PHOSPHORUS STRATIFICATION: IS IT RELEVANT TO PHOSPHORUS UPTAKE BY SOYBEAN?

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Abstract

Stratification of nutrients, observed in soils under continuous no-till management, remains an issue. Two experiments were conducted during 2001 and 2002 to evaluate the effect of stratification on P nutrition of soybean (*Glycine max* (L.) Merr.). At the first site there were five blocks with stratified and unstratified main plots and five levels of soil test P as subplots. In the second trial there were four blocks with two stratification treatments as main plots, the absence and presence of in-row P (10 kg P/ha) as subplots and four levels of soil test P as sub-subplots. Whole plants were taken at R1 and R5 for P uptake. Grain yield and grain P were measured. In general, P uptake and grain yield were greater with P stratification in soils with lower soil test P. The response to in-row P was similar to that for P stratification. There was little response to P stratification or in-row P use when soil test P was at medium-high levels. These results indicate P stratification can be beneficial to soybean P nutrition when overall soil P availability is low.

Introduction

The effect, if any, of nutrient stratification on nutrient uptake by crops has not been fully studied, and it is being highly questioned in some countries of the world (Argentina). Fertilizer placement in a one-dimensional linear band is generally beneficial to nutrient absorption in both corn and soybean. However, it is not clear if a homogeneous distribution of a nutrient within the topsoil will improve nutrient uptake relative to that observed with the surficial nutrient placement in reduced tillage productions systems. There are some models that predict greater phosphorus uptake due to a better distribution of this nutrient within the soil profile, though this is at a very high rate of phosphorus. Further, most stratification studies have involved corn, not soybean, and these species differ markedly in their root system morphologies. The objectives of this experiment were to better understand soybean phosphorus nutrition under highly stratified conditions, as the no-tillage system of soil management is becoming something of a worldwide trend. Furthermore, there is the desire to help researchers and farmers with improved phosphorus fertilization recommendations for soybean, and thus likely improving profits while reducing the environmental risk of excessive application.

Materials and Methods

Quicksand site

The experiment was conducted at the Robinson Forest Research and Education Center near Quicksand, Kentucky. The soil was a Nolin-Grisby complex, silt loam in texture, which consists of very deep, well-drained soils formed in alluvium on flood plains. Treatments consisted of two levels of P stratification, and five levels of soil P availability. Stratification treatments were created with moldboard plowing (not stratified – NS) and chisel plowing (highly stratified – HS). Light disking was done (3 passes) to break up any existing surface residues. The five levels of soil P availability were created applying 0, 15, 30, 45 and 60 kg P/ha, broadcast before tillage and planting of the 2001 soybean crop, and denoted as P1, P2, P3, P4, and P5, respectively. In moldboard plowed plots, half of the P fertilizer was applied prior to primary tillage and half was applied prior to secondary tillage. These application rates resulted in average (0-20 cm) soil test (Mehlich III) P levels of 10, 11, 15, 19 and 20 ppm P. In the second year soybean was planted without additional tillage system to maintain the established stratification. The experiment was laid out in five randomized blocks, with stratification as the main plots and with the five levels of available soil P as subplots. Plot size was 4.24 x 6.06 m.

Soybean (cv. Pioneer 94B01) was planted on May 29, 2001 and May 22, 2002 using a Tye no till grain drill set to deliver 400,000 seeds/ha. Row spacing was 52.5 cm, so each plot had 8 rows. Other fertilizer and lime materials were added as determined by soil test. Weed control was appropriate for the weed species present and consisted of both preemergence and postemergence material application.

