Concentration of Soybean Roots in Uppermost Layers of Cerrado Soils of Brazil

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The central plateau area of Brazil, so-called "cerrados", is covered with savannah type vegetation. Cerrado soils belong mostly to Ferralsols[13] and the natural soil fertility is very low due to high acidity and nutrient deficiencies.[10] The rainfall, 1,000 mm to 1,700 mm a year, is unevenly distributed with seven months of rainy and five months of dry season. Although cropping periods of annual crops in cerrado area are generally limited to the rainy season, even in the rainy season irregular short-term droughts, so-called "veranico", lasting for two or more weeks commonly occur, and result frequently in great reduction in yield. This reduction is multiplied by restriction of root distribution in deeper layers and concentration of roots in upper layers of the soils.

In acid soils root development and distribution are impeded by high acidity,[6,11] aluminum toxicity,[4] nutrient deficiency[3,15] and high bulk density[1,16] of the soils. It has generally been considered in cerrados that the root concentration in the upper layers was due to aluminum toxicity associated with the acidity of the soils.[2,9,14] To overcome a limited distribution of roots of annual crops in cerrados a deep incorporation of lime has been recommended.[5]

A series of field experiments on development and distribution of soybean roots was conducted in cerrado area. The initial experiment was carried out to define the characteristics of soybean roots concentrating in the upper layers of the soils in several areas of cerrados. Subsequently, the relationships between distribution of soybean roots and chemical properties and compaction of soils in sequential years of cropping after field reclamation at São Gotardo in Minas Gerais were studied. Finally, the effects of deep incorporation of phosphorus and lime on root development and distribution of soybean plants were examined at the fields of Centro de Pesquisa Agropecuária dos Cerrados (CPAC).

General methods used in these studies were as follows. Observation of root development and distribution: (1) Digging soil blocks of a large volume enough to keep original position of mass roots in the soil with a spade and exposing roots from the soil with a nail, which was mostly employed to observe roughly branching and distribution of the roots. (2) Digging a trench along a row for sampling a soil monolith of profile wall, 10 cm in thickness and 30 cm in depth and washing out roots in their original position from the soil monolith. Soil analysis: Soil samples for chemical analysis were taken from the soils under rows or between rows. After preparation of air-dried fine soil (passed through 2 mm round hole sieve) the soil samples were analyzed. Exchangeable Al and (Ca + Mg) were extracted with *N* KCl and determined by titration with *N*/100 NaOH and by EDTA titration, respectively. Exchangeable K was extracted

Table 1. Percentage of soybean plants with a normal root system depending on the soil type and the year after reclamation

Location	State	Soil type	Years after reclamation	Occurrence of soybean plants with normal root system* (%)
		Cerrados		
Jatai	G O	Helvic Ferralsols	–	42
Colomandel	M G	Helvic Ferralsols	2	38
Paracatu	M G	Helvic Ferralsols	3	35
Araxa	M G	Rhodic Ferralsols	1	75
Araxa	M G	Rhodic Ferralsols	2	43
Planaltina	D F	Helvic Ferralsols	1	86
Planaltina	D F	Rhodic Ferralsols	4	53
Cristalina	G O	Helvic Ferralsols	2	17
		Others		
Londrina	P R	Eutric Nitosols	–	83
Vargem Bonita	D F	Dystric Fluvisols	8	92

* Normal root system has a deeper penetration of tap-roots and better distribution of roots throughout the whole layers of soils.

with Nelson's solution ($0.05N$ HCl + $0.025N$ H_2SO_4) and determined by flame photometric method. Percentage of Al saturation was calculated as the ratio of exchangeable Al to the sum of exchangeable Al and bases. Available phosphorus was determined by Nelson's method.[12] Organic matter was measured by Kosaka's method.[8] Hardness of soils was measured with Yamanaka's hardmeter.[7]

Field survey on the root distribution depending on soil types and conditions

The present field survey aimed at defining the characteristics of soybean root distribution in cerrado soils, i.e. Helvic Ferralsols and Rhodic Ferralsols compared with those in "Terra Roxa", i.e. Eutric Nitosols and Alluvial soil, i.e. Dystric Fluvisols as described in Table 1.

