

Effect of soil compaction due to levelling on the growth and development of maize (*Zea mays*) on a reddish-brown earth soil

S. KATHIRAGAMATHAIYAH AND S. NAGARAJAH

Central Agricultural Research Institute, Peradeniya, Sri Lanka

(Received September, 1971)

INTRODUCTION

In a N P fertilizer trial with maize at Maha Illupallama conducted in the Yala season of 1970 it was observed that growth of plants was widely different in the four replicates of the experiment (plate 1). There was heterogeneity in growth even within plots. The experimental site was previously levelled using heavy machinery such as D4 tractors and earth movers. Foreground on Plate 1, gives an idea of the extent of levelling and earthwork involved. According to the detailed soil survey map of the Maha Illuppallama Farm, three replicates of the N P experiment were on Aluthwewa well drained soils and the fourth replicate happened to be on Divuluwewa moderately well drained soils. The boundary of these two soil series appear to be somewhere between the 3rd and 4th replicates of the experiment. Both these soils belong to the Reddish-Brown Earth Great Soil Group. The seriousness of the problem may also be seen from Plate 2 where rows of sorghum only a few feet apart were not uniform in their stand. The sorghum plot was in the area adjoining the maize experiment. Similar heterogeneity was also observed in other highland crops in the adjacent areas. The maize in the experimental plots as well as the other highland crops were grown in Yala 1970 under irrigation. There was no evidence of either short supply of water or any drastic differences in the drainage of the four replicates. The maize plots of the fertilizer trial had treatments with adequate or high supply of N, P, and K. The problem therefore appeared to be neither fertility nor shortage or excess of water. Hence it was suspected that the limitation in growth of maize plants may be due to some soil physical property.

High compaction has been reported to cause or be related to reduced productivity in many soils (Rosenberg, 1964). Adams *et al* (1961) reported that maize on a compacted soil matured more slowly than on an uncompacted soil. Compaction of soils, may be due to (a)

genetic factors or (b) use of heavy machinery in tillage land levelling and other vehicular traffic. It is the latter type of compaction which is of interest to us in Sri Lanka in view of the opening up and levelling of lands using heavy machinery in the Mahaweli and other river valley development schemes.

Soil physical factors that control root growth at a given temperature are (1) mechanical resistance of the soil, (2) water supply and (3) aeration (Barley and Graecen, 1967). Soil compaction causes two main effects that are detrimental to root growth. In the first instance it increases the mechanical impedance to root growth and secondly it changes both the pore volume and pore size distribution of the soil. Decreased pore volume decreases aeration or more strictly the oxygen diffusion rate (O.D.R.). Change in pore size distribution affects moisture availability. The effect of compaction on thermal conductivity of soils may not be of much practical significance under the climatic conditions in Sri Lanka.

Mechanical impedance has often been measured by penetrometer or bulk density data. Philips and Kirkham (1962) observed that the rate of elongation of roots of corn seedlings decreased linearly with increased bulk density and with decreased depth of penetration of penetrometer needle. Bertrand and Kohnke (1957) reported that corn roots did not penetrate when a clay loam was compacted to a bulk density of 1.5 g/cc. The critical bulk density however varies with the crop and nature of the soil. It is generally believed that a bulk density of 1.6-1.7 g/cc. is the critical limit on heavy soils (Rosenberg, 1964).

The effect of compaction on the pore volume and pore size distribution has been observed in many soils. Kaiser and Kunze (1968) observed that compaction decreased the volume of air in all the soils used in their experiments. The decrease in porosity inhibited or reduced root growth. Lutz (1952) in an exhaustive review summarized that compaction not only decreases the total pore space but also reduces the size of the pores. This particular aspect has an important bearing on the plant available water in soils. de Haan *et al* (1970) reported that compaction caused by D4 caterpillar tractor resulted in decreased pore volume and saturated hydraulic conductivity. Sokolovskaya (1967) showed that compaction increased the content of unavailable water per unit volume. He attributed this to the increase in the solid phase per unit volume of the soil and thus increasing the bound water which is unavailable. Ivanov and Stoiner

(1967) too reported that unavailable moisture increased with increasing compaction. However, it must be pointed out that there are a few reports which indicate that compaction increases available water especially in sands. Heinonen (1954) investigated the above phenomenon on a large number of Finnish soils and concluded that bulk density is correlated with available water of sands positively and negatively in other textures.

