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Root Growth and Phosphorus Uptake in Wide- and Narrow-Row Soybeans

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ABSTRACT

Most of the research comparing the effect of different row spacing on seed yield in soybeans [*Glycine max* (L.) Merr.] has been focused on row spacing effects on aboveground crop characteristics such as leaf area, light interception, pod number, or biomass accumulation and their relationships with seed yield. Little work has been done on the effects of narrow-row spacing on root distribution. Plant distribution may also affect root distribution and interroot competition, and therefore, exploration and use of soil resources. A field experiment was carried out on the Pampas (Argentina) to determine the effect of narrow-row spacing on root distribution within the topsoil in soybean, and whether different root distributions affect phosphorus uptake. In December 1993, soybeans were planted at two row spacings, narrow rows (0.35 m) and wide rows (0.70 m). Root density was measured during seed filling (92 days after planting) at several points within the inter-row space down to a soil depth of 30 cm. Aboveground biomass was harvested at maturity and phosphorus (P) uptake was measured. Below the row line, narrow-row soybeans showed a greater root density than the wide row treatment at 5-10 cm depth, while roots of the wide-row soybeans had more lateral growth.

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Root density at both sides of the row down to a depth of 5 cm was greater for the wide-row treatment. Average root density for each depth for a section of 70 cm wide across the row line indicated there was no significant difference between treatments at any depth. The fewer number of rows for the wide-row spacing was compensated by a greater lateral extension of roots within the interrow space. This compensation resulted in a similar root density at each depth for both planting patterns, narrow and wide rows. Aboveground biomass and phosphorus concentration in plant tissue at maturity were not affected by row spacing. A similar phosphorus uptake for both treatments was consistent with the lack of effect of the different plant distribution on soil exploration by roots and on aboveground biomass accumulation.

INTRODUCTION

Soybean [*Glycine max* (L.) Merr.] has been traditionally sown using wide row distance (0.70-1 m). This row distance causes a rectangular pattern (i.e., row spacing greater than within-row spacing) while planting soybeans in rows narrower than conventionally spaced leads to a more uniform plant distribution. The narrow-row pattern has several advantages that have been reported, narrow-rows produce a more uniform plant distribution leading to a greater light interception, even with same leaf area index than a wide row crop (Flénet et al., 1996). Light interception, crop growth and leaf area show a cause-effect relationship. The increased light interception stimulates crop growth which increases leaf area, which in turn further increases light interception (Board and Harville, 1996). Greater yields in narrow row soybeans may result from greater leaf area, light interception and crop growth, especially during early reproductive development (Taylor et al., 1982; Board and Harville, 1994). An increase in the number of pods in narrow-row soybeans leads to a more efficient use of assimilate in seed set and filling (Egli, 1994; Bullock et al., 1998). Another advantage of narrow-row spacing that has been reported is reduced weed population due to increased soybean competition and a more rapid shading of the ground (Anaele and Bishnoi, 1992).

Most of the research comparing the effect of different row spacing on seed yield in soybeans has focused on the row spacing effects on aboveground crop characteristics such as leaf area, light interception, pod number, or biomass accumulation and their relationships with seed yield. These studies have helped to clarify the physiological factors involved in narrow-row yield responses and to predict when the practice is convenient (Board and Harville, 1994).

Plant distribution may also affect root distribution and inter-root competition, and therefore, exploration and use of soil resources such as phosphorus. The uptake of P is a process that is sensitive to changes in root growth (Barber, 1995). Soil P moves primarily by diffusion, which effectively occurs only within a few millimeters around roots (Jungk and Claassen, 1997). Therefore, root growth is an important factor affecting P uptake because the size of the root system affects the amount of P available for plant absorption. Phosphorus uptake per unit of soil increased with root length density and P availability for potato and mustard (van Noordwijk and de Willigen, 1986). Phosphorus uptake by young corn plants was linearly related to the root surface per plant (Schenk and Barber, 1979). This relationship departs from linearity as the root grows, due to root aging and inter-root competition decreasing the amount of nutrient absorbed per unit of root length or surface (Barber, 1978). Little work has been done on the effects of narrow-row spacing on root distribution. Mason et al. (1982) reported greater root density for soybeans with row spacing of 0.25 m when compared with 1 m rows, unfortunately the root sampling was not replicated.