Princeton site
The experiment was conducted at the West Kentucky Research and Education Center near Princeton, Kentucky. The soil was a Sadler silt loam (fine-silty, mixed, mesic Glossic Fragiudalf). Treatments consisted of two levels of P stratification, two levels of starter P fertilizer, and four levels of "existing" soil P availability. Stratification treatments were created with moldboard plowing (not stratified – NS) and chisel plowing (highly stratified – HS) of existing sparse sod/weeds. Light disking was done (3 passes) to break up existing surface residues. The two different levels of phosphorus fertilizer applied as a starter consisted of 0 and 10 kg P/ha, and denoted S0 and S1, respectively. The four levels of "existing" soil test P were created in an earlier phosphorus fertility experiment that had been maintained in grass (tall fescue) since the last use of the experimental area had ended several years prior to the start of this experiment. Those existing levels, denoted P1, P2, P3 and P4, averaged (0-20 cm) 3.5, 4.5, 8.3, and 19.9 ppm P, respectively. In the second year soybean was planted without additional tillage system to maintain the established stratification, but starter P was applied in both years. Available soil test P levels were not modified by P amendment during our experiment. The experimental design was laid out in four completely randomized blocks, with a split-split plot treatment arrangement. The four existing soil test P levels treatments were main plots, with the stratification treatments as subplots, and the 2 levels of starter P as sub-sub plots. The plot size was 3 x 12 m.

Soybean (cv. Pioneer 94B01) was planted on May 8, 2001 and June 17, 2002, using a John Deere 7000 series no till planter equipped set to deliver 400,000 seeds/ha in 2001 and 500,000 seeds/ha in 2002. The row spacing was 76.2 cm. Other fertilizer and lime materials were added as determined by soil test. Weed control was appropriate for the weed species present and consisted of both preemergence and postemergence material application.

Both sites
Whole plant samples (50 cm of row) were taken at R1 and R5 (Fehr and Caviness, 1977) for determination of growth and P uptake. Leaves, stems and pods plus seeds (when present) were separated and then analyzed for tissue P concentration. At crop maturity, grain yield was determined by combine harvest of the center two rows of each plot and a grain sample was saved

for P analysis. The P tissue determination was done by automated colorimetry, subsequent to wet acid digestion using micro-Kjehldal procedures, according to the Fiske and Subbarow (1925) method. Soil samples, consisting of composites of 8 to 10 cores per plot, were taken in 2.5-cm increments to a depth of 20 cm in all plots and subjected to Mehlich III extraction for P. Subsequent extract P determination was done via plasma emission spectroscopy. All data were statistically evaluated using appropriate analysis of variance procedures. When there was a significant effect due to the level of available P, and this factor did not interact with any of the other factors; an LSD test was used to separate mean effects due to this treatment factor.

Results and Discussion

Quicksand site

Table 1 illustrates the initial fertility of the soil at this location. Organic matter levels were high, pH was a bit low, and other fertility parameters were adequate. Additional K and Zn were added prior to planting. The influence of the tillage induced stratification treatments on soil test P (at the highest soil test level) is illustrated in Figure 1. Tillage greatly reduced phosphorus stratification in those plots.

At this site, which was characterized by medium to high levels of soil test P and as having a high yield potential, neither soil P stratification, nor differences in soil test P levels caused differences in leaf P leaf concentrations at R1 and R5, P uptake at R5, or grain yield (Table 2). Interactions between these two factors were not significant for any of the measured variates.

Princeton site

Table 3 illustrates the initial fertility of the 'existing' soil P availability treatments. Organic matter was low, available K was low, and other fertility parameters were adequate. Additional K and Zn were added prior to planting. The influence of tillage induced stratification treatments on soil test P (at the highest soil test level) is illustrated in Figure 2.

At this site, which in general had lower available soil P levels, R1 leaf P concentrations were positively affected by the main effects of increasing soil test P level and use of starter P (Table 4). At R5, leaf P concentrations were similarly responsive to the main effects of soil test P level and starter P, but were also positively influenced by P stratification (Table 4). Phosphorus uptake at R5 was affected by the main effect of soil test P, but there was only a non-significant trend for greater P uptake with greater P stratification or use of starter P (Table 4). Grain yield was similar to R5 P uptake in responding to the treatment main effects (Table 4).

An interaction between P stratification and use of P starter was observed in R5 leaf P (Figure 3), R5 P uptake (Figure 4) and grain yield (Figure 5). The interaction was similarly expressed in all three measured variates. Regardless of soil test P level, stratification was beneficial to soybean P nutrition and grain yield when no starter P was applied. Said another way; the crop responded more to the use of starter P when the surface 20 cm of soil contained a rather uniform vertical distribution of soil test P. Phosphorus stratification was generally as effective as starter P in improving soybean P nutrition and grain yield.

