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I. Gravel concentration and bulk density effects

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SUBSOIL GRAVEL HORIZON AND MAIZE ROOT GROWTH

I. GRAVEL CONCENTRATION AND BULK DENSITY EFFECTS

by O. BABALOLA and R. LAL

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SUMMARY

A series of factoral experiments involving the effects of gravel concentration in the subsoil horizon, the effect of inter-gravel bulk density, the depth of the surface soil above the gravel horizon and the interaction between soil moisture regime and gravel concentration, on growth and development of maize roots were conducted in the greenhouse. Increasing sub soil gravel concentration decreased the total porosity and the available waterholding capacity. Though the root growth of maize seedlings was adversely affected by gravel concentration above 20 per cent, lower concentration of gravels had a beneficial effect on roots. The root development and the leaf concentration of N, P and K improved with increasing depth of surface soil above the gravel horizon. The symptoms of mechanical impedance, such as thickening of root tips and profuse branching behind the tip were commonly observed on the root axis penetrating the gravelly horizon.

INTRODUCTION

Field observations in Nigeria indicate the inhibitory effects of gravelly horizons at shallow depths in the soil profile on root development. Soils with gravel horizon or stone line at shallow depths comprise approximately 54 per cent of the land surface in Western Nigeria [15]. The occurrence of similar soils has been reported elsewhere in West Africa [1 3 6 12 14], Latin America [9 13], South East Asia [11] and the tropics in general [17]. Almost all of these reports however, were made on the origin, genesis and geographical distribution of the stoneline.

There are conflicting reports in the literature concerning the

effects of gravels in the soil on root development. Lutz and Chandler[9] and Lutz[7] reported that the presence of gravels could be deleterious to root growth in sandy soils and beneficial for air and water movement in clayey soil. Takijima and Sakuma[16] found that rice growth was depressed by a mixture of coarse sand and gravel and the roots were bent and thickened. Gravels depressed root growth up to 40% and coarse sand up to 70 per cent. Malmgren[10] indicated that the presence of gravel in the soil could affect root development and dilute both water and nutrients contents of soils. On the other hand, Unger[18 19] reported the usefulness of gravel band in the subsoil on water retention and availability for a clayey soil with no visible differences in root distribution. Bouchard and Damour[2] also reported that subsurface gravel horizons in the soils of eastern Malagasy did not appear to limit the development of oil palm roots. Egharavba and Ballaux[4] reported a significant yield decline in maize due to gravel layer.

The objective of this report is to describe the effects of gravel concentration and inter-gravel bulk density on the root development of maize seedlings.

MATERIALS AND METHOD

The investigations were conducted in a series of greenhouse experiments described as follows:

1. *Experiment I*

The effect of gravel concentration on root development investigated for 0, 10, 25, 50 and 75 per cent gravel on a wight basis. The gravel comprised the following size fraction: 4.8 mm (8.7%), 8–15 cm (26.1%) and 15–40 mm (65.2%). The inter-gravel material used was the sandy clay loam subsoil of an Egbeda soil from the IITA experiment farm near Ibadan, Nigeria (Classification: Ferric Luvisol – FAO, Paleustalf – USDA). The gravel-soil mixture were packed to provide inter-gravel bulk densities of 1.2 and 1.4 g/cm^3.

2. *Experiment II*

The effects of gravel horizons in the subsoil on root development was investigated for 5, 10, and 15 cm depths of the surface soil. The gravel concentration of the same composition and as described in Experiment 1, in the subsoil horizon was maintained at 60 per cent at an overall bulk density of 1.7 g/cm^3.

3. *Experiment III*

The effect of gravel concentration at a 5-cm depth below the surface was

investigated for five concentrations mentioned in Experiment 1. Three inter-gravel bulk densities of 1.0, 1.2 and 1.4 g/cm^3 were maintained for this study.

4. Experiment IV

Inter-gravel bulk densities of 1.0, 1.1, 1.2, 1.3 and 1.4 g/cm^3 were maintained along side gravel concentrations described in Experiment 1.

The pore size distribution, overall bulk density and moisture retention characteristics were determined for different gravel soil mixtures and bulk density values on soil cores obtained from soil packed drums. Total porosity and pore size distribution were calculated from moisture retention characteristics.

