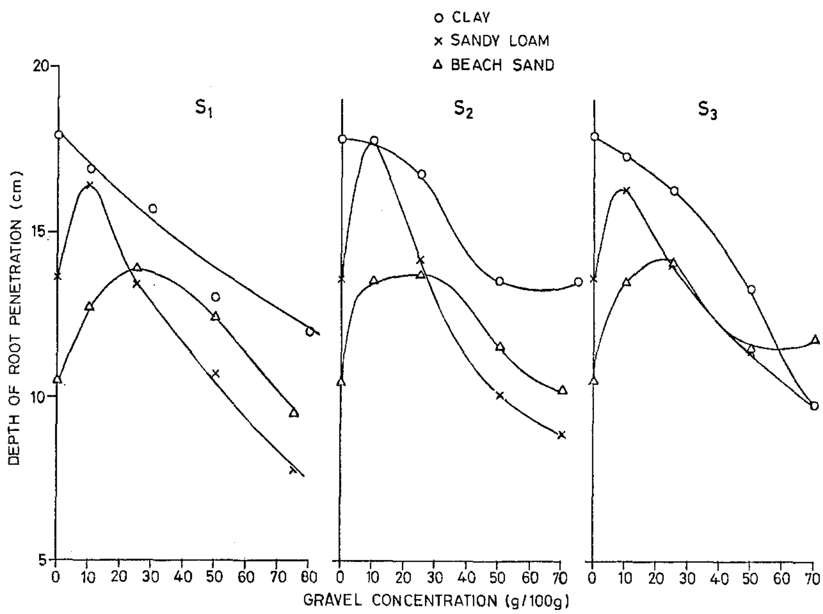
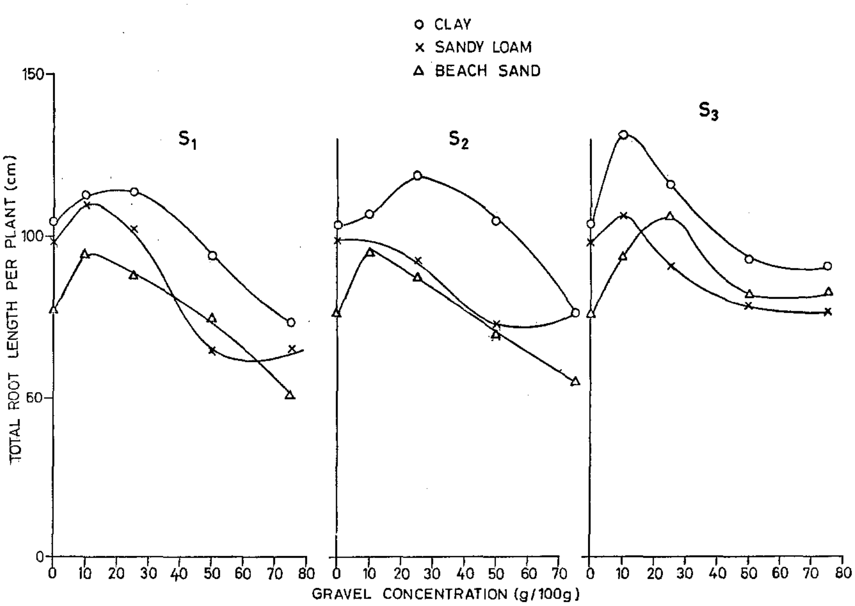


Fig. 2. Effect of gravel size and inter-gravel texture on depth of root penetration (S_1 = 4–8 mm gravel size, S_2 = 8–15 mm gravel size, S_3 = 15–40 mm gravel size).