The objective of this study was to determine (i) the effect of narrow-row seeding pattern on root distribution within the topsoil in soybean and (ii) whether different root distributions affect P uptake. We hypothesized that narrow-row spacing would increase root density at the topsoil due to a more uniform plant distribution and less within-row root competition, and that this greater root density would increase P uptake.

MATERIALS AND METHODS

An experiment was conducted on a Bragado sandy loam soil (Typic Hapludoll) located at the Bragado county, Buenos Aires Province, Argentina (35° 04' south, 30° 31' west). Table 1 gives some soil characteristics for the Ah horizon.

Treatments were two row spacings, narrow rows (NR, 0.35 m) and wide rows (WR, 0.70 m). The experimental design was a complete randomized block with four replications. Size of plots was 4.2x12 m.

Soybean (cv. Asgrow 5308, MG V, determinate growth habit) inoculated with *Bradyrhyzobium japonicum* was planted on December 21, 1993, using a no-till grain drill, and providing a plant density of 42 plants m^{-2} once the crop was established. Plant spacing within the row was 7 and 3.5 cm for the NR and WR treatment, respectively. Diamonium phosphate (20 kg P ha^{-1}) was band-applied at planting. Soybean was double-cropped after wheat. Previous crops were corn, sunflower, rapeseed and sorghum, and using no tillage for all of them.

Root density and distribution in the top soil was measured at 92 days after planting, when the crop was at the seed filling period (R6, Fehr and Caviness, 1977). Root samples were taken using a soil core sampler of 8 cm diameter (30 cm long). Four subsamples per plot were taken: at the row, at both sides of the row (8 cm from the row), and at the inter-row line (at 17.5 and 35 cm from the row for the NR and WR treatments, respectively). Soil cores were divided into four separated layers corresponding to a depth of 0-5, 5-10, 10-20, and 20-30 cm, respectively. Roots were washed from the soil using a 0.5-mm sieve, oven dried at 65°C and weighed. Root density was calculated for each depth as g of root per kg of soil. The average of root density for a 70 cm wide section across rows was calculated for each depth interval and row spacing pattern. A linear variation of

TABLE 1. Soil characteristics (Ah horizon).

Particle-size distribution[a]		
Clay	%	14.2
Silt	%	15.6
Sand	%	70.2
Organic carbon[b]	%	0.9
Total nitrogen[c]	%	0.09
Phosphorus (Bray 1)	$\mu g\ g^{-1}$	5.7
pH (soil:water 1:2.5)		5.8
C.E.C.[d]	$cmol\ kg^{-1}$	7.1
Ca[d]	$cmol\ kg^{-1}$	4.74
Mg[d]	$cmol\ kg^{-1}$	1.2
K[d]	$cmol\ kg^{-1}$	0.85
Na[d]	$cmol\ kg^{-1}$	0.08

[a]Pipet method (Klute, 1986).
[b]Walkley-Black method (Sparks, 1996).
[c]Kjeldahl method (Sparks, 1996).
[d]Ammonium acetate method (Sparks, 1996).

root density was assumed for the interval between two adjacent sampling positions. Linear interpolation between sampling positions was also used to draw a contour graph of the root distribution in the topsoil.

At maturity (R7, 116 days after planting) all the plants in one meter of row were harvested, and fallen leaves at the inter-row space collected. Samples were divided into leaves, stems, pods and seeds, oven dried at 65°C and dry weighed. Phosphorus concentrations in each tissue were measured colorimetrically after wet digestion.