Root development was investigated by packing soil-gravel mixtures in sequential layers 5-cm thick in drums, 40 cm tall, 35 cm in diameter and lined with clear plastic. The two halves were cut longitudinally and bolted together with straps to facilitate root observations. The soil moisture content at 15-cm depth was maintained at 0.3 bar suction as determined by gypsum blocks. Evaporation from the soil surface was reduced by a 1 cm thick gravel mulch. Six pre-germinated seedlings of maize hybrid ($TZBC_3$) were planted in each container in a concentric circle 5 cm from the centre and were thinned to 4 per drum soon after emergence. Seedlings were grown for 7 days in experiments I and IV and for 21 days in experiments II and III. Fertilizer was applied at the rate of 200 ppm of N, 100 ppm of P_2O_5 and 50 ppm of K.

Observations made were: seedling emergence, plant height, leaf area, leaf number, total root length, depth of root penetration, root number and diameter, shoot and root weights. Thin sections of root tips were also examined.

Leaf samples of Experiment II were analysed for N, P, K, Ca, Mg and Zn. Leaf N was determined by micro-kjeldahl steam distillation, P by the vanadomolybdate colorimetric procedure, K by flame photometry, and Ca, Mg and Zn by mass absorption spectrophotometry.

Treatments were arranged in a randomized block design with three replications.

RESULTS AND DISCUSSION

1. Physical characteristics of soil gravel mixtures

Within each inter-gravel bulk density, overall bulk density increased and total porosity decreased with increase in gravel concentration, with a maximum decrease in porosity for the highest inter-gravel bulk density of 1.4 g/cm^3. For instance, the total porosity for 75 per cent gravel concentration was 35.8, 29.8, 27.6, 24.9 and 19.1 per cent for inter-gravel bulk density of 1.0, 1.1, 1.2, 1.3 and 1.4 g/cm^3, respectively. Similarly affected was the pore size distribution. The volume of macropores increased with increasing gravel concentration while that of micro pores decreased. The average macro

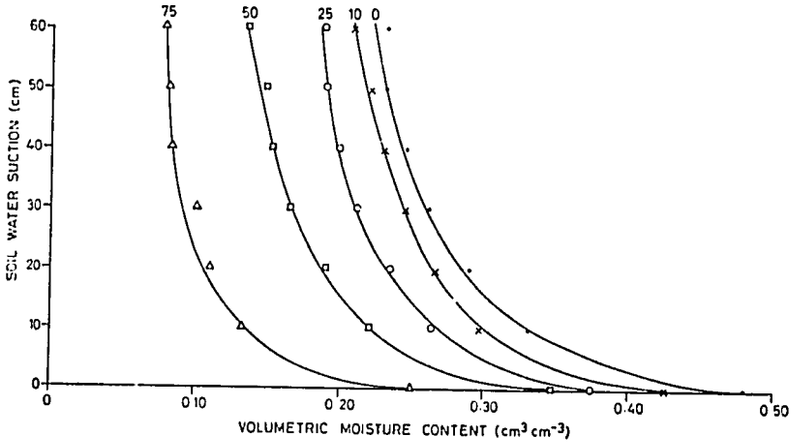

Fig. 1. Moisture retention characteristics as affected by gravel concentration.

pores volume was 28.8, 29.3, 30.4, 36.0 and 44.4% of total porosity for 0, 10, 25, 50 and 75 per cent gravel concentration. The decrease in volume of micro pores with increase in gravel concentration was more at low than at high inter-gravel bulk density.

Soil moisture retention characteristics were significantly affected by gravel concentration and inter-gravel bulk density. In general, the moisture retention decreased with increase in gravel concentration (Fig. 1).

2. Shoot growth

Seedling emergence was delayed for one or two days when gravel percentage was greater than 25. Emerging leaves were distorted and rolling due to mechanical impedance by gravels. Plant height was 19, 21, 17, 15 and 13 cm for gravel percentage of 0, 10, 25, 50 and 75 respectively. Plant height was not related to inter-gravel bulk density. Also the fresh and dry shoot weights were significantly affected by gravel concentration (Table 1) and inter-gravel density.

