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Influence of Certain Soil-Profile Characteristics upon the Distribution of Roots of Grasses[1]

R. L. Fox, J. E. Weaver and R. C. Lipps[2]

A METHOD has been devised by Weaver and his co-workers (15) by which a root system may be sampled from the soil surface to a depth of maximum root penetration. The root system may then be separated from the soil without vertical displacement, photographed, and compared with soil profile characteristics. In the present investigation an attempt has been made to relate some chemical and physical properties of the soil to root distribution.

REVIEW OF LITERATURE

The roots of many grasses normally reach a depth of 4 to 8 feet in Chernozem and Prairie soils (13, 14). Their ability to absorb both water and nutrients from great depths has been demonstrated (3, 6). The upper soil layers, of course, are especially important since here have occurred most of the changes resulting from centuries of plant growth. However, the importance of the subsoil is demonstrated by the relatively great quantity of roots found there. An oven-dry weight of more than 300 pounds per acre of grass roots alone has been found in the fourth foot of unbroken bluestem-prairie soil in eastern Nebraska. Large amounts of legume roots, with abundant nodules, and roots of other prairie forbs were also present.

While the roots of native grasses are somewhat shallower in the more adequately watered prairies of Illinois (11) than in the eastern areas of Nebraska, and are relatively very shallow in the Podzolic soils eastward (12), an even greater depth of penetration has been found in the deep, readily permeable, loessial soils of central Nebraska (5).

It was early recognized that the importance of the subsoil in supporting plant growth varies with the conditions under which the soil developed. Alway *et al.* (2) cite references to the relative unproductivity of humid subsoils compared with more arid ones. They explained this unproductivity as a lack of available phosphorus or potassium or both.

A considerable body of information has been accumulated on the effects of physical properties of the soil on root development (9). It is well known that zones of compaction and relatively impervious horizons may act as physical barriers to root penetration. Total pore space and size of pores are known to affect moisture availability and gaseous diffusion. The relative concentrations of oxygen and carbon dioxide, modified by soil temperature, as these affect total plant growth and root distribution have been investigated. Soil aeration may influence the degree of branching, length, thickness and extent of surface of roots and the production of root hairs.

The influence of soil horizons on root distribution of trees seems better understood than similar effects upon grass. Lutz *et al.* (8) present a thorough review of previous work on forest and fruit trees and the effects of soil aeration, soil temperature, texture, structure, acidity, and nutrient relations on root distribution. They found root development was better in horizons having relatively higher clay content, which increased total exchange capacity and resulted in a greater quantity of exchangeable bases.

Sprague (12), working with a Podzolic soil in New Jersey, attempted to correlate root occupation of the several soil layers with their specific soil properties. Practically all of the roots of the six perennial grasses used occurred in the upper 9 inches of soil, their abundance decreasing rapidly with depth. He found no correlation between root depth and organic carbon content of the soil, but ascertained that decreased root development, below the 6-inch layer, was associated with greater soil acidity and less organic matter and available phosphorus. Gist and Smith (4) sampled several common forage grasses in West Virginia to a depth of 18 inches. They found that a decrease in soil organic matter with depth was accompanied by a decrease in root weight and an increase in volume-weight.

Weaver *et al.* (16) found, in grassland soils of Nebraska, an approximate linear relationship between the amount of root material and the amount of organic matter in the various soil horizons to depths of 4 to 7 feet. This did not indicate that root distribution is a function of organic matter content but rather that organic materials had accumulated in larger quantities at those depths where the roots had been most concentrated.

Fertilizers often tend to concentrate root development in the region of placement and a single small rootlet which penetrates a zone well supplied with nutrients may develop into a mass of roots. It is logical to assume that the fertility level of the soil will be reflected by root concentration whether the nutrients are supplied artificially or are naturally present.

A study of the profile characteristics of two soil series used in this investigation, Crete and Butler, has been made by Smith and Rhoades (10). Marked variation in profile characteristics and abrupt boundaries between horizons especially with regard to physical properties were found. Greatly reduced pore space occupied by air at approximate field carrying capacity was noted in both of these soils. The phosphorus status of these soils has been studied by Allaway and Rhoades (1) and Lipps and Chesnin (7). Regions of restricted phosphorus solubility were found in the A_2 and B horizons.

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MATERIALS AND METHODS

The root systems used in the present investigation, except for smooth brome, are those excavated by Weaver and Darland (15) and Weaver and Voigt (17). Root systems were obtained, by these investigators, from many soils of widely different profile characteristics. Correlations of soils and descriptions of the profiles were made by James Thorp, W. I. Watkins and B. H. Williams. These data have been presented (15, 17) and are not repeated in this report. Marked variation in root habit of the same species of grass growing in different soils was observed. In some soils there was a gradual decrease of roots with depth; in others, root distribution was greatly retarded in portions of the B horizon, although roots developed abundantly at greater depths. An attempt was made to correlate root distribution with soil environment by observing the color, texture, structure, consistence, and pH of the soils in the various subdivisions of each horizon. This characterization was not sufficiently quantitative and further study seemed desirable.

