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EFFECT OF SEED PHOSPHORUS CONCENTRATION, SOIL pH, AND SOIL PHOSPHORUS STATUS ON THE YIELD OF WHITE LUPIN

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ABSTRACT

Previous research has suggested that successful establishment of narrow-leaf lupin (*Lupinus angustifolius* L.) in the field may be limited by low phosphorus (P) content of the seed. This relationship has not been evaluated for white lupin (*Lupinus albus* L.) and thus the primary objective of this study was to evaluate the effect of seed P concentration on the growth of a winter-hardy white lupin (cultivar, "Tifwhite-78"). A large pot study was conducted to evaluate the effects of lupin seed P concentration, soil pH and P fertilizer rate on the growth of white lupin. The study was conducted using an inherently acidic (pH 4.5), P infertile Troup loamy

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sand (loamy, siliceous, thermic, Grossarenic Kandiudult). Treatments included three lupin seed P concentrations (0.25, 0.43, and 0.91% P), two initial soil pH levels (4.5 and 6.5) and three rates of P fertilizer (0, 50, and 100 mg P kg^{-1} soil). The test was conducted outside using pots having an inside diameter of 25.4 cm and a length of 67 cm and the plants were allowed to grow until physiological maturity. As expected, addition of P to this P deficient soil increased lupin seed yield, total dry matter production of shoots and roots, and the concentration of P in the various plant parts of the lupin plant. Results of this study show that lupin seed yields may be affected by the concentration of P in the planted seed, but only under high or optimum P fertility conditions. Soil pH had only minor effects on lupin seed and dry matter production. At the highest rate of applied P (100 mg P kg^{-1}), slightly higher yields were observed at the lowest pH. Results of this study suggest that low seed P concentrations should have minimal effects on the growth and production of winter-hardy white lupin.

INTRODUCTION

White lupin is a winter-grown annual legume that is adapted to well-drained, low-fertility, coarse-textured, neutral to acidic soils (1,2) such as those in the Southern Coastal Plain of the United States (3). Separately, there has been considerable research published concerning the factors of soil pH, soil P, and seed P and how varying these factors affect the growth of lupin (1,4–8). However, a majority of this research has been conducted using spring-type varieties of lupin and narrow leaf lupins instead of winter-types.

Gardner and Parberry (6,7) studied the acquisition of P by white lupin, focusing mainly on varying levels of pH and soil P. They discovered that proteoid root formation was greatly affected by P supply to the plant. Proteoid roots are clusters of rootlets located on lateral roots which secrete chelating substances to enhance the uptake of certain nutrients. Proteoid roots develop in response to nutrient stress, especially P (9). Gardner and Parberry (7) also reported that when exposed to low levels of soil P, the uptake of P by white lupin was enhanced by exudation of chelates, reducing agents, and protons. When the combined effects of pH and P were considered, they concluded that the ability of white lupin to utilize soil and added P decreased as pH increased (6).

Seed P concentration has also been determined to play a role in lupin production and P fertilizer use efficiency. Bolland et al. (5) reported that narrow-leaf lupin (*Lupinus angustifolius* L. cv. Danja) seed containing high levels of P increased the effectiveness of P fertilizer in sandy soils. Thompson et al. (4) reported depressed early shoot and root growth and nodule formation in narrow-leaf lupin plants developing from seed containing low levels of P. Low seed P depressed nodule number and biomass at all levels of external P supply, but the depression was more distinct at low levels of external P. Thompson et al. (4) concluded that low seed P may limit the successful crop establishment of lupin in the field especially in P deficient soils.

Soils in the Southern Coastal Plain are generally acidic and inherently low in P, and winter-hardy white lupin should be adapted to these soil conditions. However, the relationship between white lupin seed P content and lupin growth and performance has not been studied. The objective of this large pot study was to evaluate the effects of lupin seed P concentration, soil pH, and P fertilizer rates on the growth of a winter-hardy white lupin.

MATERIALS AND METHODS

A large replicated pot study was conducted outdoors during the winter 1994–spring 1995 to determine the effect of low seed P concentration on winter-hardy white lupin plant response. "Tifwhite-78" white lupin was previously grown on two experiment station sites in southern Alabama with varying concentrations of extractable soil P (10). Lupin seed were collected from these tests which contained P concentrations ranging from 0.25 to 0.61%.