Bateman (1963) observed reduction in corn yield on a silty clay loam when the porosity decreased from 22 per cent. to 11 per cent. by compaction. A quantitative estimate of aeration is made nowadays by measuring the oxygen diffusion rate (O.D.R.) (Rosenberg, 1964). It was reported that generally soil oxygen diffusion rate was greatly reduced by compaction (Rosenberg, 1964). Since porosity and bulk density are closely related the effects observed on soils due to bulk density variation would also apply to variation in porosity.

In the light of the literature cited above, it was hypothesized that soil compaction caused by levelling by heavy machinery possibly under unsuitable moisture conditions led to the stunting of maize (Plate 1), sorghum (Plate 2) and other highland crops grown under irrigation at Maha Illuppallama. The following describes the experiments and observations carried out to test the above hypothesis.

MATERIAL AND METHODS

Field determinations

Representative maize plants (Veracruz 181 x Antigua 2-1A) from the stunted and non-stunted areas were uprooted by digging the soil around the plants to a depth of about 2 feet. The roots were washed free of soil and the dry weight determined. Core samples were taken from two representative locations of each replicate of the NP trial for bulk density determination (Black, 1965). Samples were taken at depths of 0-5, 15-20 and 30-35 cm. Moisture percentage of the samples was also determined.

Plant growth experiment

Soil from the four replicates were taken to a depth of 35 cm. for growing maize (Veracruz 181 x Antigua 2-1A) in green house. Pits were dug and soil filled in glazed pots (20 cm. diameter) in the same horizon sequence as existed in the field. The compacted soil was loosened by hand before filling into the pots. Each pot contained

10 Kg. soil. Four maize seeds of the variety Veracruz 181 \times Antigua 2-1A were dibbled into the pots and the soil was maintained approximately at field capacity. Sufficient NPK fertilizers were added to the pots. Plants were thinned to one per pot at the end of 10 days. After six weeks of growth the plants were uprooted and roots washed free of soil. The plant height and root weight (dry) were determined.

RESULTS

Plants in the second, third and fourth replicates were stunted compared to those in the first replicate of the NP experiment. Replicates 1 and 2 were in one liyadde and replicates 3 and 4 were in another liyadde adjoining replicates 1 and 2. (A uniform basal application of K was given to all plots). The root system was not well developed and maturity delayed in the stunted plants (Plates 3 and 4). It is of interest to note that there was no silk emergence in the stunted plants irrespective of fertilizer treatment. Root weights (Table 1) show the wide disparity in the root development in areas which were only a few feet apart.

TABLE 1.—Root Weights (g) (Dried at 105° C)

	$N_3 P_3^{**}$		$N_0 P_0$	
Non-stunted	..	100.4	..	20.9
Stunted	..	19.3	..	6.1

** N_3	=	120lb. N/ac.
N_0	=	No N fertilizer
P_3	=	120lb. P_2O_5 /ac.
P_0	=	No P fertilizer

TABLE 2—Soil Analysis Data

	R_1	R_2	R_3	R_4
pH	.. 5.8	.. 5.6	.. 5.6	.. 5.7
N (%) Total	.. 0.17	.. 0.18	.. 0.14	.. 0.20
P (lb. P_2O_5 /ac., Olsen's)	.. 27	.. 18	.. 2.5	.. 27
K (m.e.%, Exchangeable)	.. 0.7	.. 0.7	.. 0.5	.. 0.5
O.M. (%)	.. 2.6	.. 2.6	.. 1.5	.. 2.3

Soil analysis data indicated (Table 2) that there was no significant difference in fertility of the sites studied.