There were P stratification by soil test P level and starter P by soil test P level interactions on soybean grain yield (Table 4, Figures 6 and 7). In the P stratification by soil test P interaction, vertical P stratification produced 16% higher yields than unstratified P at the lowest soil test P level, but this difference disappeared, even becoming negative, at highest soil test P level (Figure 6). In the P starter by soil test P interaction, use of P starter produced 24% greater yields at the lowest soil test P level, but the benefit of P starter was greatly reduced at higher soil test P levels.

Conclusions

Phosphorus stratification improved P uptake and grain yield in soybean grown at low soil test P level, as did the use of a low rate of starter P, suggesting that both act as a form of 'banding' where P acquisition by the soybean root system is concerned. Removal of vertical P stratification with tillage never improved the P nutrition and yield of soybean. The benefit of vertical P stratification (and P starter) to soybean P nutrition was not observed at medium to high soil test P levels.

References

Fehr, W.R. and C.E. Caviness. 1977. Stages of soybean development. Iowa State University. Special Report 80.

Fiske, C.H and W. Subbarow. 1925. The colorimetric determination of phosphorus. J.Biol. Chem. 66:375-400.

Table 1: ***Initial soil fertility information – Quicksand, 2001.***

Organic Matter (%)	*pH (H_2O)*	*Mehlich III K (mg/kg soil)*	*Mehlich III Ca (mg/kg soil)*	*Mehlich III Mg (mg/kg soil)*	*Mehlich III Zn (mg/kg soil)*
3.6	5.5	152	1260	102	5.5

Figure 1: ***Soil test P (P5 level) stratification – Quicksand, 2001. LS – low stratification; HS – high stratification.***