Soil used in the test was a Troup loamy sand (loamy, siliceous, thermic Grossarenic Kandiudults) with an initial soil test P rating of "very low" (2.8 mg kg^{-1}, Mehlich 1 extractable P). The initial soil pH was 4.5. Prior to initiation of the test, half of the collected sample was adjusted to pH 6.5 by the addition of reagent grade calcium oxide. Soil at both pH levels (4.5 and 6.5) received supplemental additions of 10 mg kg^{-1} S as $K_2SO_4 \cdot 2MgSO_4$, 100 mg kg^{-1} K as $K_2SO_4 \cdot 2MgSO_4$ and KCl, and 33 mg kg^{-1} of a complete micronutrient fertilizer (11). No extra Ca was supplied to the low pH soil. Treatments included two levels of soil pH (4.5 and 6.5), three P fertilizer rates (0, 50 and 100 mg P kg^{-1}) and three lupin seed P concentrations (0.25, 0.43, and 0.61% P). Phosphorus was applied as reagent grade monocalcium phosphate [$Ca(H_2PO_4)_2$]. Treatments were arranged as a factorial within a randomized complete block with 4 replications.

The test was initiated on November 4, 1994 using large pots. Individual pots consisted of 67 cm tall sections of 27 cm inside-diameter PVC pipe. Each section of PVC pipe was cut vertically using a band saw and the two halves were held together using metal clamps which improved the efficiency of collecting lupin roots from the entire pot at harvest. Pots were arranged outdoors on wooden platforms designed to shelter the below ground soil volume with pine bark chips to simulate natural edaphic conditions while leaving the aerial portion of the plant exposed to natural atmospheric environmental conditions. Water was applied on an as-needed basis and no additional fertilizer was applied during the course of the study.

Five lupin seeds were planted per pot after inoculation with *Rhizobium* and Kodiak® biological seed protectant. Lupin plants were harvested (May 30, 1995) when the better treatments reached physiological maturity. Harvested plants were divided into various parts, weighed, dried to constant moisture content, and re-weighed. Lupin roots were removed from the soil by washing to determine root biomass, root dry matter, and proteoid root development. Harvested plants and roots were dried at 60°C for 72 h for the determination of dry matter and nutrient analysis. After grinding of the above ground plant material, a 0.5-g subsample of each plant part was ashed at 450°C for 4 h. The resulting ash was digested in acid (12) and P determined using inductively coupled argon plasma spectrophotometry (ICAP-9000, Thermo Jarrell-Ash Corp., Franklin, MA).

After plant harvest and prior to collection of roots, soil samples were collected from each pot for the determination of soil pH and Mehlich I extractable P (12). Yield, plant P and soil test data were analyzed using the SAS procedures (13). Mean separation was performed using Fisher's LSD and an *a priori* significance level of $P \leq 0.10$.

RESULTS

Mehlich I extractable soil P increased with the rate of applied P as expected (Table 1). At harvest soil pH averaged 5.2 and 6.4 in treatments with initial pH values of 4.5 and 6.5, respectively. The increase in pH in the low soil pH treatments may have resulted from the combined effects of adding K and Mg fertilizer and the response of white lupin roots to low pH conditions. Mehlich I extractable

Table 1. Effect of Fertilizer P Rates and Initial Pre-plant Soil pH on the Level of Extractable Soil P[a] (Mehlich 1) After Lupin Harvest

Soil P Application Rate ($mg\ kg^{-1}$)	Initial Soil pH 4.5[b]	Initial Soil pH 6.5[c]
0	1.0	0.8
50	15	10
100	31	21
Interaction $LSD_{(0.10)}$	2.5	

[a] $mg\ kg^{-1}$ extractable soil P
[b] Final soil pH at harvest (averaged across P rates) = 5.2.
[c] Final soil pH at harvest (averaged across P rates) = 6.4.

P was slightly higher in the low pH treatments as compared to the high pH treatments.

Lupin seed yields were affected by soil pH, P rate, and their interaction ($P \leq 0.10$; Fig. 1). The soil used in the study was very low in available P and as shown in Figure 1, the unfertilized soil produced very little lupin seed regardless of seed P concentration. At a P rate of 50 mg kg^{-1}, the highest seed yields were obtained at a pH of 4.5 (the soils natural pH) whereas at a rate of 100 mg P kg^{-1}, the highest yields were obtained at pH 6.5. Lupin seed yields were also affected ($P \leq 0.10$) by the interaction between P rate and the concentration of P in the seed (Fig. 2). At a P rate of 50 mg kg^{-1}, the highest yields were observed with seed having the lowest concentration of P, however, at a rate of 100 mg P kg^{-1}, lupin seed yields increased with increasing seed P concentration. Thus, at a near optimum P rate (100 mg P kg^{-1} soil) for this very low P soil, lupin seed yields increased with increasing P content in the seed.