The depth to gravel layer significantly affected shoot growth. For example, daily rate of growth was 4, 5 and 5 cm for 5, 10 and 15-cm depths respectively. Similarly the leaf area was 0.3, 0.4 and 0.4 m^2 per plant for increasing depth to gravel layer. Fresh and dry shoot weights, though not statistically significant, increased with

TABLE 1

Effect of gravel concentration on shoot growth (g/pot). Experiment 1

Shoot weight	Inter-gravel density g/cm³	Gravel concentration (%)					LSD (.05)
		0	10	25	50	75	
Fresh	1.2	3.0	3.0	2.8	2.0	1.2	0.6
Fresh	1.4	2.0	4.7	3.4	2.3	1.8	0.6
LSD (.05)	1.0						
Dry	1.2	0.23	0.54	0.32	0.30	0.28	0.09
Dry	1.4	0.29	0.52	0.40	0.31	0.26	0.09
LSD (.05)	0.14						

TABLE 2

Effect of soil depth to gravel layer on fresh and dry shoot weights (g/pot). Experiment II

Depth cm	Fresh shoot weight	Dry shoot weight
5	127	14
10	161	19
15	160	18
LSD (.05)	58	8

increase in depth to gravel layer (Table 2). Inter-gravel density was not significantly related to fresh and dry shoot weight.

Nutrient content of maize leaves also showed a trend related to depth of gravel layer (Table 3). Leaf concentration of N, P, K increased with increasing depth. This effect may be due to decreased root volume for shallower depths, because the roots are piled up against the inert surface and not surrounded by the soil. A similar effect was termed 'Barrier Effect' by Fox and Kamprath [5]. The leaf concentration was 0.90% for Ca, 0.11% for Mg and 78 ppm for Zn. Inter-gravel bulk density was similarly related to nutrient content (Table 4). Increased soil as compared to inert material with increasing inter-gravel density decreased the barrier effect thereby increasing the nutrient concentration of N and Ca.

The effects of gravel concentration at 5-cm depth (Experiment III) on shoot weight were not significant.

3. *Root growth*

Effect of gravel concentration. The correlation coeffi-

TABLE 3

Effect of depth to gravel layer on nutrient content* of maize leaves. Experiment II

Depth (cm)	N	P	K
5	4.26	0.37	3.44
10	4.49	0.43	3.60
15	4.70	0.42	3.50
LSD (.05)	0.55	0.06	0.35

* Each value is an average of 9 separate analyses

TABLE 4

Effect of inter-gravel density on nutrient content of maize leaves (%). Experiment II

Density g/cm³	N	P	K	Ca
1.0	4.25	0.40	3.53	0.81
1.3	4.50	0.40	3.64	0.89
1.5	4.70	0.42	3.32	0.96
LSD (.05)	0.55	0.06	0.35	0.15

TABLE 5

Regression equation of root length (Y) with soil and other parameters (X)

Independent variable (X)	Correlation coefficient (r)	Regression equations
Pore size less than 46 microns	−0.63*	Y = −52.9 − 1.9X
Total porosity	+0.83**	Y = −67.0 + 3.0X
Gravel concentration	−0.83**	Y = 73.7 − 0.9X
Fresh shoot weight	+0.83**	Y = −19.9 + 20.3X
Fresh root weight	+0.94**	Y = −63.42 + 29.4X
Plant height	+0.89**	y = −62.8 + 6.4X

* Significant at 5%
** Significant at 1%

cient between pore size distribution and different parameters of root growth are shown in Table 5. Total root length and depth of root penetration were quadratic functions of gravel concentration (Table 6). Total root length decreased by 50% per cent for 25 and 75 per cent for 75 per cent gravels (Fig. 2). The average depth of root penetration was 20, 17, 8, 2 and 1 cm for gravel per cent of 0, 10, 25, 50

TABLE 6

The weighted polynomial regression equations of growth variables (Y) with gravel concentration (X) for the best fit

Dependent variable (Y)	r	Regression equation
Plant height	−0.94**	$Y = 20.33 - 0.102X$
Fresh shoot weight	−0.94**	$Y = 2.67 + 0.113X - 0.004X^2 + 0.00003X^3$
Dry shoot weight	−0.77**	$Y = 0.299 + 0.019X - 0.0006X^2 + 0.00005X^3$
Fresh root weight	−0.96**	$Y = 32.85 - 0.015X$
Dry root weight	−0.90**	$Y = 0.473 + 0.041X - 0.002X^2 - 0.00002X^2$
Root length	−0.99**	$Y = 85.94 - 2.38X + 0.019X^2$
Root depth	−0.99**	$Y = 28.75 - 0.919X + 0.007X^2$