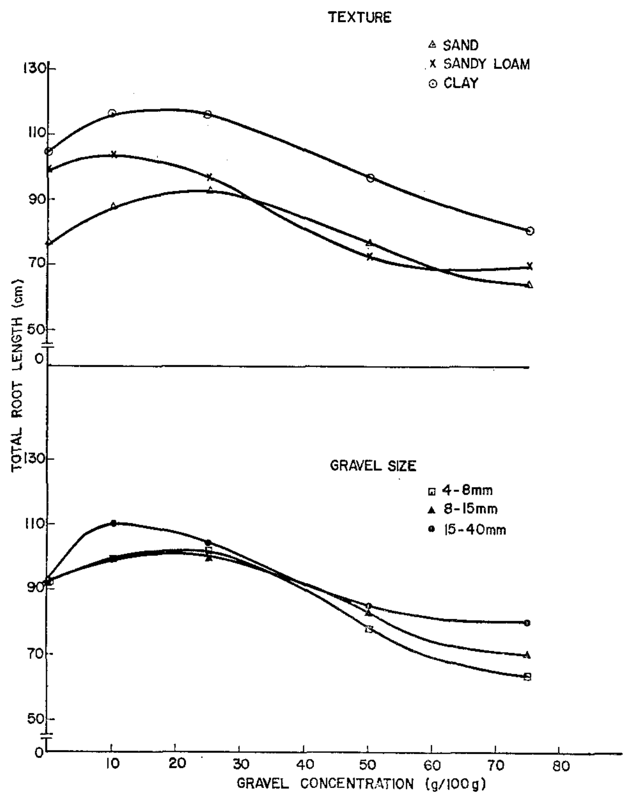


Fig. 4. Effect of inter-gravel texture and gravel size on total root length.

(Fig. 2). These results are in general agreement with those obtained by Takijima and Sakuma [5], and Vine [6].

Both gravel size and gravel concentration had a significant effect on root length. Root length decreased with increase in gravel concentration from 10 to 75 per cent for clay and sandy loam inter-gravel material and from 25 to 70 per cent for sand (Fig. 3). The reduction in root length was the greatest for sandy texture at all gravel concentrations (Fig. 4).

Fig. 3. Effect of gravel size and inter-gravel texture on total root length per plant (S_1 = 4–8 mm gravel size, S_2 = 8–15 mm gravel size, S_3 = 15–40 mm gravel size).

Experiment II. Effect of natural gravel horizon on root development under field conditions

Physical properties of the soils. Loosening of the gravel horizon increased total porosity by only 6.4 per cent (Table 3). The pore size distribution was, however, significantly affected. The volume of large pores (> 292 microns) increased by 28 per cent and that of small pores (less than 58 microns) was unaffected by loosening. The total percentage of pores less than 58 microns were larger in the fine earth subsoil and Egbeda surface soil than either the loosened or intact gravel layer. Loosening of the gravel layer influenced the soil moisture retention in the lower suction ranges only.

TABLE 3

Physical properties of the field soils

Soil treatments	Gravel concentration (g/100g)	Bulk density g/cm³	Porosity %	Fractional pore volume having diameters			
				>292	292–146	146–58 (microns)	58
Natural gravel layer	59.6	1.70	35.8	19.4	10.1	10.9	50.6
Natural gravel layer (loosened)	59.6	1.64	38.1	24.8	8.6	17.5	49.1
Fine earth (inter-gravel soil).	0	1.44	45.7	15.6	6.5	6.8	71.1
Egbeda surface soil	0	1.46	44.9	12.0	9.7	9.9	68.4

Shoot growth. The seedling emergence was adversely affected by the gravelly horizon. The emergence in treatments with gravel was delayed by one to two days. The treatments did not produce significant differences in plant height and weight of fresh and dry shoot. Plant height, fresh and dry shoot weights were, however, increased by 9, 28 and 7 per cent respectively, by loosening of the gravel layer. The removal of gravels increased plant heights by 8 per cent, fresh shoot weights by 21 per cent and dry shoot weights by 8 per cent over natural profile. Replacement of subsoil by surface soil increased plant height, fresh shoot and dry shoot by 11, 37, and 11 per cent respectively, over the natural profile.

Root growth. There were highly significant differences among treatments in root length, and mean depth of root penetration (Table 4). The fresh and dry weights of roots were not significantly different. The loosening of the gravel horizon increased total root length by 56 per cent, rooting depth by 47 per cent, fresh root weight by 23 per cent and dry root weights by 7 per cent. The removal of gravel increased rotal root length by 84 per cent, rooting depth by 74 per cent and fresh root weights by 6 per cent.

The average root diameter was 0.95 mm for gravel free and 1.10 mm for the gravelly horizons. The roots in the gravelly horizon were distorted showing symptoms of mechanical impedance such as stunted tip growth with profuse branching and marked crookedness (Plate 1).

TABLE 4

Effect of gravel layer on root growth in the field

Yield variable	Natural gravel layer	Loosened gravel layer	Inter-gravel soil	Egbeda surface soil	LSD (0.05)
Root length (cm)	69	108	127	125	3.60*
Mean root depth (cm)	11.4	16.7	19.8	21.1	5.66*
Fresh root weight (g)	7.60	9.35	8.03	11.20	3.75
Dry root weight (g)	1.03	1.10	0.81	1.04	0.31

* Indicates level of significance at 5%.