Total dry matter yields of the above ground plants increased with P rate (Table 2), but were not affected by soil pH or P concentration in the planted seed. Lupin harvest index (HI) values were calculated as the ratio of the seed weigh to the total above ground dry matter weight. Harvest index was affected by the inter-

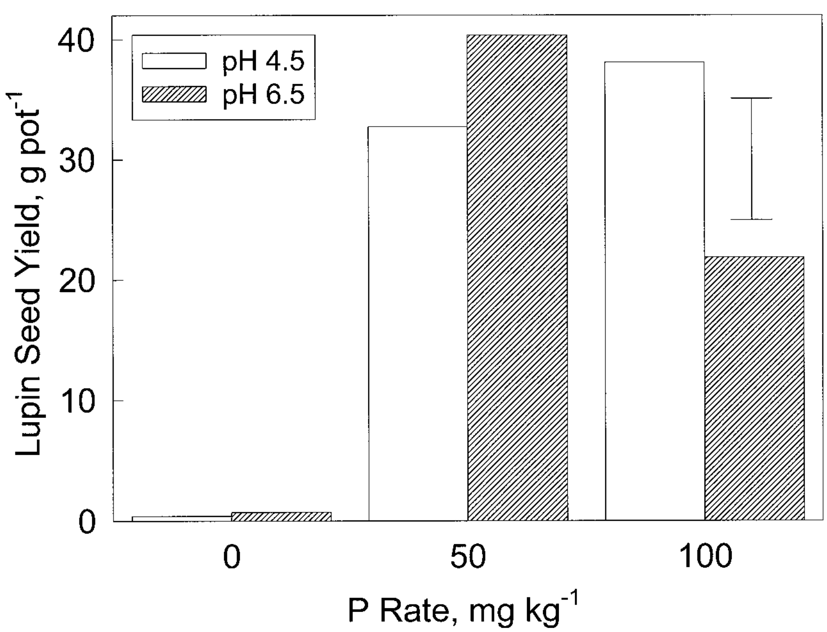

Figure 1. Winter-hardy white lupin grain yields as affected by fertilizer P rate and soil pH. Error bar represents the interaction LSD(0.10).

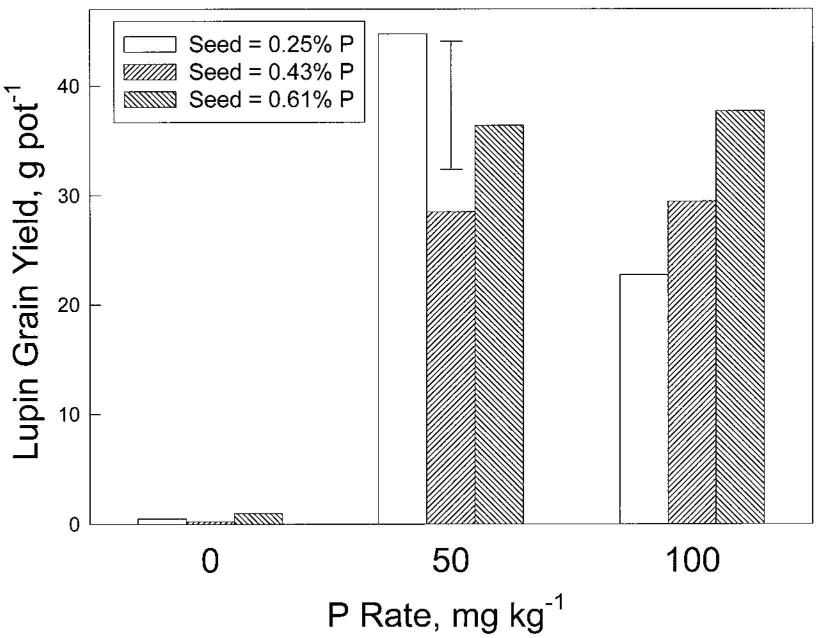

Figure 2. Winter-hardy white lupin grain yields as affected by fertilizer P rate and lupin seed P concentration. Error bar represents the interaction LSD(0.10).