Soil samples from five sites where roots had been excavated were used for a more detailed study of the relationships between root development and soil properties. Butler silty clay loam, supporting western wheat grass (*Agropyron smithii* Rydb.), was selected because of a very strongly developed claypan and a marked reduction in root distribution in the upper part of the claypan. Two Crete soils with intermediate claypan-like subsoils, one supporting western wheat grass and the other smooth brome (*Bromus inermis* Leyss.), were studied because of variations in root distribution between the two profiles. A Judson silt loam soil, developed on colluvial material of loessial origin, and a Carrington silty clay loam, developed from highly weathered glacial drift, were selected to compare root development of Kentucky bluegrass (*Poa pratensis* L.). Neither of these soils had a pronounced horizon of clay accumulation.

Trenches from which the roots were previously obtained were reopened and soil samples were taken from the undisturbed walls. Samples were obtained by 4-inch increments except for two in the B horizon of the Butler soil which were taken by 6-inch increments. Volume-weight was determined by sampling a known volume of soil at field moisture content. An exception was the Butler soil where volume-weight was determined from paraffin-coated air-dry clods. Mechanical analysis was made using the hydrometer method. Specific gravity on each sample was ascertained and percentage of the total pore space was calculated. Phosphorus was extracted with Bray's extracting solution (0.03 *N* NH_4F in 0.025 *N* HCl). Cation exchange capacity was measured by a Kjeldahl determination of absorbed NH_4^+ after leaching with neutral normal ammonium acetate. Ions of calcium, potassium and sodium were determined in the ammonium acetate leachate with a Beckman flame photometer. Magnesium was determined by the method of Yien and Chesnin (19), and hydrogen ion by the method of Woodruff (18). The pH was measured with the glass electrode using a 1:1 suspension.

Table 1.—Mechanical analysis, pH, exchangeable cations and cation exchange capacity of Butler, Crete, Carrington and Judson soil profiles.*

Depth (Inches)	Mechanical Analysis			pH	Exchangeable cations, m.e./100g.					Cation exchange capacity m.e./100g.
	% Sand	% Silt	% Clay		Ca++	Mg++	K+	Na+	H+	
Butler silty clay loam (Western wheat grass)										
0– 4	17	55	28	5.5	10.5	2.9	0.8	0.04	5.1	20.1
4– 8	16	44	40	5.7	15.0	3.4	1.1	0.04	3.7	24.3
8–12	10	35	55	5.8	22.9	8.6	1.0	0.46	3.4	37.2
12–16	10	35	55	5.8	31.7	8.2	1.2	1.25	1.9	36.3
16–22	11	35	54	6.6	22.5	9.4	1.1	1.25	1.3	36.0
22–28	11	41	48	7.3	23.6	9.8	1.1	1.31	0.0	34.9
28–32	11	47	42	7.6	30.0	9.3	1.0	1.47	.0	29.8
32–36	10	51	39	7.7	27.6	8.7	0.9	1.47	.0	28.1
Crete silt loam (Western wheat grass)										
0– 4	21	54	25	5.6	11.9	6.4	1.7	0.38	4.1	21.5
8–12	10	45	45	5.5	15.6	7.7	0.8	.45	2.1	25.7
16–20	7	43	50	6.4	19.7	7.6	.9	.49	1.0	29.8
24–28	6	51	43	7.7	19.6	9.7	.8	.45	0.0	28.3
32–36	6	57	37	7.7	17.7	9.2	.7	.40	.0	25.7
44–48	5	62	33	7.5	18.3	8.5	.7	.49	.0	24.4
56–60	10	60	30	7.8	20.4	7.2	.7	.54	.0	24.7
68–72	36	41	23	7.7	21.0	7.3	.6	.56	.0	24.6
Crete silty clay loam (Smooth brome)										
0– 4	11	55	34	5.2	11.5	5.3	1.8	0.31	4.6	20.5
8–12	10	52	38	5.3	15.2	7.1	0.8	.37	3.8	24.4
16–20	6	45	49	5.5	18.0	9.5	.8	.45	2.4	30.8
24–28	5	55	40	5.6	18.4	9.4	.8	.45	1.6	28.8
32–36	4	61	35	6.3	17.8	9.3	.7	.47	1.6	23.8
44–48	6	59	35	6.1	18.9	7.9	.6	.43	1.1	22.5
56–60	7	58	35	6.5	20.9	——	.6	.45	0.2	22.1
68–72	6	62	32	7.3	21.0	——	.4	.47	.0	22.3
Carrington silty clay loam (Kentucky bluegrass)										
0– 4	15	52	33	6.0	14.3	5.9	0.6	0.34	3.1	20.9
8–12	15	50	35	5.9	16.3	6.0	.4	.36	2.6	24.0
20–24	24	41	35	6.4	15.0	6.4	.3	.33	2.1	18.4
32–36	24	41	35	6.5	13.9	——	.3	.40	1.0	19.4
Judson silt loam (Kentucky bluegrass)										
0– 4	11	65	24	5.8	15.6	4.8	1.2	0.41	3.6	19.9
8–12	13	59	28	5.9	14.5	5.3	1.0	.24	2.6	19.0
20–24	11	58	31	5.9	14.8	5.1	1.0	.34	2.6	19.4
32–36	11	57	32	5.8	16.9	3.9	0.7	.37	2.6	20.7
44–48	13	54	33	5.9	16.9	——	.7	.39	2.6	21.3

* Complete data for the Butler soil are presented. Only representative depths were selected from the other profiles.