EFFECT OF SOIL COMPACTION ON GROWTH OF MAIZE

TABLE 3.—Bulk Density (g/cc)

Depth (cm.)	R_1		R_2		R_3		R_4	
	A	B	A	B	A	B	A	B
0-5	1.44	1.42	1.34	1.48	1.22	1.22	1.28	1.44
15-20	1.44	1.49	1.55	1.51	1.66	1.62	1.52	1.53
30-35	1.54	1.48	1.60	1.57	1.63	1.65	1.53	1.60

* R_1 , R_2 , R_3 and R_4 refer to replicate in the NP experiment and A and B refer to the 2 Samples taken from each replicate.

Bulk density data clearly showed (1) an increase in bulk density down the profile and (2) the soils of replicates 2, 3 and 4 at depth of 15-35 cm. had higher bulk density than replicate 1 (Table 3). The latter order agreed closely with the observed general stand of the maize crop. However, as could be seen from these figures compaction was not uniform both between and within replicates. This trend was also reflected in the stand of the crop.

The core samples for bulk density determination were taken 2 days after irrigation and the soils were approximately at field capacity. Air porosity and moisture content were also calculated (Tables 4 and 5). Air porosity values also showed a decrease down the profile and this was very marked in R_2 , R_3 and R_4 . The Munsell colours of core samples are shown in Table 6. Soils in replicates 1, 2 and 3 appeared to be of the same colour, but soils of replicate 4 was slightly different in colour.

On loosening the soil, maize plants grew equally well on all soils (Plate 5) and the root development was also remarkably good (Plate 6). There was hardly any difference in the heights and root weights (Table 7).

TABLE 4.—Air Porosity* (%) at Field Capacity

Depth (cm.)	R_1		R_2		R_3		R_4	
	A	B	A	B	A	B	A	B
0-5	14.1	13.1	13.2	11.3	12.7	26.9	25.4	9.3
15-20	8.8	12.8	11.3	19.9	5.1	7.9	13.8	8.6
30-35	10.5	12.9	9.3	7.3	4.7	6.6	12.9	5.9

* The conventional value of 2.65 was used for particle density in the calculations.

TABLE 5.—Moisture Content at Field Capacity (g/100g)

Depth (cm.)	R ₁		R ₂		R ₃		R ₄	
	A	B	A	B	A	B	A	B
0-5	.. 16.5 (26.1) *	.. 19.4 (27.5)	.. 19.8 (26.4)	.. 22.3 (32.9)	.. 34.0 (41.4)	.. 22.3 (27.1)	.. 20.6 (26.3)	.. 25.1 (36.3)
15-20	.. 18.8 (30.3)	.. 20.9 (31.1)	.. 19.3 (30.0)	.. 21.9 (33.1)	.. 19.6 (32.5)	.. 19.2 (31.1)	.. 18.9 (28.7)	.. 20.1 (31.8)
30-35	.. 18.7 (29.6)	.. 22.3 (31.4)	.. 18.9 (30.3)	.. 21.3 (33.5)	.. 20.6 (33.7)	.. 18.8 (31.0)	.. 19.2 (29.4)	.. 21.0 (33.7)

* Figures in parantheses are volumetric moisture contents.

TABLE 6.—Munsell Colours of Soils

Depth (cm.)	R ₁		R ₂		R ₃		R ₄	
	A	B	A	B	A	B	A	B
0- 5	..5yr. 4/6	..5yr. 4/6	..5yr. 4/4 -4/6	..5yr. 4/4	..5yr. 4/4	..5yr. 4/4	..5yr. 4/4	..5yr. 4/4 -3/4
15- 0	..5yr. 4/6	..5yr. 4/8	..5yr. 4/6	..5yr. 4/6	..5yr. 4/4	..5yr. 4/6	..5yr. 4/6	..5yr. 4/4 -4/8
30-35	..5yr. 4/6	..5yr. 4/8	..5yr. 4/8	..5yr. 4/8	..5yr. 4/4	..5yr. 4/6	..5yr. 4/4	..5yr. 4/4 -4/8

TABLE 7.—Height and Root Weight (dry) of Maize Grown in Greenhouse on Loosened Soil

	Height (cm.)	Root Weight (g)
R ₁	.. 150	.. 11.3
R ₂	.. 155	.. 8.8
R ₃	.. 160	.. 7.7
R ₄	.. 152	.. 8.0