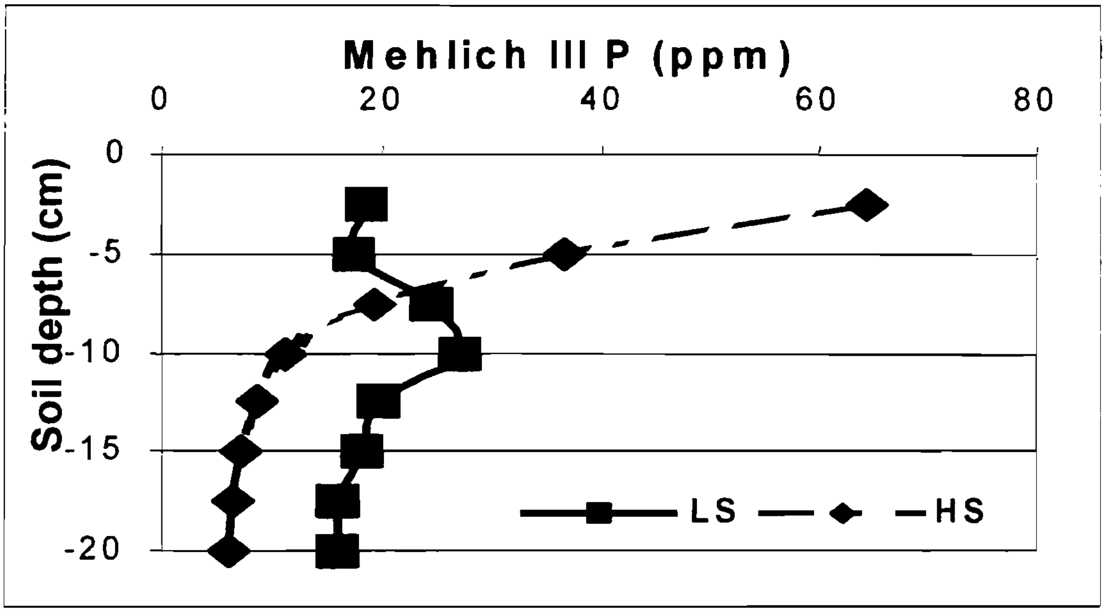


Table 2: ***Leaf P, P uptake and grain yield of soybean – Quicksand, 2001.***

Source of Variation	***R1 Leaf P Concentration (%)***	***R5 Leaf P Concentration (%)***	***R5 P Uptake (kg P/ha)***	***Grain Yield (kg/ha)***
Stratification:				
High (HS)	0.39 a	0.33 a	34.6 a	4300 a
Low (LS)	0.37 a	0.32 a	31.6 a	4280 a
Soil Test P Level:				
P1	0.38 a	0.32 a	31.4 a	4430 a
P2	0.37 a	0.32 a	30.9 a	4150 a
P3	0.39 a	0.32 a	31.1 a	4160 a
P4	0.38 a	0.33 a	38.8 b	4340 a
P5	0.39 a	0.33 a	33.6 a	4390 a
Stratification by Soil Test P Level Interaction	Not Significant†	Not Significant	Not Significant	Not Significant

†NS = not significant at the 90% level of confidence; means within a box followed by the same letter are not significantly different at the 90% level of confidence.

Table 3: ***Initial soil fertility information – Princeton, 2001.***

Soil Test P Level	*Organic Matter (%)*	*pH (H_2O)*	*Mehlich III P (mg/kg)*	*Mehlich III K (mg/kg)*	*Mehlich III Ca (mg/kg)*	*Mehlich III Mg (mg/kg)*	*Mehlich III Zn (mg/kg)*
1	1.7	6.5	3.4	70	1380	69	4.5
2	1.7	6.6	3.7	69	1350	63	5.3
3	1.8	6.5	7.1	69	1380	60	4.8
4	2.2	6.8	15.2	79	1600	78	10.3

Figure 2***: Soil test P (P4 level) stratification – Princeton, 2001. LS – low stratification; HS – high stratification.***

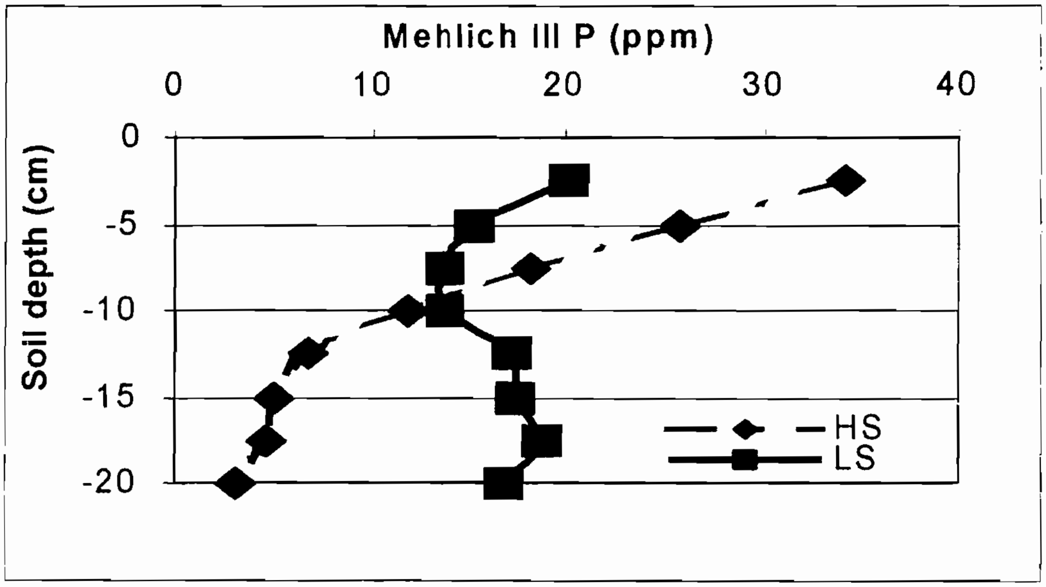


Table 4: ***Leaf P, P uptake and grain yield of soybean – Princeton, 2001.***

Source of Variation	*R1 Leaf P Concentration (%)*	*R5 Leaf P Concentration (%)*	*R5 P Uptake (kg P/ha)*	*Grain Yield (kg/ha)*
Stratification:				
High (HS)	0.29 a	0.26 a	9.1 a	2930 a
Low (LS)	0.29 a	0.24 b	8.8 a	2870 a
Starter P:				
No (S0)	0.28 a	0.24 a	8.7 a	2800 a
Yes (S1)	0.30 b	0.26 b	9.2 a	3000 a
Soil test P level:				
P1	0.26 b	0.21 c	5.6 b	2320 d
P2	0.27 b	0.21 c	6.2 b	2530 c
P3	0.32 a	0.27 b	12.1 a	3270 b
P4	0.33 a	0.31 a	12.0 a	3480 a
Stratification by P Level	NS†	NS	NS	**
Stratification by Starter	NS	*	*	**
Starter by P Level	NS	NS	NS	**

†NS = not significant at the 90% level of confidence; * = significantly different at the 90% level of confidence; ** = significantly different at the 95% level of confidence.

