SOIL PHOSPHORUS STRATIFICATION AND THE PHOSPHORUS NUTRITION OF SOYBEAN

THESIS

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THESIS

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ABSTRACT OF THESIS

SOIL PHOSPHORUS STRATIFICATION AND THE PHOSPHORUS NUTRITION OF SOYBEAN

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 soil P as main plots and five levels of soil test P as subplots. In the second trial, main plots consisted of a complete factorial combination of stratified and unstratified P at four levels of soil test P, with the absence and presence of in-row P (10 kg P/ha) as subplots. Whole plants were taken at R1 and R5 for tissue P and P uptake. Grain yield and grain P were measured. In general, tissue P, P uptake and grain yields were not affected by soil P stratification. The response to in-row P was more evident at early stages of the crop or at low soil test P level and where soil P was not highly stratified. There was little response to in-row P use when soil test P was at medium-high levels. These results clearly indicate that soil P stratification is not prejudicial to soybean P nutrition.

KEYWORDS: phosphorus, nutrient stratification, soybean nutrition, no-till.

CHAPTER 1

INTRODUCTION

As is widely known, grain crop production is very important in the world. It is not only a way of living for many farmers or just an important source of income to many countries, but is also one of the main sources of food for the world's population. There are different ideas regarding the scarcity of food. Some people believe that food itself is limiting, and others think that the problem is food distribution among the world's population. In order to maximize world food production it is extremely relevant to optimize the use of resources necessary to produce grains. It is very important to optimize use of both renewable resources, such as herbicides, insecticides, fungicides, fertilizers, seeds, etc. and non-renewable ones, such as land, certain fuels, etc. The misuse of any of the renewable resources could lead to lower efficiency in food production, or to environmental contamination problems which can be harmful to the population or plants and animals which sooner or later will affect humans.

There are some countries, important in world agriculture production, which do not have their own resources of some nutrients, such as phosphorus and potassium, and consequently must import all their needs. In these countries the maximization of efficiency in the use of any of these nutrients is important for their economies. On the other hand, in other, developed countries the contamination of water resources by excess nutrients has proven to be a real problem and needs to be controlled.

The misuse of the non-renewable resources, such as land, can lead to their degradation to the point that they can become useless for food production. Though this is the most drastic consequence of land degradation, the intermediate alternative, where productive land is transformed to low productivity due to bad management is also considerable.

There are several factors that can cause a piece of land to lose productivity. These factors can be inherent to the land itself, or to the environment directly or indirectly affecting the piece of land. Among the factors inherent to the land itself are two large groups, those that are physically related factors and those that are chemically related factors. Both of these groups can, in certain ways, be managed by human beings in order to make the land more or less productive and sustainable for grain production. Soil erosion is one of the main causes of the destruction of physical properties of agricultural lands, and one of the management alternatives that farmers have in order to reduce this soil erosion is the no-tillage soil management system. Furthermore, no-tillage is not only an excellent system for prevention of soil erosion, it has also been shown to improve water use efficiency due to increased infiltration and reduced evaporation of water. And water is, in many areas of the world, a limiting resource for grain production.

Some years ago, farmers around the world started to use no-tillage farming techniques. This practice is expanding through several countries of the world at very rapid rates year through year. As use of the no-tillage system expands, questions regarding related crop and soil management practices (crop establishment, weed control, insect control, nutrient management) have arisen. For example, the use of no-tillage is known to cause nutrients with low soil mobility, such as phosphorus, potassium zinc, etc. to be “stratified” within the rooting zone. Stratification means that these nutrients tend to be localized in the uppermost portion (surface 2.5 to 5.0 cm) of soil relative to the rather thorough mixing throughout the upper 15 to 20 cm that would occur with regular inversion (moldboard plow) tillage. Stratification happens because nutrients applied as fertilizers or animal waste are usually broadcast over the soil surface and also because crop residues are returned to the surface of the soil and decompose there with minimal soil mixing.

The effect, if any, of nutrient stratification on nutrient uptake by crops has not been fully studied, and this is a question of importance in some countries, such as Argentina and the United States. Fertilizer placement in one-dimensional linear band is generally believed beneficial to nutrient absorption by 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 common in reduced tillage production systems. There are some root-nutrient acquisition models which predict greater phosphorus uptake with better distribution of this nutrient within the topsoil profile. Further, most stratification studies have involved corn (Zea mays), not soybean (Glycine max (L.) Merr.), and these species differ markedly in their rooting system morphologies. The results of this experiment will be important to a better understanding of soybean phosphorus nutrition under highly stratified conditions and to evaluate the impact that no-tillage, which is becoming a worldwide soil management trend, might have on the matter. Furthermore, the results of this experiment will help researchers and farmers improve phosphorus fertilization recommendations for soybean, thus improving profit potential while minimizing environmental risk due to excessive phosphorus application.