Data collected was statistically analyzed by Analysis of Variance. When treatment variances were not homogeneous, an empirical power transformation was performed to stabilized variances (Kuehl, 1994). Contrasts (Student t test) between row spacing at each depth were done.

RESULTS AND DISCUSSION

Figure 1 shows the root density at the row, at both sides from the row, and at the interrow line. At the row, at a depth of 5-10 cm, narrow-row soybeans showed a greater root density than the wide row treatment (Figure 1a). Wide-row soybeans had a greater root density at both sides of the row down to a depth of 5 cm (Figure 1b). At the inter-row line, root density for both treatments had decreased to similar values (Figure 1c), suggesting a faster reduction in root density for the NR treatment since the inter-row line was closer to the row for NR than for WR treatment (17.5 and 35 cm, respectively). Figure 2 shows the root density distribution in a 70 cm

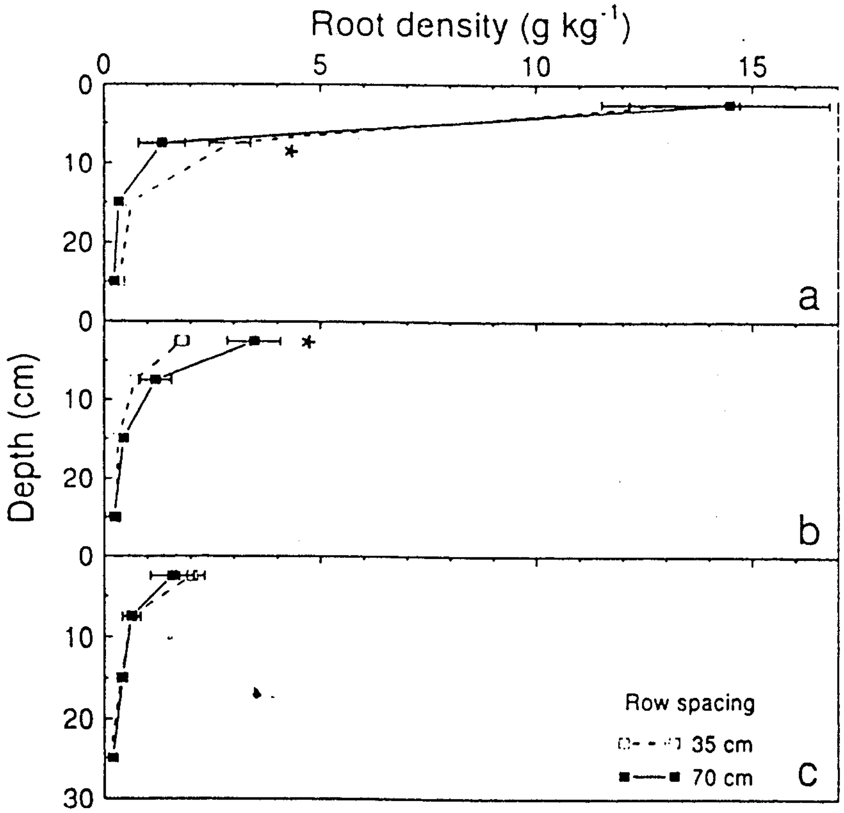

FIGURE 1. Effects of row spacing on root density at (a) the row line, (b) 8 cm from the row line (average of both sides), and (c) the interrow line. Horizontal bars indicate means ±S.E. *Significant differences between row spacing treatments at that depth ($p<0.05$).

wide soil section across rows for both treatments. Lateral roots tend to grow outward from the taproot, almost horizontally to the interrow line, they then turn down due to inter-root competition (Raper and Barber, 1970; Mitchell and Russell, 1971). Our results suggested that competition between lateral roots of plants in adjacent rows increased when the rows were closer, decreasing the extension of lateral roots within the interrow space in the narrow-row treatment.

The average root density for a 70 cm wide section across the row was calculated for each depth interval and row spacing pattern (Figure 3). Root densities were not significantly different ($p>0.05$) between treatments at any depth (Figure 3). Fewer number of rows within a given section for the wide-row pattern may have allowed a greater lateral extension of roots within the inter-row space. This resulted in a similar root density at each depth for both planting patterns, narrow and wide rows.