With the exception of soybean plants grown in the first year fields after reclamation, percentages of occurrence of soybean plants with normal root system in the cerrado soils were lower than those in Terra Roxa and Alluvial soils (Table 1). The tap-roots of soybean plants without normal root systems in the cerrado soils did not develop in the deeper layers of the soils and lateral roots with ramification near the surface of the soils grew actively along the soil surface, resulting in a concentration of roots in the uppermost layers. On the other hand, soybean plants grown in the first year fields after reclamation of cerrados showed relatively a deeper penetration of tap-roots and better vertical distribution of root systems although the volumes of roots were rather small. The tap-roots grown in Fluvisols and Nitosols penetrated well into the deep layers of the soils and lateral roots distributed throughout the whole layers as shown in Plate 1.

Influence of years after reclamation on soybean root distribution

In the previous survey attention has been drawn to the restricted tap-root development and sparse root distribution of soybean plants in the deep soil layers of the fields from the second year on after reclamation in cerrado area. The present investigation on

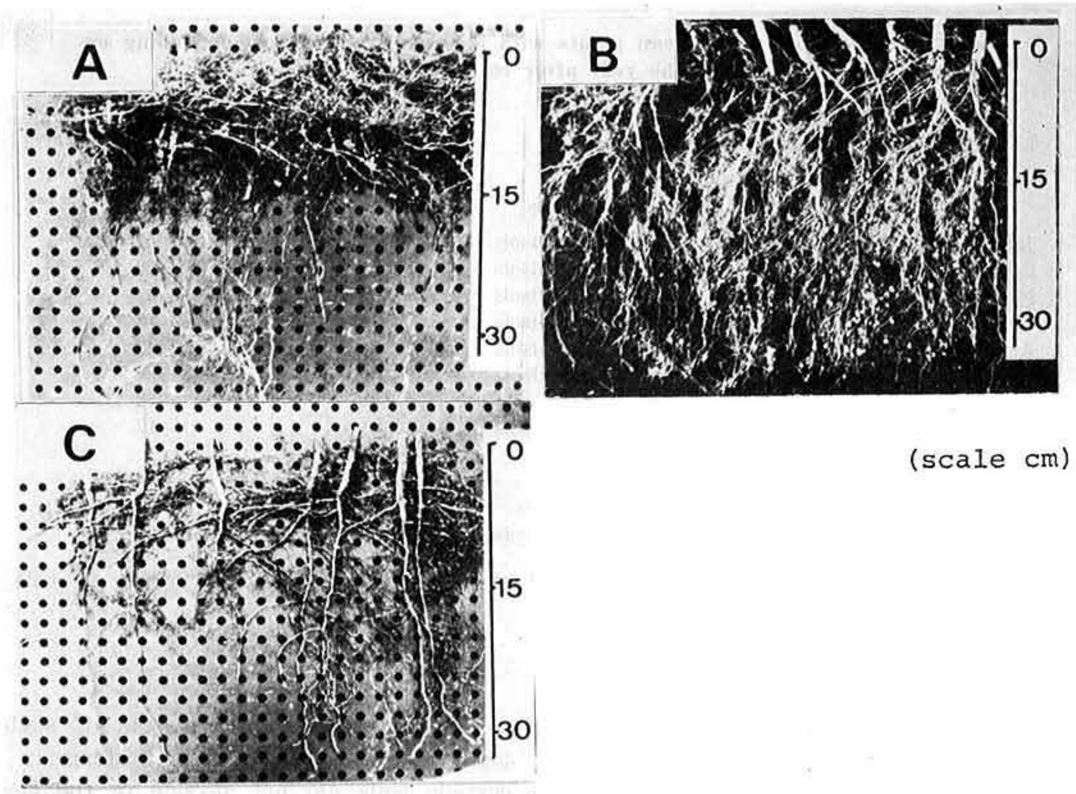


Plate 1. Distribution of soybean root systems in different soils
A: Rhodic Ferralsols at São Gotardo
B: Dystric Fluvisols at Vargem Bonita
C: Eutric Nitosols at Londrina

the relationships between such restriction of tap-root development resulting in concentration of soybean roots in upper layers and soil characteristics depending on the cropped years after reclamation was undertaken at São Gotardo.