CONCLUSIONS

1. Gravel concentration had a highly significant effect on total root length and root depth. In general, the depth of root penetration and total root length decreased with increase in gravel concentration from 10 to 75 per cent. Root development was generally improved by lower gravel concentration of 10 per cent over no gravel.
2. The inhibitory effect of gravel size on root development was more pronounced for small rather than for large gravel size.
3. Coarse inter-gravel soil texture had the most adverse effect on root growth and development. The inhibitory effect of coarse inter-gravel material may be attributed to low water availability and thuse to low turgor pressure development in the roots.
4. The results of field experiments conclusively indicate the inhibitory effect of natural gravel horizon on the root development of maize seedlings. The average rate of root penetration in the gravelly horizon was 1.6 cm/day as compared with 3.0 cm/day in the surface soil.

5. The loosening of the gravel horizon improved root development over the natural compacted horizon. The root development in gravel-free horizon, however, was significantly superior to that of loosened gravel horizon.

6. The agronomic relevance of these experiments is obvious in soil management and land capability classification.

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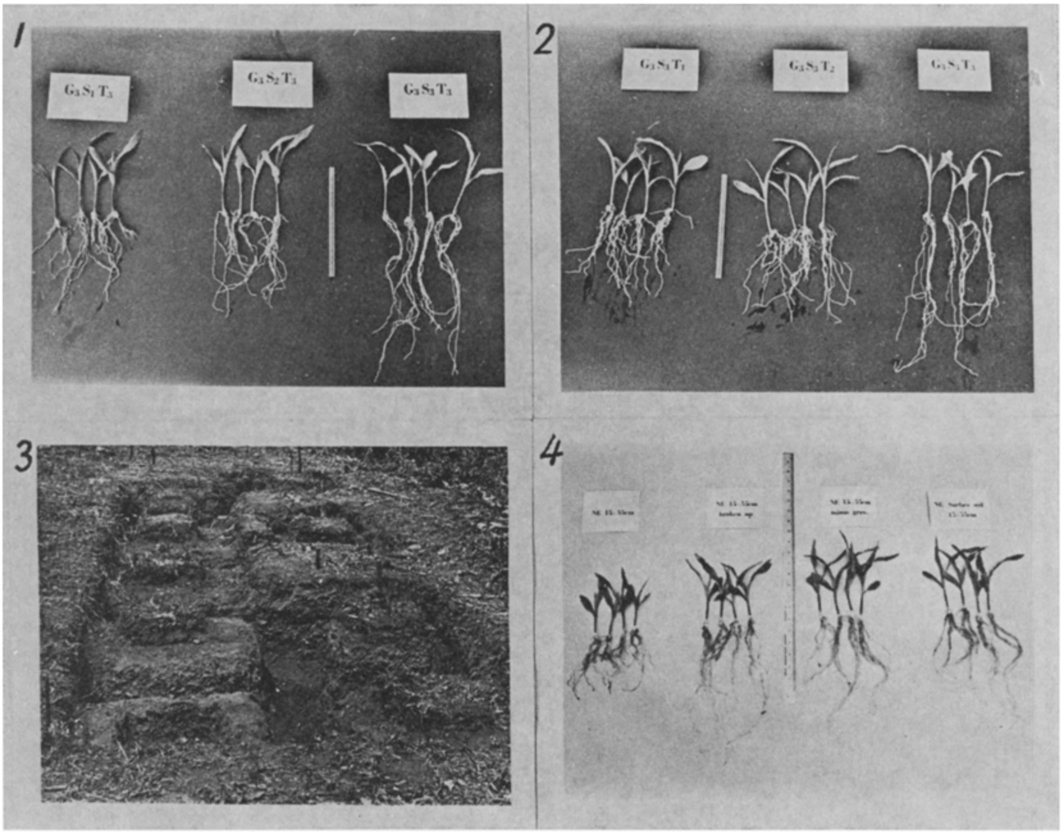

Plate 1.

1. Effect of gravel size on root growth (S_1 = 4–8 mm, S_2 = 8–15 mm, S_3 = 15–40 mm).
2. Effect of inter-gravel texture on root growth (T_1 = Sand T_2 = Sandy Loam T_3 = Clay).
3. Field lay out to investigate the effect of natural gravel horizon on root growth.
4. Effect of different treatments on root growth in the field set up.