* Significant at 5%
** Significant at 10%

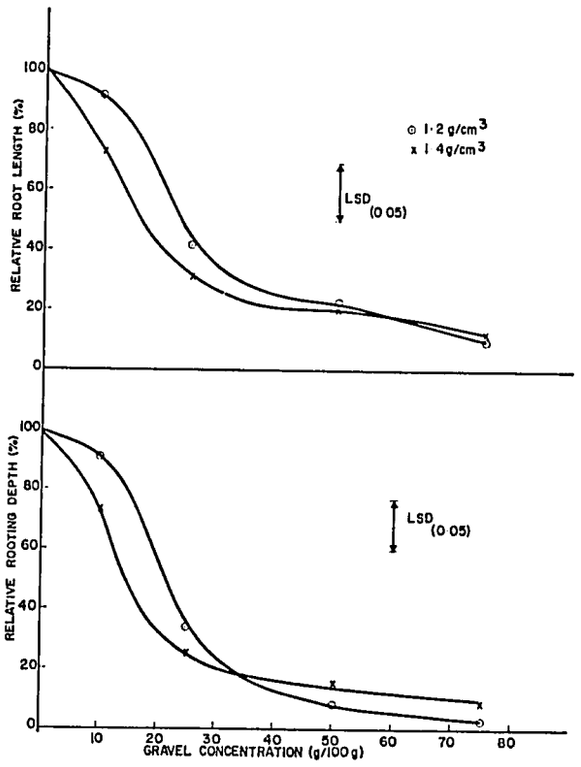

Fig. 2. Effect of gravel concentration on relative depth and length of root penetration.

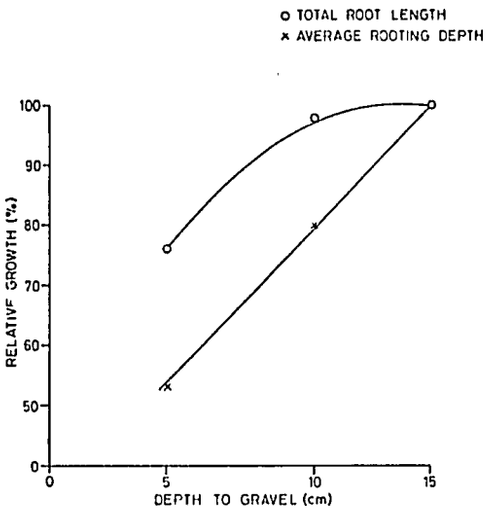

Fig. 3. Effect of depth to gravel layer on total length and average rooting depth.

and 75 respectively. Inter-gravel bulk density did not affect root development significantly. Roots from high gravel treatments were mechanically impeded with symptoms of increase in root diameter, profuse branching behind the root tips and distortion of cortical cells (Plate 1).

Effect of depth to gravel layer. Mean root length was increased by 30 per cent when depth to gravel was increased from 5 to 10 cm (Fig. 3) Root weight also increased with increasing gravel concentration, but was not significantly inflenced by depth to gravel layer. Root tips in the gravel layer were distorted like those shown in Plate 1.

Gravel concentration at 5-cm depth. Mean root length for gravel percentage of 10, 25, 50 and 75 was in the ratio of 1 : 0.97 : 0.92 : 0.87. Similarly affected was the depth of root penetration and was in the ratio of 1 : 0.90 : 0.75 : 0.65 for 10, 25, 50 and 75 per cent gravels. Fresh and dry root weights also decreased with increasing gravel concentration.

Effect of inter-gravel bulk density. Root number, dry and fresh root weights, mean root length and depth of root penetration were not significantly affected by inter-gravel density. The effects

TABLE 7

Effect of inter-gravel bulk density on the depth of root penetration at different gravel concentrations

Density g/cm³	Gravel concentration (%) 0	10	25	50	75	Average	LSD (0.05)
1.0	8.2	7.0	6.4	5.4	5.3	6.5	
1.1	8.9	7.0	7.0	5.7	5.0	6.7	
1.2	8.5	7.5	7.5	4.4	5.6	6.7	0.52
1.3	8.1	7.4	6.8	5.3	4.9	6.5	
1.4	8.3	7.0	6.0	5.8	5.1	6.4	
Average	8.4	7.2	6.7	5.3	5.2	—	
LSD (0.05)			0.52**				1.16

** Signficant at 1%
* Significant at 5%

of gravel concentration on root length and depth of penetration were, however, highly significant (Table 7).

CONCLUSIONS

Increasing subsoil gravel concentration affected the pore size distribution, overall bulk density and moisture retention characteristics. The increase in bulk density with increasing gravel concentration decreased both total and micro porosity and increased the percentage of macro pore volume. Available water holding capacity decreased with increasing gravel concentration.