EXPERIMENTAL RESULTS

The extreme variations which occur within certain soil profiles are illustrated by the Butler soil. Two soil properties, soluble phosphorus and percentage pore space, with the associated root distribution, are presented in figure 1. The cation status and mechanical composition at various depths is presented in table 1. Limited root development of western wheat grass in the upper region of clay accumulation was a feature of this profile. A reduction in branching was observed at a depth of 8 inches and extended to a depth of 20 inches. Associated with this was a greatly reduced phosphorus supply and restricted pore space. Increased branching of roots in the lower B horizon (20–28 inches) was associated with an increased percentage of pore space and with a soluble phosphorus content of nearly 2.5 times that present in the region of restricted development. Root weight was one-third greater in the lower B horizon, within the depth of 20 to 28 inches, than the weight of roots from an equal volume of soil in the region of restricted root growth. The root system from the Butler soil was also characterized by limited development in the surface soil. An explanation of this may be found in the very low percentage saturation (about 50) of the soil colloids with calcium. The distribution of total nitrogen in this soil is presented in figure 6. A nearly constant level of nitrogen within the depth of 4 to 22 inches represents an accumulation of organic matter. Unfavorable environmental conditions for biological activity, together with increased surface area due to the concentration of clay may account for this accumulation.

Comparison of Root Systems

Chemical and physical variability of soils within a soil series may be reflected in root distribution. This type of variation is represented by two Crete soils, one supporting smooth brome, the other western wheat grass. A comparison of the root systems of these grasses, together with their respective soil properties, is presented in figures 2, 3, and 6 and table 1. In the soil from which smooth brome roots were excavated the clay content of the surface was greater and, in the A and B horizons, total pore space was somewhat more restricted. Marked differences in soluble phosphorus, pH and total nitrogen were found between these two soils. Much less soluble phosphorus was found in the B horizon of these soils than in the A and C horizons. However, the minimum amount extracted from the B horizon of the soil occupied by western wheat grass was less than one-third of the minimum extracted from the soil from which smooth brome roots were taken. Soluble P_2O_5 decreased from 35 ppm. in the surface of the Crete soil under western wheat grass to 2 ppm. in a zone of restricted root branching. In addition, the zone of greatly reduced phosphorus solubility was much more extensive in the Crete soil under western wheat grass. In this soil, below a depth of 32 inches, the quantity of soluble phosphorus increased very slowly with increasing depth. This trend continued to the maximum depth sampled. Root branching also increased below a depth of 32 inches, but below 44 inches a rather abrupt decrease in branching was evident. Within the depth of 32 to 42 inches, the quantity of soluble phos-