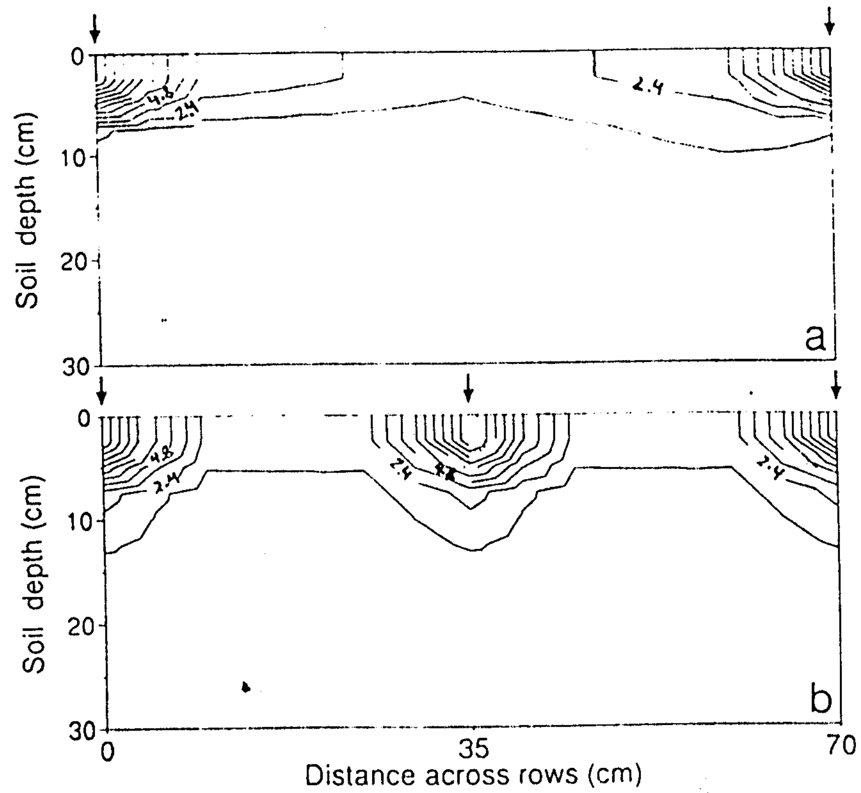

FIGURE 2. Root-density distribution for a 70-cm wide section of the soil across the row for both treatments: (a) wide and (b) narrow row spacing. Arrows indicate row positions. The difference between two adjacent root-density isolines is 1.2 g root kg^{-1} soil.

Aboveground biomass at maturity was similar for both treatments. There was no effect ($p>0.05$) of row spacing on the biomass accumulation of different plant organs (Table 2). Narrow-row yield responses were reported in conditions where total dry matter in wide rows at harvest was below 800 g m^{-2} (Board and Harville, 1994). Lower biomass accumulation was related to incomplete canopy closure and reduced growth rate during early reproductive stages (Egli et al., 1987; Board and Harville, 1994). Our results were above this proposed threshold, suggesting that both planting patterns attained sufficient growth prior to seed filling.

Phosphorus concentration in plant tissue and P uptake were not affected by row spacing (Table 2). A similar P uptake for both treatments was consistent with a similar soil exploration by roots and aboveground biomass accumulation. Phosphorus absorption dependency on root growth has been reported for soybeans and other crops. Otàni and Ae (1996) observed a high correlation ($r=0.84$) between root length and P uptake by several crops, soybean among them. Similarly, linear