As shown in Table 2 and Plate 2 almost all of soybean plants grown in fields one and two years after reclamation had normal root systems, showing the penetration of the tap-roots into the deep soil layers and distribution of the lateral roots throughout the whole soil layers. On the other hand, plants grown in fields three or more years after the fields had been reclaimed had an impaired tap-root development and showed a sparse root distribution in the deep layers of the soils. The poor development and abnormal distribution of the roots tended to become more pronounced as the cropped years after reclamation increased.

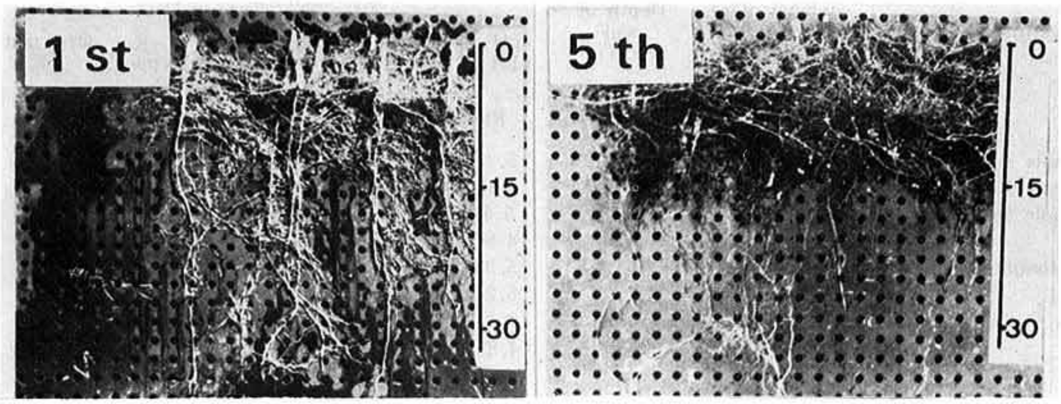
Soil samples taken at a depth of 0 to 30 cm showed pH values of above 5 and aluminum saturations in the range of 0 to below 10, respectively, in fields from the second year on after reclamation, suggesting that the level of acidity was low and aluminum toxicity was negligible. On the other hand, a rather high aluminum saturation such as 19% was observed in the first year field after reclamation where almost all of the soybean plants had normal root systems. These results do not suggest that tap-root development and root distribution in the deeper layers can be ascribed to low pH and high aluminum toxicity.

Instead, it appeared that the tendency to restrict the tap-root penetration and proper

Table 2. Occurrence of soybean plants with normal root systems and soil chemical properties of fields depending on the years after reclamation at São Gotardo

Years after reclamation	Occurrence of soybean plants with normal root systems (%)	Soil chemical properties**						
		Depth (cm)	pH (1:1)	Al-sat. (%)	Ca+Mg (me/100 ml)	P (ppm)	K (ppm)	Org. matter (%)
0*		0-5 (A_1)	4.8	59	0.5	1.2	36	7.0
		5-15(A_3)	4.9	34	0.5	0.6	30	5.2
		15-30	5.1	25	0.4	0.6	19	4.2
1	96	0-12(Ap_1)	5.3	4	1.3	3.8	32	4.7
		12-22(Ap_2)	5.0	14	0.6	2.2	28	4.8
		22-30	4.7	19	0.4	0.6	26	4.4
2	100	0-15(Ap_1)	6.4	tr.	4.5	4.5	22	4.6
		15-26(Ap_2)	6.0	tr.	3.0	0.9	21	4.5
		26-30	5.3	3	0.7	0.4	18	3.5
3	58	0-12(Ap_1)	5.7	tr.	3.2	6.5	39	5.0
		12-25(Ap_2)	5.4	1	1.7	0.9	22	4.6
		25-30	5.0	10	0.6	0.5	16	3.8
4	45	0-12(Ap_1)	5.4	tr.	2.4	4.4	34	5.1
		12-24(Ap_2)	5.4	1	1.5	1.5	36	5.0
		24-30	5.0	1	0.7	1.5	25	3.9
5	30	0-13(Ap_1)	5.5	tr.	3.0	12.0	28	5.5
		13-23(Ap_2)	5.2	9	0.9	0.7	23	4.2
		23-30	5.0	3	0.6	0.4	19	3.7
6	47	0-8 (Ap_1)	6.7	tr.	4.6	10.6	33	5.2
		8-18(Ap_2)	6.1	tr.	3.6	2.4	41	5.0
		18-30	5.5	tr.	1.7	0.4	25	4.0