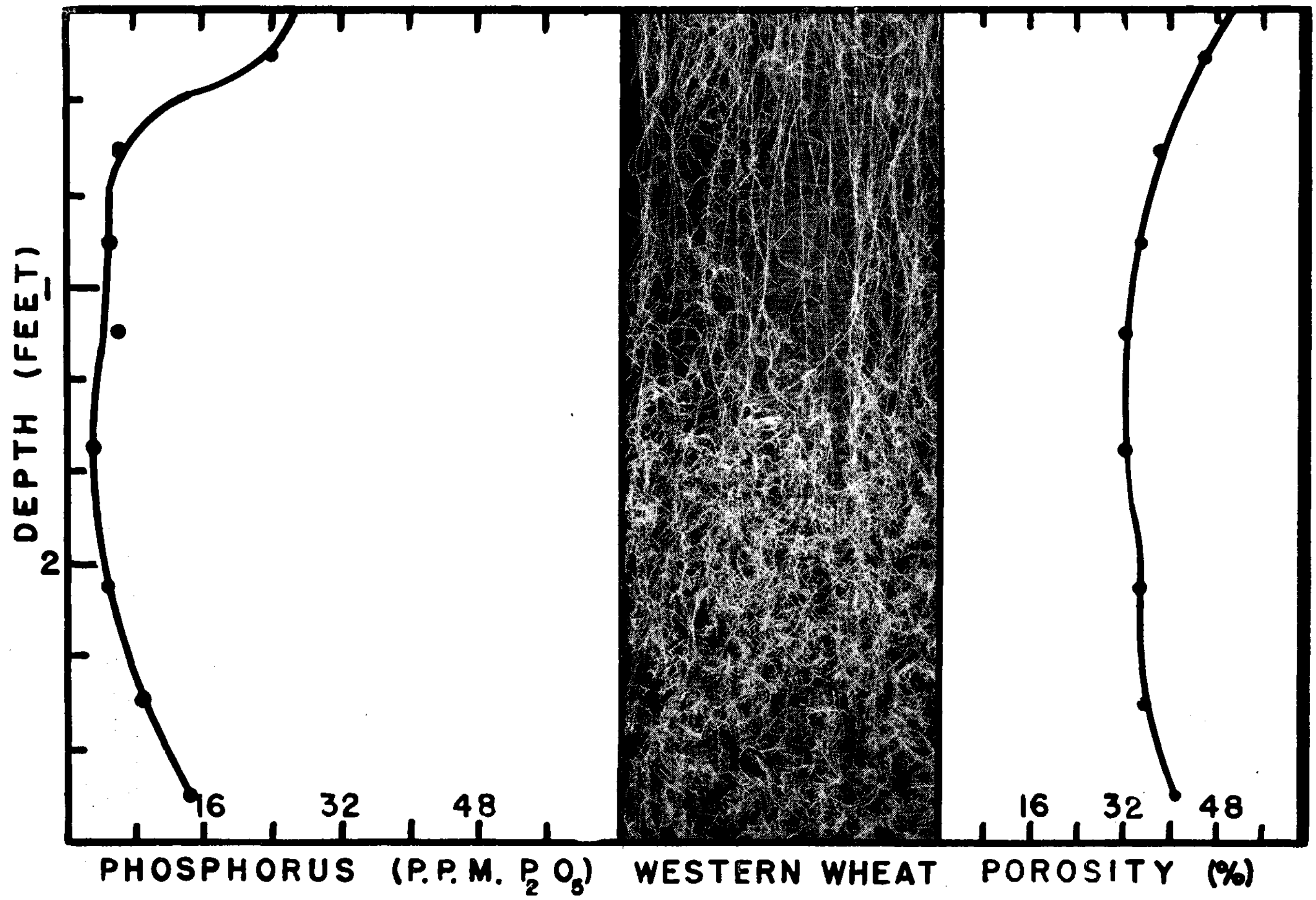

FIG. 1.—Representative root system of western wheat grass taken from a 3-foot monolith of Butler silty clay loam near Carleton, Neb., with associated soil properties—soluble phosphorus and percent total pore space. Root photograph, courtesy of Ecological Monographs, (See Ref. 15, Lit. Cited).