action between soil pH and P rate ($P \leq 0.10$) (Fig. 3). Harvest index decreased with increasing P rate at pH 6.5, but HI increased slightly with increasing P rate in the low pH treatments (Fig. 3). There was also a significant interaction between seed P concentration and P rate (Fig. 4). The highest HI was obtained at the highest seed P concentration in the no P treatments whereas the lowest HI values were obtained at the highest P rate. Depending on the treatment, HI values ranged from 0.10 to 0.27 (Figs. 3 and 4). These findings are in contrast to Bolland et al. (5) who studied the effects of lupin seed P concentration and P fertilization rates on the growth of *Lupinus angustifolius*. They evaluated two levels of seed P and four rates of fertilizer P and reported HI values ranging from 0.27 to 0.29, regardless of the P concentration in the seed or the rate of fertilizer P applied to the soil.

Selected root characteristics as affected by treatments are presented in Tables 2 and 3. Total root and lateral root dry matter production were highest at the initial pH of 4.5 (Table 3). Dry matter in proteoid roots was lowest at initial pH 4.5 (Table 3), and decreased with increasing P rate (Table 2). As shown in Table 2, fresh weight of root nodules as well as dry matter in laterals, taproots, and the total root system increased with P rate. The concentration of P in the planted seed had no effect on any of the measured root parameters. Shoot/root

Table 2. Effect of P Rate on Total Above Ground Dry Matter Yield of Winter-Hardy White Lupin Plants, Fresh Weight of Root Nodules, and Dry Weight of Roots

	Shoot	Lupin Roots					
		Nodules	Dry Weight				
P Rate ($mg\ kg^{-1}$)	Total Dry Matter ($g\ pot^{-1}$)	Fresh ($g\ pot^{-1}$)	Total Roots ($g\ pot^{-1}$)	Laterals ($g\ pot^{-1}$)	Taproots ($g\ pot^{-1}$)	Proteoid ($g\ pot^{-1}$)	Shoot/Root Ratio
0	2.4	0.08	2.02	1.21	0.64	0.17	1.19
50	189	8.55	37.88	17.63	20.19	0.06	4.99
100	220	11.32	46.28	22.9	23.35	0.03	4.75
$LSD_{(0.10)}$	19	2.31	4.88	3.32	2.20	0.04	0.53

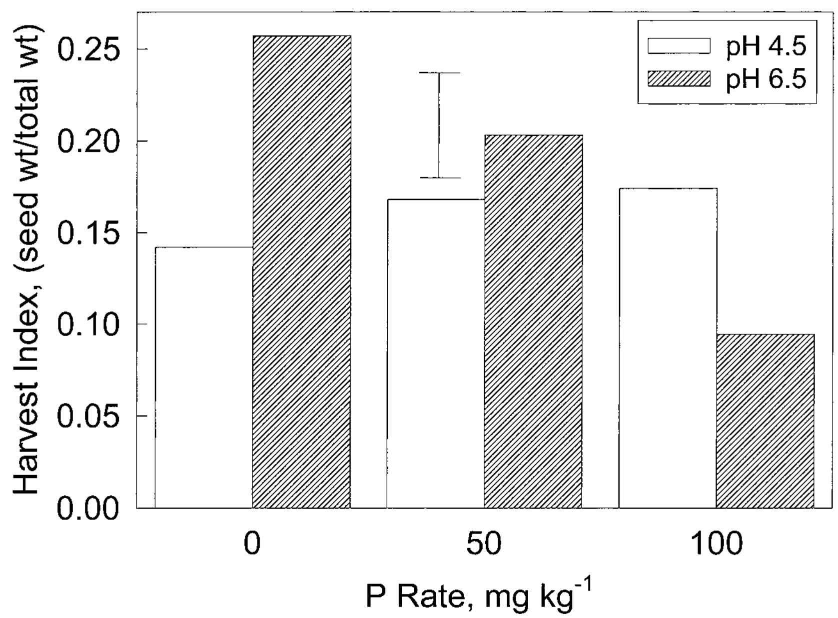

Figure 3. Harvest index (seed weight/total dry matter weight) as affected soil fertilizer P rate and soil pH. Error bar represents the interaction LSD(0.10).

ratios increased with P rate (Table 2) and soil pH (Table 3), but they were not affected by the seed P concentration or any interactions.