* Virgin soil
** Samples were taken from the soils between rows.



(scale cm)

Plate 2. Distribution of root systems of soybean plants in the fields of the first and fifth year after reclamation at São Gotardo

root distribution in the deep layers of the soils might be associated with significant differences in phosphorus or (Ca + Mg) contents between the Ap_1 and Ap_2 layers of the soils, since the Ap_1 layers tended to accumulate phosphorus and (Ca + Mg) following the application of fertilizers for cultivation each year, while the Ap_2 layers remain unimproved.

Soil compaction appeared slightly in the lower part of plowed layers of all fields at maximum value of 15 kg/cm^2 in the second year field after reclamation. This value was considered to be not so great to impede root penetration into the deeper layers of the soils.[1,16]

Effects of deep incorporation of phosphorus and lime on root development and distribution

To evaluate the effect of phosphorus and lime on the root distribution in the deep layers, an experiment was carried out in fields of two typical cerrado soils, Helvic Ferralsols and Rhodic Ferralsols. The soil layer was divided into two parts, 0–15 and 15–30 cm depth from the soil surface. Triple superphosphate and dolomite were applied, together or separately, to the deeper layer as shown in Table 3. A basal dressing of N (urea), P_2O_5 (triple superphosphate) and K_2O (potassium chloride) of 10 kg, 100 kg and 100 kg/ha, respectively, was applied in rows at the seeding time.

As shown in Table 4 and Plate 3 and 4 the highest percentages of occurrence of soybean

Table 3. Incorporation of triple superphosphate and dolomite in the deep soil layers

Treatment	Depth of soil (cm)	P_2O_5 (kg/ha)	Dolomite (t/ha)
Triple superphosphate	0–15	400	1
and dolomite	15–30	400	1
Triple superphosphate	0–15	400	2
	15–30	400	0
Dolomite	0–15	800	1
	15–30	0	1
No fertilizers	0–15	800	2
	15–30	0	0

Table 4. Effect of the deep incorporation of fertilizers on the occurrence of soybean plants with normal root systems and soil chemical properties at grain filling stage of soybean plants

Treatment	Occurrence of soybean plants with normal root systems (%)	Depth of soil (cm)	Soil chemical properties*					
			pH (1:1)	Al-sat. (%)	Ca+Mg (me/100 ml)	P (ppm)	K (ppm)	Org. matter (%)
			Rhodic Ferralsols					
Triple superphosphate	88	0–15	5.4	6	1.6	82.3	100	2.7
and dolomite		15–30	5.1	32	0.7	22.2	32	2.6
Triple superphosphate	67	0–15	5.4	tr.	2.9	89.9	61	nd
		15–30	4.8	57	0.7	28.3	23	nd
Dolomite	52	0–15	5.3	12	2.0	46.2	46	nd
		15–30	5.2	28	1.4	2.3	28	nd
No fertilizer	54	0–15	5.5	tr.	2.8	89.8	55	nd
		15–30	4.8	62	0.6	1.3	29	nd
			Helvic Ferralsols					
Triple superphosphate	95	0–15	5.7	4	2.3	40.3	54	4.2
and dolomite		15–30	5.8	3	2.2	8.3	26	3.8
Triple superphosphate	90	0–15	5.4	8	1.8	25.4	45	nd
		15–30	5.1	27	0.7	7.1	29	nd
Dolomite	82	0–15	5.5	6	1.8	29.3	70	nd
		15–30	5.7	tr.	1.6	0.5	42	nd
No fertilizer	70	0–15	5.5	1	2.2	17.2	39	nd
		15–30	5.1	22	0.8	0.4	43	nd

* Samples were taken from the soils under rows.