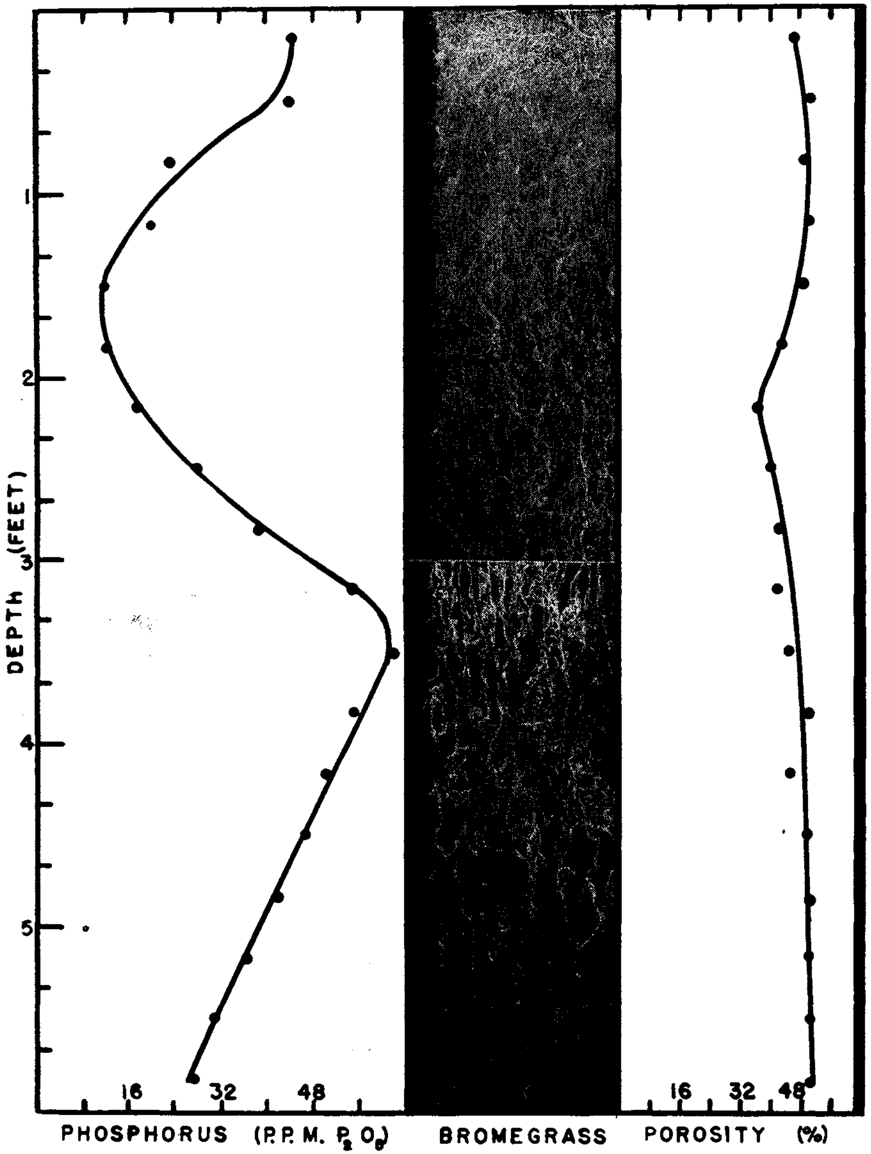

FIG. 2.—Root system of smooth brome from a 6-foot monolith of Crete silty clay loam near Lincoln, Neb., with associated soil properties—available phosphorus and percent total pore space.

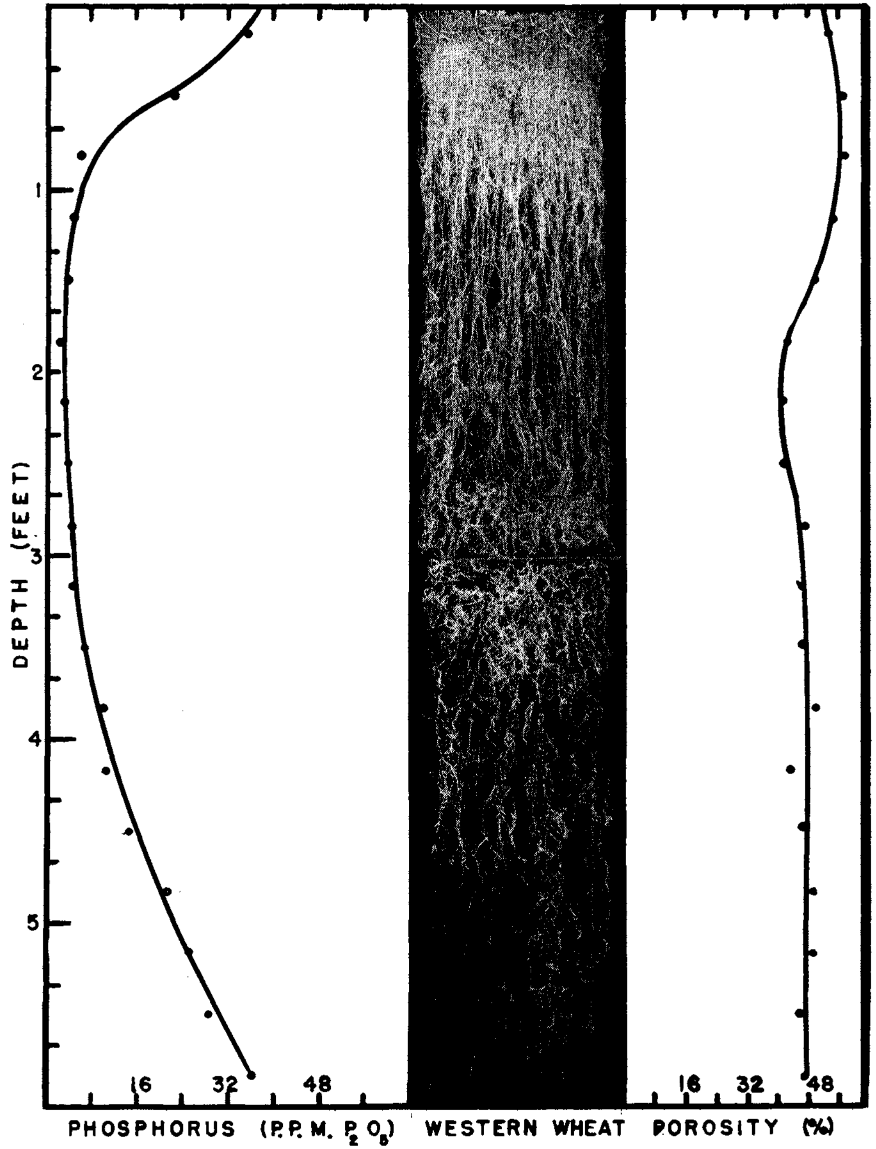

FIG. 3.—Root system of western wheat grass from a 6-foot monolith of Crete silt loam in prairie adjacent to the field of smooth brome shown with two associated soil properties—available phosphorus and percent total pore space. Root photograph courtesy of the Botanical Gazette and The University of Chicago Press, (See Ref. 17, Lit. Cited).

phorus in the Crete soil supporting smooth brome increased greatly. No increased branching was noted in this zone, however, probably because the amount of available phosphorus was relatively high at all depths even in the claypan-like B horizon. Neither was root growth restricted in the zone of reduced pore space and reduced phosphorus availability in this soil.