DISCUSSION

Data presented in the earlier section (Tables 3 and 4) show that a physical non-uniformity in the soils has been brought about by compaction. The bulk density values at 30-35 cm. depth are almost in the critical range reported for impedance to root penetration (Rosenberg, 1964). A state of compaction is very evident at depths 15-35 cm. in R₂, R₃ and R₄. Lower bulk density values for the top soil is

probably due to tillage operations. Poor root penetration and secondary root development of highland crops at Maha Illuppallama have also been observed by other agronomists (ECI, Summary Progress Report on the Mahaweli Development Project 1, 1970). They suggested that this poor root growth was due to the soil characteristic known "firmness in place", which the present authors believe is synonymous with soil compaction. Bulk density data at depths 15-35 cm. reported in this paper are higher than those reported for similar soils in the report cited above (ECI, 1970). The porosity values at 15-35 cm. depth are also on the minimal side compared to values like 20% reported in the literature for optimal growth of maize (Table, 1966).

The greenhouse experiment on the loosened soil proved that the observed stunting was caused by soil compaction. It should also be mentioned that even though the greenhouse experiment was not replicated, the observations were quite clear to make the above mentioned inferences.

The drainage characters of the soil in R_4 (Divuluwewa, moderately well drained) were not as good as in the first three replicates. The difference was reflected in the colour of the soils (Table 6). The present authors are quite aware of the fastidiousness of maize to drainage conditions, but the good growth in the green house experiment on R_4 soil shows that the main factor involved is soil compaction. It is possible that slight difference in drainage may also have been superimposed on the effect of compaction. It is highly unlikely that there would have been any major difference in the drainage of soils of the first three replicates, or in the rows of sorghum plot which were only a few feet apart (Plates 1 and 2). The question may be asked "why R_2 , R_3 and R_4 were compacted more than R_1 ". This is possibly due to the variations in the amount of cutting and levelling done in that area. It may be that the heavy machinery moved less number of times on R_1 than on others.

It is not possible to say from this investigation whether increased mechanical strength or decreased aeration and water availability as a result of compaction was the major limiting factor on the growth of maize. Bulk density data have been used in this paper as a measure of compaction, however hydraulic conductivity has also been

used by others to measure the same effect (Rosenberg, 1964). In the context of the effect of compaction on available water it may be appropriate to quote Marshall (1959) who said "the actual amount of water covered by the available range depends on structure rather than texture—the total volume of pores which are of the right size to be full at field capacity and empty at permanent wilting point". It is the structure and pore size distribution which are primarily affected by compaction. The degree of aeration could be quantitatively measured by oxygen diffusion rate (O. D. R.) measurements. Any change in water availability can be ascertained by constructing the water retention or moisture characteristics curve of the compacted soil and a virgin counterpart. These two investigations are necessary to determine the exact effect of compaction on these soils.

Land levelling may be inevitable under certain irrigation systems. But compaction may be reduced to a minimum by carrying out the operations under suitable conditions. Baver (1965) stated that peak compaction occurred at moisture contents near the lower plastic limit. Avoiding such moisture conditions would be a practical way to minimize compaction. Deep tillage and subsoiling have been done to counteract the effects of soil compaction and promote root penetration and distribution (Baver, 1965, Gliemorth *et al*, 1968). In the light of the data and discussions presented here, the authors feel that any experimental result obtained on levelled sites at Maha Illuppallama without due consideration to the non-uniformity created by compaction, may be of questionable validity.

SUMMARY

An investigation was carried out to determine the cause of stunting of maize on a levelled site at Maha Illuppallama. Determination of bulk density and calculation of air porosity showed that heterogeneity in the soil was brought about by compaction. The results of a greenhouse experiment with loosened soils confirmed that compaction was the cause of poor growth and poor root development of maize.

ACKNOWLEDGMENT

The authors express their sincere thanks to Messrs. K. B. Alahakoon and R. P. Goonetillake for the photographs and Mr. M. M. M. Jauffer for typing the manuscript.