Root growth and development were adversely affected by increasing concentration of gravels. Small concentration of gravel may however, by useful for clayey soils. Root development improved with increasing depth to gravel layer and with low gravel concentration in the sub-soil. The distortion symptoms on root tips at high gravel concentration were similar to those of mechanical impedance. Leaf nutrient concentration of N, P, and K decreased with decreasing depth to gravel layer.

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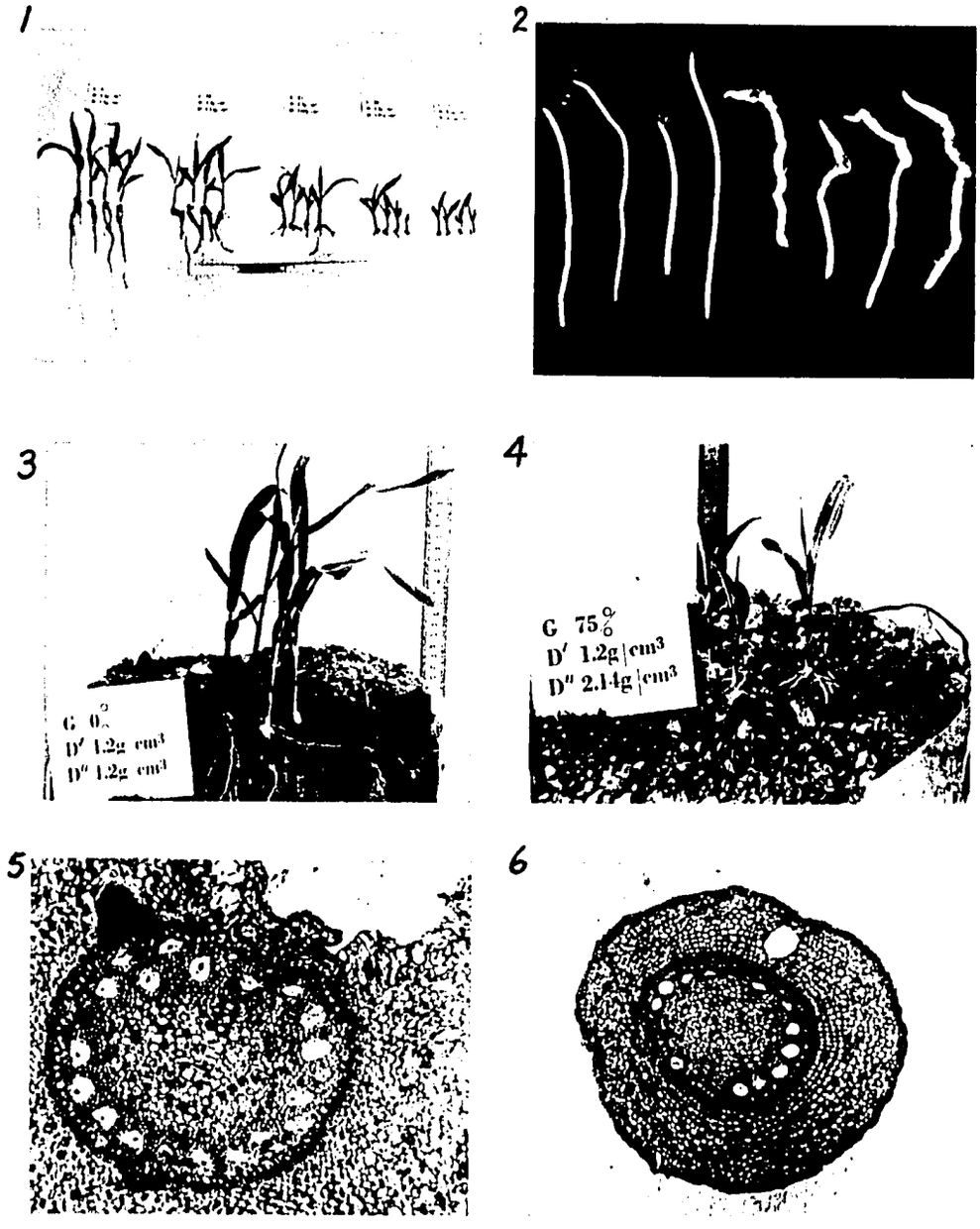

Plate 1.

1. Effect of gravel concentration on root and shoot development of maize seedlings.
2. Normal root tips as compared to root tips from gravelly horizon.
3. Maize seedlings growing in non-gravelly soil.
4. Maize seedlings growing in a gravelly soil.
5. Cross-section of an impeded root tip from the gravelly horizon.
6. Cross-section of a normal root tip.

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