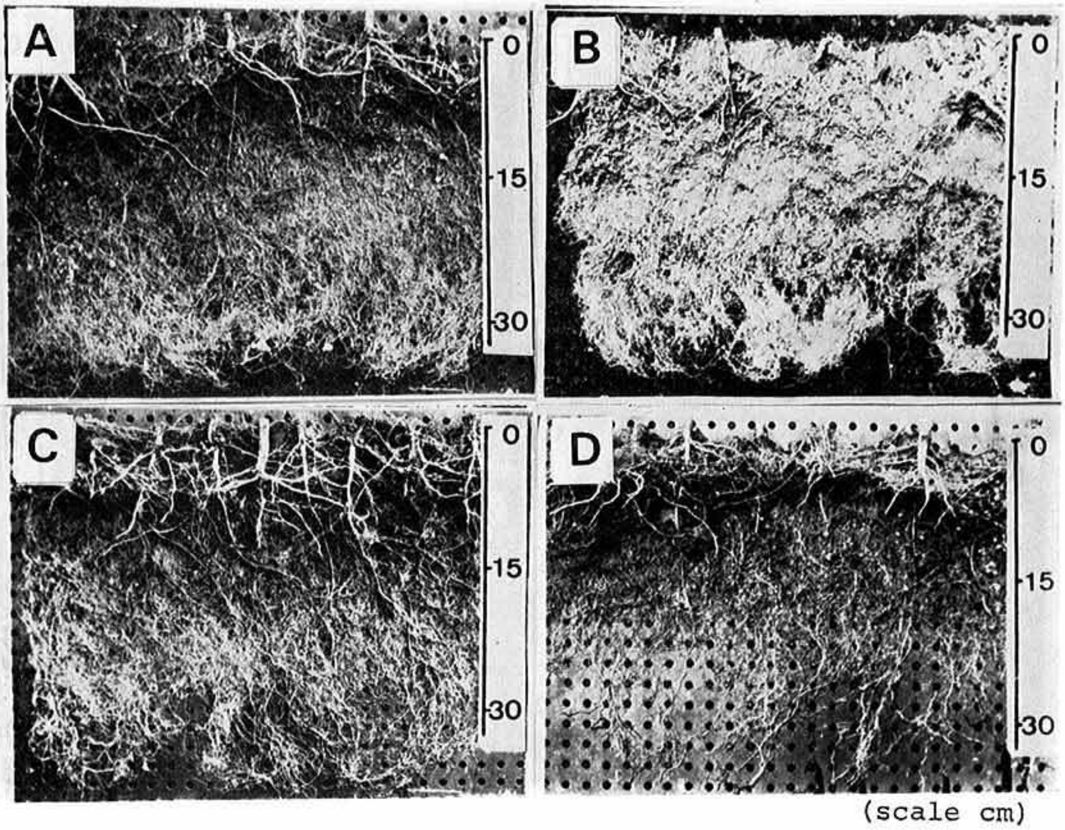
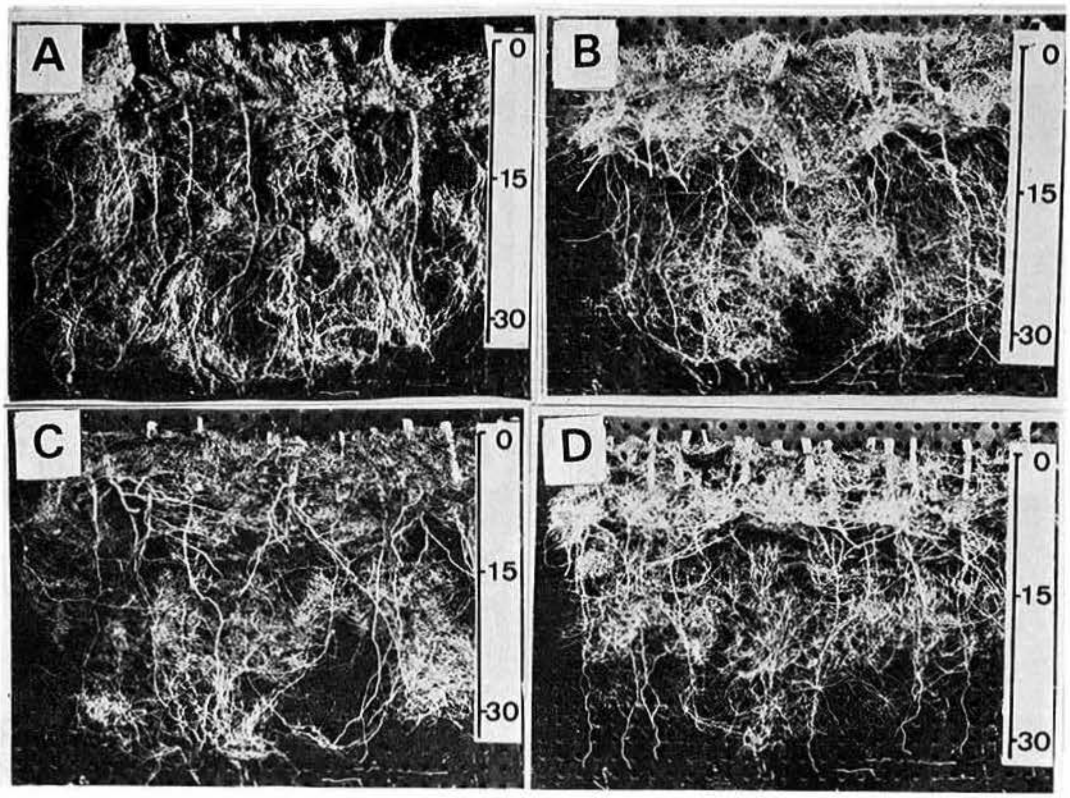