Effect of Different Soil Types

A comparison was made of the root systems of Kentucky bluegrass in two different soil types, a Judson silt loam and a Carrington silty clay loam (figures 4 and 5). A marked difference in the depth of root penetration, 22 inches in the Carrington and 48 inches in the Judson, reflect wide differences in soil properties. A comparison of physical and chemical properties revealed that the Carrington soil contained a greater content of clay than did the Judson soil, especially in the surface horizon (table 1). Total pore space in the 0–4 inch depth of the Carrington soil was somewhat less than at a similar depth in the Judson soil; but, throughout the remaining depths, percentage pore space and clay contents in the two soils were not greatly different. The total nitrogen content in the Carrington was lower than in the Judson soil. Soluble phosphorus content was extremely low in the Carrington soil; and at a depth of 20–24 inches, which marks the deepest penetration of roots, the level of phosphorus was only one-tenth that at the same depth in the Judson soil.

The Judson soil was well supplied with mineral nutrients at all depths. Although the soil was acid, the exchangeable bases were sufficient for plant nutrition and nitrification of soil organic matter. The total soil nitrogen content was the highest of any of the soils studied (figure 6). The phosphorus level in the surface soil was not so great as in the Crete soils or the Butler soil. However, it was sufficient throughout the profile to promote excellent root development at all depths.

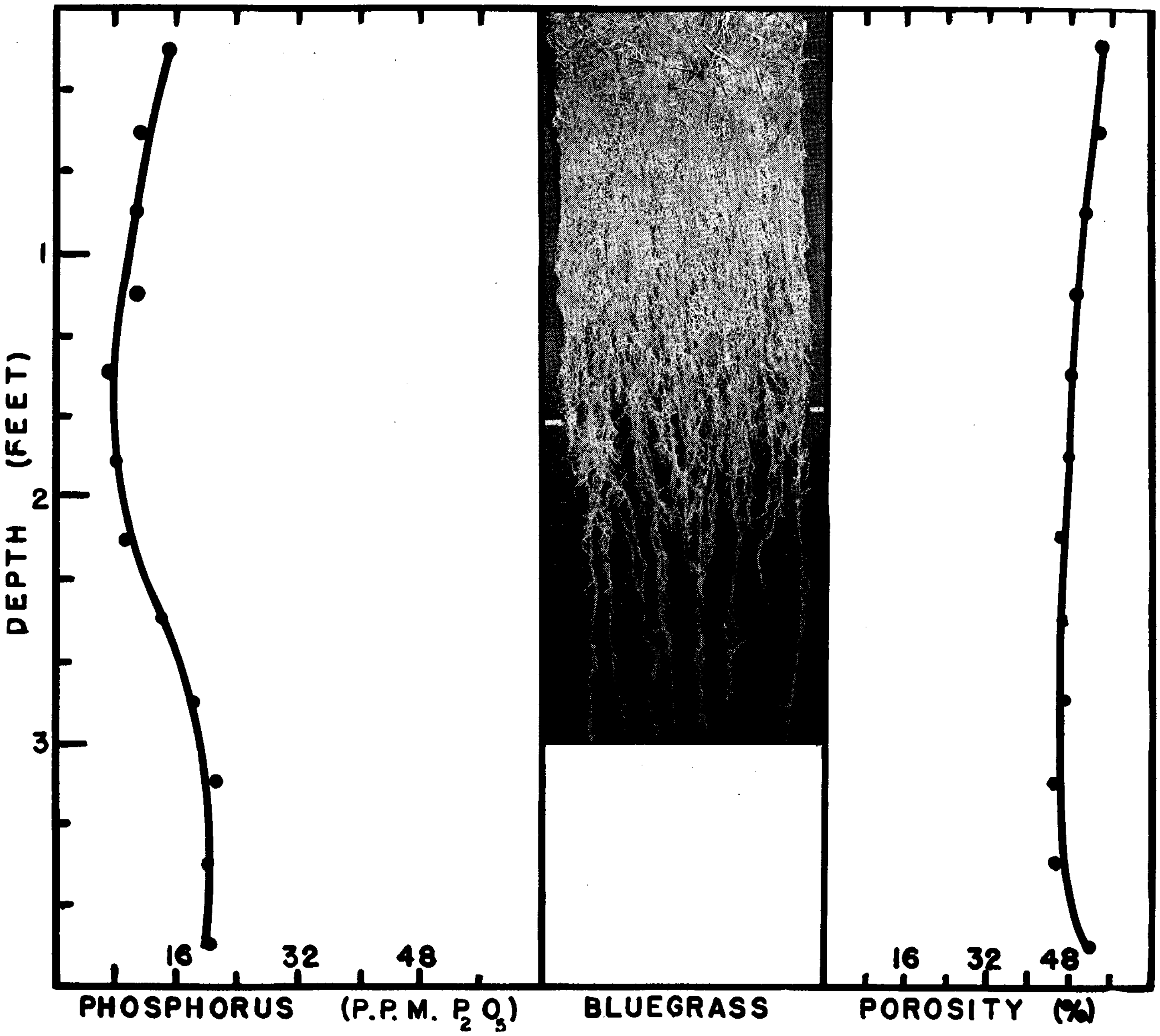

FIG. 4.—Roots of Kentucky bluegrass from a monolith of Judson silt loam obtained near Lincoln, Neb., showing the associated phosphorus level and percent total pore space at 4-inch increments of depth in the profile. Some extremely well branched roots, not included in this photograph, extended to 4 feet. Photograph, courtesy of Ecological Monographs, (See Ref. 15, Lit. Cited).