Phosphorus concentration in leaves, stems, seed and seed pods increased with increasing P rate (Table 4). Surprisingly, P concentrations were not affected by soil pH. Phosphorus concentration in the planted seed had no effect on the P concentration in any plant part of the harvested lupin plants. The critical value for P in young, white lupin shoots has been reported to be 1400 mg P kg^{-1} (14), which is not directly comparable with these results which were collected on physiologically mature white lupin plants.

DISCUSSION

Results of this large pot study, using an acid, P infertile soil show that lupin seed yields may be affected by the level of P in the planted seed, but only under optimum P fertility conditions. Soil pH had only minor effects on seed and dry matter production. In this study, lupin seed yields, total dry matter production, and

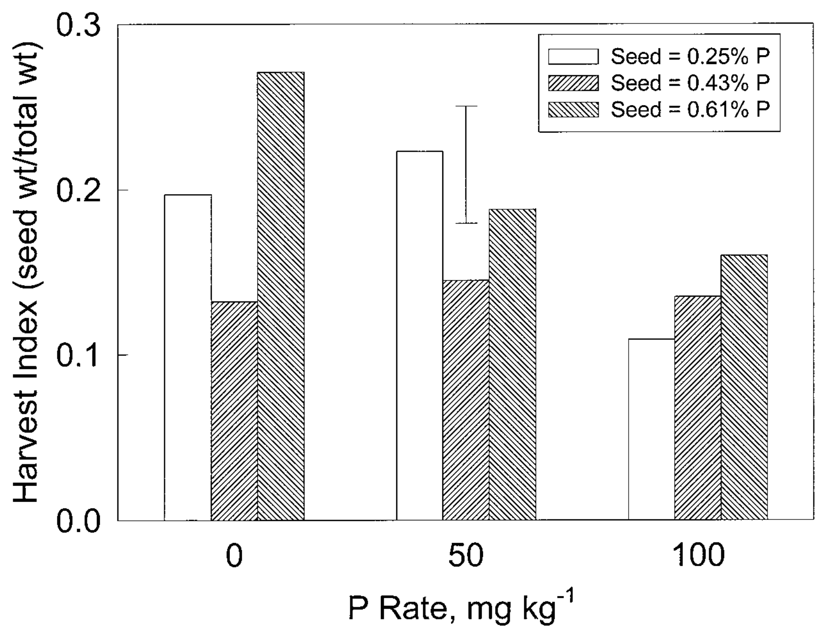

Figure 4. Harvest index (seed weight/total dry matter weight) as affected by fertilizer P rate and lupin seed P concentration. Error bar represents the interaction LSD(0.10).

Table 3. Effect of Soil pH on Dry Weight of Total Roots, Laterals, and Proteoid Roots and the Shoot/Root Ratio of Winter-Hardy White Lupin

	Root Weight			
Initial Soil pH	Total Roots (g pot^{-1})	Laterals (g pot^{-1})	Proteoid (g pot^{-1})	Shoot/Root Ratio
4.5[a]	31.10	16.37	0.05	4.20
6.5[b]	26.35	11.45	0.12	5.44
$LSD_{(0.10)}$	3.98	2.71	0.04	0.43

[a] Soil pH at planting. Final pH at harvest was 5.2.
[b] Soil pH at planting. Final pH at harvest was 6.4.

Table 4. Phosphorus Concentration[a] in Winter-Hardy White Lupin Plant Parts as Affected by Rate of Applied Fertilizer P

Soil P Rate ($mg\ P\ kg^{-1}$)	Lupin Plant Part: Leaves	Stems	Seed	Seed Pods[b]
0	683	425	2120	604
50	743	791	5280	1070
100	1253	1852	5843	2537
$LSD_{(0.10)}$	295	543	335	317

[a] $mg\ P\ kg^{-1}$ Dry Matter.
[b] Pods remaining after removal of lupin seed.

growth of the root system were determined primarily by the rate of added P. It can be concluded from this study that low seed P concentrations should have minimal effects on the growth and production of winter-hardy white lupin. However, lupin seed should be produced on soils having good P fertility.

For the Southern Coastal Plain of the Southern United States, winter-hardy white lupin is an attractive alternative crop since it could be incorporated into existing crop rotations and it has shown promise as a winter cover crop (2). To sustain yields and profitability, most producers maintain adequate soil pH levels and soil P fertility levels through fertilization practices. Thus, unless lupin seed has been produced under very low P fertility conditions, which is unlikely, the level of seed P in winter-hardy white lupin should not be a concern for the Southern United States regardless of whether winter-hardy white lupin is grown as an alternative source of grain or as a winter cover crop.

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