Plate 3. Distribution of root systems of soybean plants in Rhodic Ferralsols of CPAC following deep incorporation of fertilizers
A: Triple superphosphate and dolomite, B: Triple superphosphate,
C: Dolomite, D: No fertilizers

plants with normal root systems showing better penetration of tap-roots and distribution of roots in the deeper layers of the soils were observed in the plots where both triple superphosphate and dolomite had been applied in the deeper layers, resulting in high contents of P and (Ca + Mg). A similar tendency was also observed in the plots with deep incorporation of phosphorus only, in spite of the fact that pH and percentage of aluminum saturation of the plot in Rhodic Ferralsols were 4.8 and 57, respectively, which corresponded to a comparatively high level of acidity and aluminum toxicity. A slight improvement of the root distribution in the deep layers of the soils was observed in the plots subjected to deep incorporation of dolomite only, although in Rhodic Ferralsols the percentage of occurrence of soybean plants with normal root systems of the dolomite plot did not increase in comparison with that of no fertilizer plot.

Thus the deeper incorporation of triple superphosphate and/or dolomite increased the contents of P and/or (Ca + Mg) in the deeper layers and resulted in improvement of the root distribution in the soils.

On the basis of results obtained in the series of the experiments it can be concluded that the concentration of soybean roots in the upper layers of cerrado soils is not due to high aluminum toxicity associated with the low pH of the soils, but to the lower level of P and/or (Ca + Mg) contents in the deeper layers, in particular, to the significant dif-



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A: Triple superphosphate and dolomite, B: Triple superphosphate,
C: Dolomite, D: No fertilizers

ference in P and/or (Ca + Mg) contents between the upper and deeper layers of the soils since fertilizers are applied each year to the former whereas the latter remains unimproved. Such abnormal root distribution can be improved by deep incorporation of phosphorus and lime.

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