In the Carrington soil, only the levels of calcium and magnesium appeared to be optimum for root growth. The soluble phosphorus content was extremely low. The exchangeable potassium was lower here than in any other soil studied and it may have been a limiting factor in root growth.

DISCUSSION

The degree of soil development or the depletion of plant nutrients within certain horizons of a soil profile may be regarded as an expression of the varying intensity with which chemical and physical forces have operated at varying depths within the soil. Furthermore, the distribution of plant roots may serve as an index of the degree of soil development or the extent of nutrient depletion.

Soil profile characteristics often vary greatly, and horizon boundaries may be well defined. Under such conditions, variations of environment within the soil are marked. Thus, a deeply penetrating root system throughout its downward course encounters not one but numerous, diverse, environmental conditions. Each partial environment exerts its separate influence. The effects of these different environments on a single, representative root system offer an excellent opportunity for a study of problems relating to the effect of soil environment on root distribution.

Several factors are important in limiting root penetration and branching in claypan or claypan-like soils. Soils with well developed claypans have been subjected to long or intense developmental processes. Phosphorus may be decidedly less available in the zone of clay accumulation than in other soil horizons. This low level of available phosphorus may restrict root development. Significance may also be given to the effect of a highly developed claypan in presenting a physical barrier to root penetration. Perhaps even greater effects may be attributed to its influence upon gaseous diffusion.

The favorable influence of available nutrient cations, especially calcium, upon root development has been reported. In only one of the soils studied (Butler A horizon) was there an indication that the exchangeable calcium was sufficiently low to influence root growth adversely. This effect may have been one of limited calcium as a nutrient or an indirect one in limiting the decomposition of organic matter.

Kentucky bluegrass is often considered a shallow-rooted grass, and under many environmental conditions this may be true. The depth of root penetration of bluegrass in a Carrington silty clay was only 22 inches. In contrast, its roots extended to 48 inches in a Judson silt loam. Roots of blue gramma, *Bouteloua gracilis* (H.B.K.) Lag., growing in association with bluegrass on these two soils, developed in a similar manner (15). Roots of both grasses from Judson soil were more than three times as heavy as those from Carrington soil. A comparison of the quantity of plant