LITERATURE CITED

1. ADAMS, E. P., BLAKE, G. R., MARTIN, W. P., and BOELTER, D. H. 1961. Influence of Soil Compaction on Crop Growth and Development. *Trans. 7th Int. Congr. Soil Sci. Madison Wisc.* Vol. 1 : 607-615.
2. BARLEY, K. P. and GRAEACEN, E. L. 1967. Mechanical Resistance as a Soil Factor Influencing the Growth of Roots and Underground Shoots. *Advan. Agron.* 19 : 1-40.
3. BATEMAN, H. P. 1963. *Trans Am. Soc. Agr. Engrs.* 6 : 19-25.
4. BAVER, L. D. 1965. *Soil Physics.* John Wiley and Sons. N. Y. 3rd Edition.
5. BERTRAND, A. R., and KOHNKE, H. 1957. Subsoil Conditions and Their Effects on Oxygen Supply and the Growth of Corn Roots. *Soil Sci. Soc. Am. Proc.* 21 : 135-140.
6. BLACK, C. A. 1965. Methods of Soil Analysis Part I. *Agronomy 9, Amer. Soc. Agron. Madison, Wisc.*
7. DE HAAN, F. A. M., VALK, G. and VANDER, M. 1970. Relationship between Soil Compaction and Ground Water Regime in Bulb Culture. *Soils and Fertilizers 33 : Abs. 1117.*
8. ECI, Summary Progress Report on the Mahaweli Ganga Development Project I, Stage I. 1970. Engineering Consultants Incorporated, Denver, Colorado, U. S. A.
9. GLIENMORTH, G., KARNT G., and SIDIRAS, N. 1968. Effect of Subsoil Compaction on Root Growth and Nutrient Economy. *Soils and Fertilizers 31 Abs. 4089.*
10. GRABLE, A. R. 1966. Soil Aeration and Plant Growth. *Advan. Agron.* 18 : 57-106.
11. HEINONEN, R. 1954. Moisture Conditions in Finnish Top Soils. *Agric. Res. Centre, Dept. Soil Sci Helsinki, Agrogeol, Pub. 62.*
12. IVANOV, A., and Stoiner, K. 1969. Effect of Soil Compaction on Soil Fertility and Content of Unavailable Moisture. *Soils and Fertilizers 32 : Abs. 292.*
13. KAISER, M. and KUNZE, A. 1969. Effect of Bulk Density of Different Soil Types on Some Physical Properties of Soil and Development of Winter Rye. *Soils and Fertilizers 32 : Abs. 2765.*
14. LUTZ, J. F. 1952. Mechanical Impedance and Plant Growth. In B. T. Shaw ed., *Soil Physical Conditions and Plant Growth. Agronomy 2 : 43-71 Academic Press, N. Y.*
15. MARSHALL, T. J. 1959. Relations Between Water and Soil. *Tech. Com. No. 50 Commonwealth Bureau of Soils, Harpenden, England.*
16. PHILIPS, R. E. and KIRKHAM, D. 1962. Soil Compaction in the Field and Corn Growth *Agron. J.* 54 : 29-34.
17. ROSENBERG, N. J. 1964. Response of Plants to the Physical Effects of Soil Compaction *Advan. Agron.* 16 : 181-196.
18. SOKOLOVSKAYA, N. A. 1967. Effect of Soil Compaction on Size Distribution of Pores and Hydrophysical Properties. *Soils and Fertilizers 32 : Abs. 291.*



PLATE 1. (top).—Uneven growth of maize in the 4 replicates of the N P experiment. (Left to Right).— R_4 , R_3 , R_2 and R_1 .) The two persons standing at the two extremities are of the same height. Note the amount of earth cutting, levelling and moving involved in the foreground.

PLATE 2. (bottom).—Uneven growth of sorghum, the rows were only a few feet apart.

EFFECT OF SOIL COMPACTION ON GROWTH OF MAIZE



PLATE 3(left).—Difference in the growth, root development and maturity of fully fertilized plants from the stunted (right) and unstunted (left) areas.

PLATE 4 (right).—Difference in the growth, root development and maturity of non-fertilized plants from the stunted (right) and unstunted (left) areas.