Figure 3: P stratification by P starter interaction on R5 leaf P concentration.

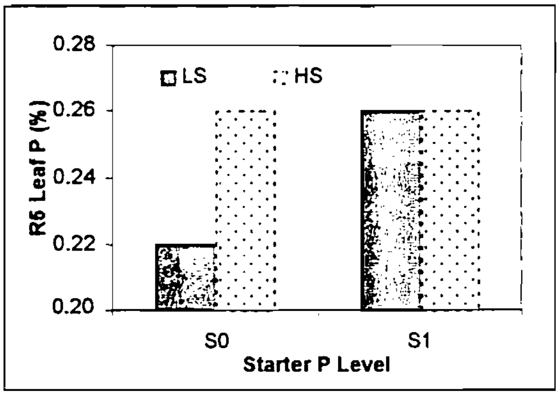


Figure 4: P stratification by P starter interaction on R5 P uptake.

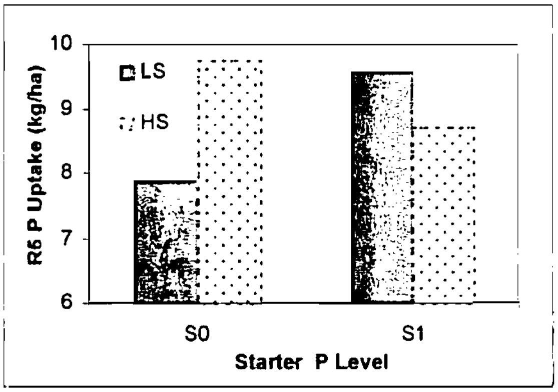


Figure 5: P Stratification by P starter interaction on soybean grain yield.

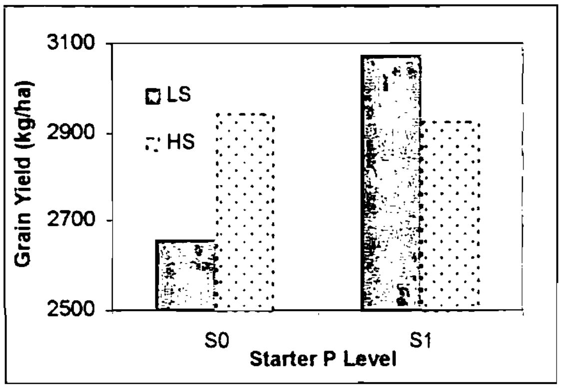


Figure 6: Soil test P level by P stratification interaction on soybean grain yield.