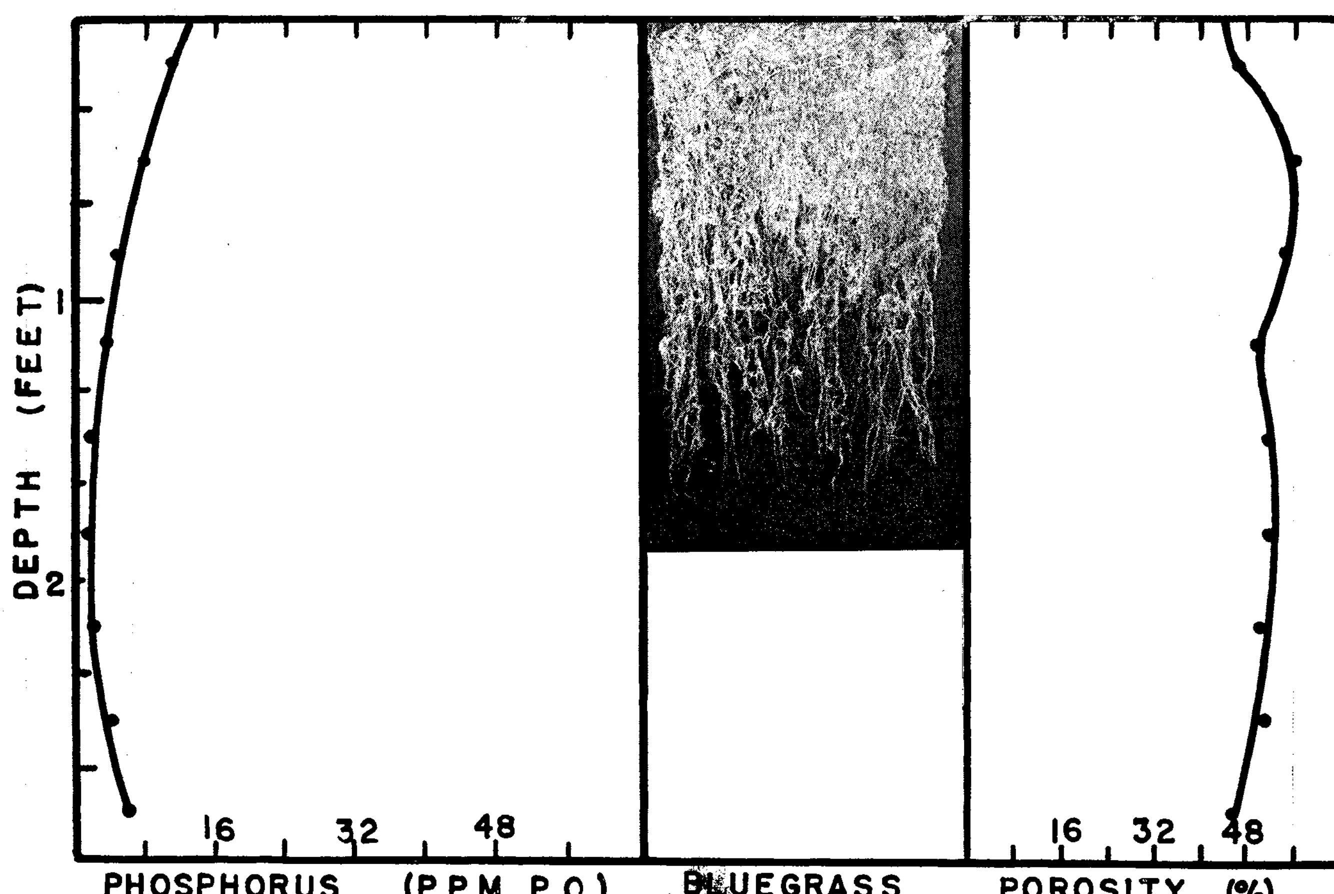

FIG. 5.—Roots of Kentucky bluegrass from a monolith of Carrington silty clay loam obtained near Lincoln, Neb. Maximum root depth is 22 inches. In contrast to the Judson profile the level of available phosphorus is very low at all depths except the surface soil. Oven-dry weight of these roots was less than one-third of those in figure 4. Root photograph, courtesy Ecological Monographs, (See Ref. 15, Lit. Cited).

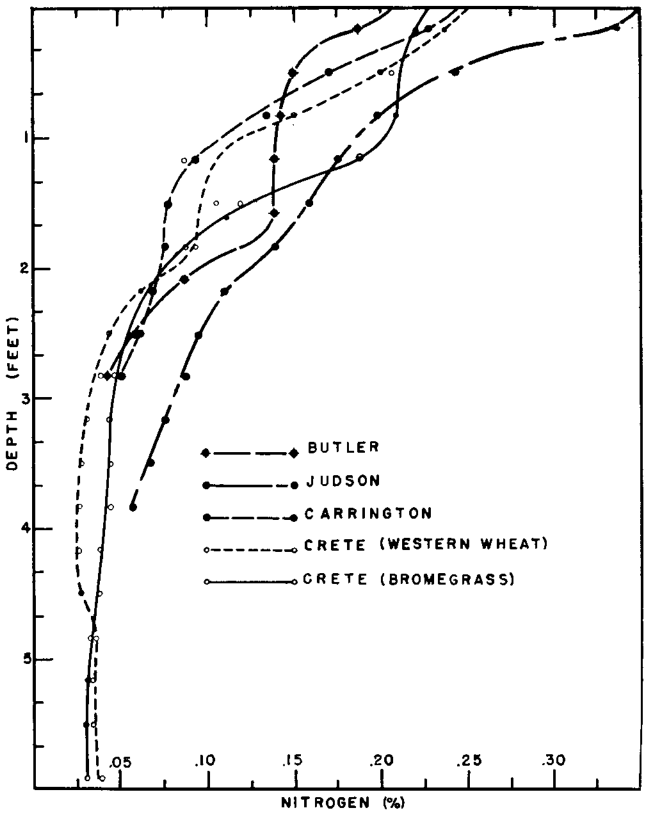

FIG. 6.—Percent nitrogen in five soil profiles as a function of depth.

nutrients available from these soils indicates that the Judson soil, in which bluegrass was deeply rooted, was much better supplied with soluble phosphorus, exchangeable potassium, and total nitrogen. In addition, the percentage of total pore space was somewhat greater in the surface of the Judson soil than in the Carrington soil.

SUMMARY

A study was made of some physical and chemical properties of five Nebraska soils. These properties were related to the distribution of grass roots.

Limited root development in the surface horizon of a Butler soil was associated with low exchangeable calcium and low nitrogen content.

Root branching was restricted in the claypans of a Butler and a Crete soil. Restricted root development in this horizon was related to severe limitations in available phosphorus. Root development was not limited in the B horizon of a second Crete soil characterized by a relatively high level of soluble phosphorus throughout the profile.

Deep rooting of Kentucky bluegrass occurred in a Judson soil which presented a favorable supply of plant nutrients at all depths in the profile. A Carrington soil, deficient in available phosphorus in the subsoil, produced bluegrass with a shallow root system. Exchangeable potassium and soil nitrogen may also have been limiting factors for root development in this soil.

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