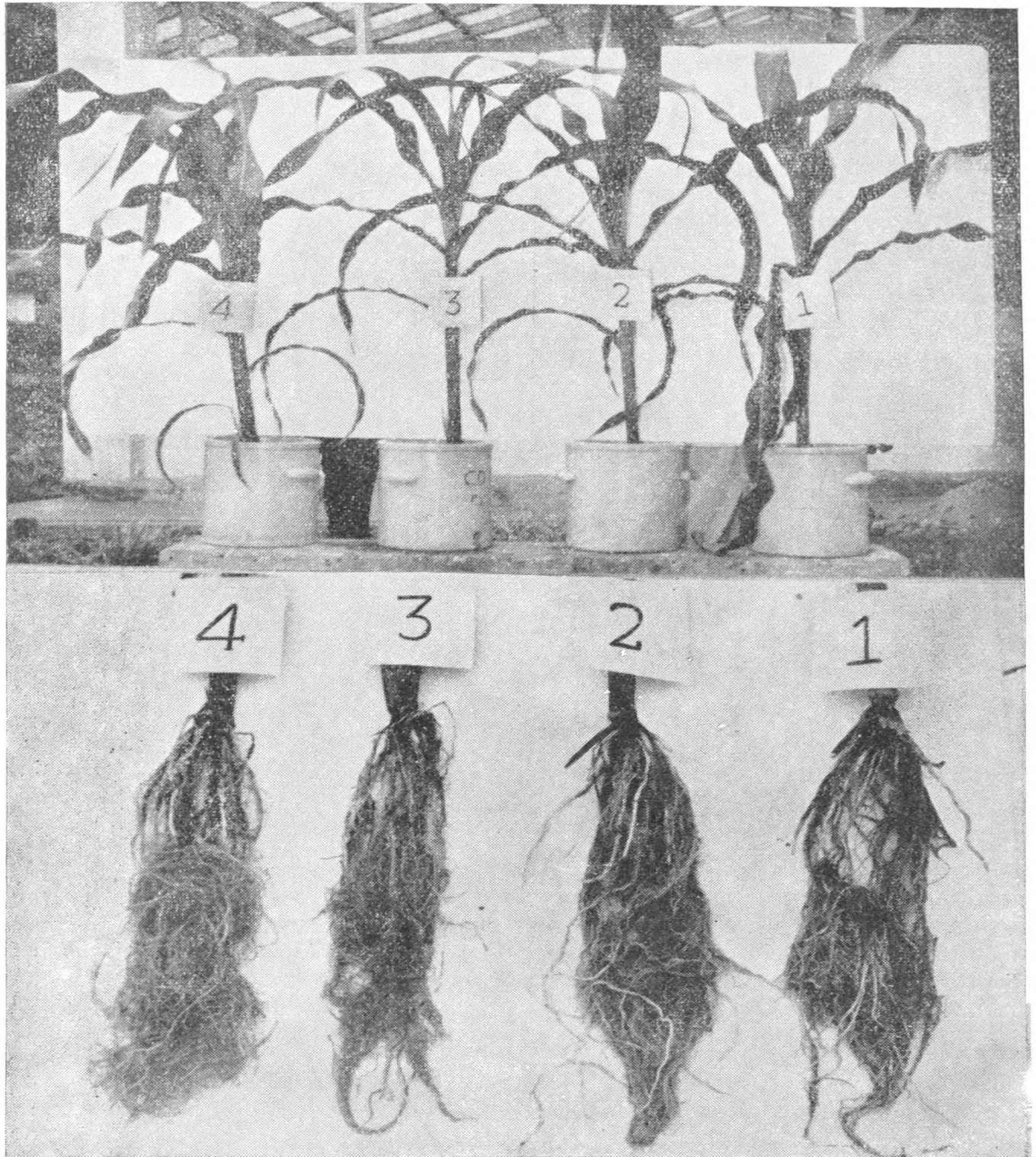


PLATE 5 (top)—Maize grown in greenhouse on loosened soil from the four replicates in the N P experimental area. (Note the almost even growth.)

PLATE 6 (bottom)—Root development of maize grown in greenhouse on loosened soil from the four replicates in the N P experimental area. (Note the equally good root growth in all cases.)