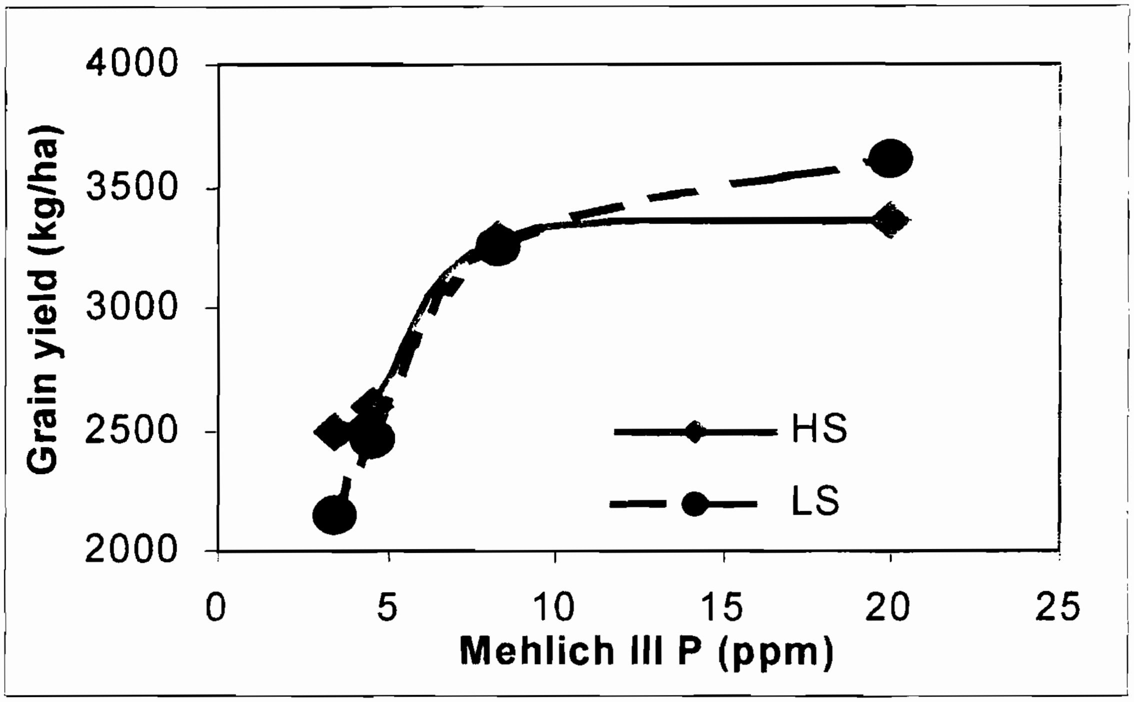
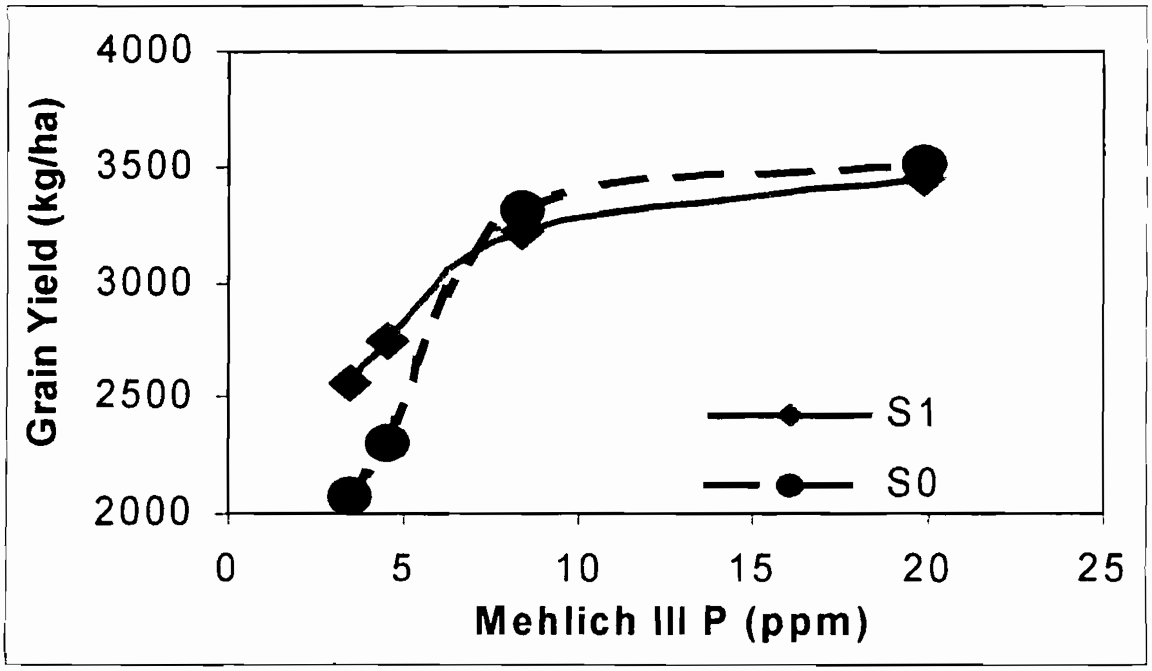


Figure 7: Soil test P level by starter P interaction on soybean grain yield.



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