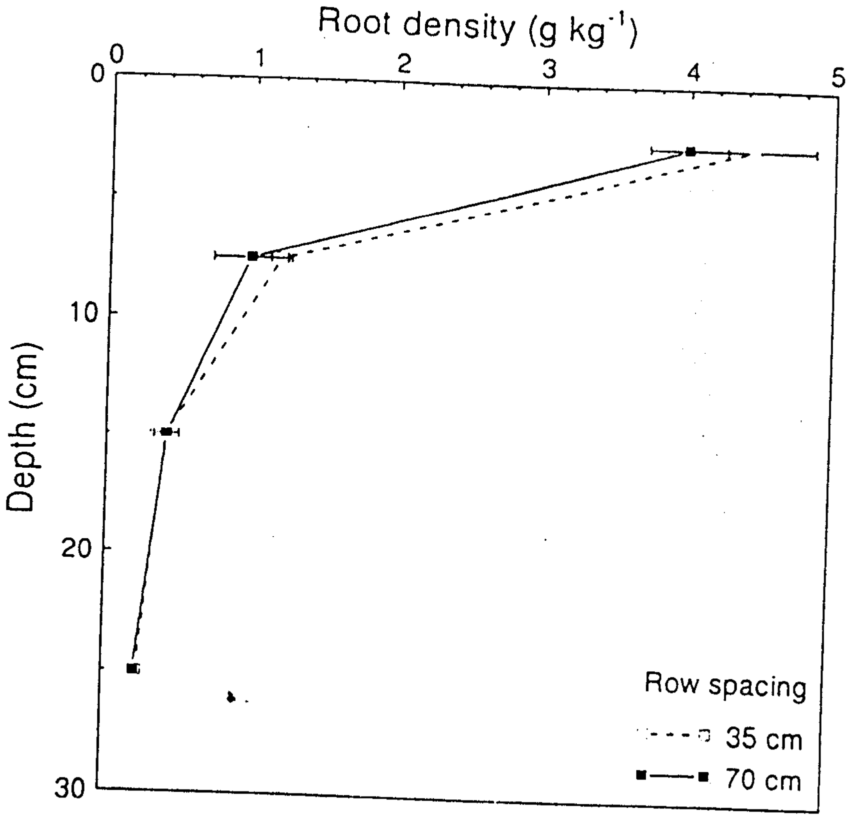

FIGURE 3. Average of root density for each depth interval and row spacing pattern. Horizontal bars indicate means ±S.E.

TABLE 2. Means and associated standard errors for biomass accumulation, phosphorus concentration, and content in different plant organs at maturity (116 days after planting).

Plant organ	Treatment	Dry weight[a] --- kg ha^{-1} ---		P concentration[a] --- mg g^{-1} ---		P content[a] --- kg ha^{-1} ---	
		$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.
Stems	NR	2190	391	0.61	0.129	1.44	0.523
	WR	1830	213	0.64	0.167	1.09	0.319
Leaves	NR	2910	479	1.37	0.254	3.97	0.655
	WR	2730	158	1.32	0.201	3.62	0.209
Pods	NR	1260	279	1.12	0.153	1.43	0.380
	WR	1240	105	1.35	0.157	1.68	0.279
Seeds	NR	2330	429	6.34	0.184	14.87	2.903
	WR	2230	243	6.04	0.355	13.28	1.131
Total	NR	8690	1543			21.71	4.349
	WR	8030	680			19.4	1.573

[a]No letters mean no significant differences between treatments.

relationships between root growth and P uptake were reported for ryegrass (Cornish et al., 1984), corn (Schenk and Barber, 1979), barley, and sugar beet (Hoffman and Jungk, 1995).

CONCLUSIONS

Narrowing row spacing resulted in a different pattern of root distribution down the soil profile. However, when a whole soil section was considered, row spacing did not affect root density at any depth interval. The more uniform plant distribution in the narrow-row pattern was compensated by a greater lateral root growth within the interrow space in the wide-row treatment. Row spacing, and therefore plant distribution, did not affect the extent of soil exploration by roots. The hypothesis that narrow-row culture would increase root density at the topsoil due to a more uniform plant distribution was rejected, and no effect of planting pattern was observed on plant phosphorus concentration and uptake.

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