LITERATURE REVIEW

Soil erosion is a problem in world crop production. Conservation tillage systems, such as no-tillage and minimum (chisel) tillage are recommended as cost-effective ways of reducing soil erosion (Amemiya, 1977; Unger and McCalla, 1980). These conservation tillage systems have some additional benefits other than soil erosion prevention. Conservation tillage systems leave crop residues at the surface, reducing evaporation of surface soil moisture, a valuable benefit in dry areas. Tillage reduction can economize time during peak labor demand periods, which can also be very important to farmers.

Besides these “obvious” benefits, there are some other changes in the physical, chemical and biological properties of the soil caused by these conservation tillage systems (Bharati et al., 1986), and whose effects on crop production are still being discussed. Soils under no-tillage management are usually cooler, wetter and less aerated than those under plow tillage management (Buah et al., 2000). Such conditions influence plant nutrient absorption by slowing root growth, reducing the diffusion rate of the nutrients in the soil, and reducing the release of the nutrients from soil organic matter mineralization. Mackay and Barber (1985a, 1985b) studied the effect of changing soil moisture on phosphorus (P) and potassium (K) uptake by corn and concluded that increased soil moisture positively affected P and K uptake. This was mostly due to a higher root growth rate rather than to higher P and K diffusion rates in the moist soils. Mackay and Barber (1984) studied the effect of soil temperature variation on corn P uptake, and concluded that higher soil temperature positively affected corn P uptake, basically by increasing root growth. In this experiment, the P diffusion rate seemed to play a minor role in changes in corn's P uptake with different soil temperatures. These effects of soil moisture and temperature on nutrient uptake were only studied in corn, important but incomplete knowledge. Barber (1978) observed that P and K influx to root systems were different for corn than for soybean.

Conservation tillage practices usually lead to P and K stratification in soils. Nutrients accumulate at the soil surface as a result of minimal mixing of surface applied fertilizers and crop residues deeper into the topsoil, as well as limited P and K movement in most soils (Shear and Moschler, 1969; Griffith et al., 1977; Mackay et al., 1987; Howard et al., 1999). If nutrients are highly concentrated in the uppermost layer of soil, which dries out most often, and if soil moisture is important to nutrient uptake, as noted by Mackay and Barber (1985a, 1985b), then stratification might result in reduced uptake. The upper layer of the soil is also most subject to changes in temperature, another factor affecting nutrient uptake (Mackay and Barber, 1984).

There have been many researchers who have investigated the most efficient way to apply P and K fertilizers to different crops, under different conditions, but results have not been very consistent, and placement is still under discussion. In a laboratory experiment, Anghinoni and Barber (1980) found that the degree of mixing P with the soil that gave the greatest P recovery by corn depended on both the rate of P application and the P adsorption properties of the soil. Borkert and Barber (1985) found that the greatest amount of P recovered by soybean and corn plants occurred when P was mixed with the entire soil volume, although this experiment was conducted at very high soil P levels.

In field experiments with corn, Ketcheson (1980) found no differences in response to P addition among six different tillage systems, ranging in intensity from moldboard plow to no-till. Blevins et al. (1986) found no differences in P uptake when no-till was compared to moldboard plow tillage, though this experiment was done on a Kentucky soil derived from phosphatic limestone. When different placement strategies for P fertilizer were compared in no-tillage and other tillage systems, Singh et al. (1966) found that surface broadcast P resulted in greater P uptake by young corn than P broadcast and then mixed into the soil with a rototiller. No differences in P uptake were found at later sampling dates in this same experiment. Eckert and Johnson (1985) found that banded P resulted in higher P uptake and produced higher corn yields than broadcast P in some Ohio soils with medium soil test P levels. Another group of experiments, reported by Bordoli and Mallarino (1998), Mallarino et al. (1999) and Borges and Mallarino (2001), found no differences in conservation tillage corn yields due to P placement in comparisons of deep banding, shallow bands applied at planting, or surface broadcasting. Mallarino et al. (1999) did observe higher P uptake in the early stages of crop development with the two banding treatments. These experiments were carried out on different soils in Iowa, under a wide range in soil test P levels, and under widely varying rainfall distribution patterns. In Kentucky, Belcher and Ragland (1972) reported no differences in P uptake by no-tillage corn when surface broadcast P was compared to several different banded P and banded plus broadcast P treatment combinations.

There have also been some field studies designed to clarify the most efficient fertilizer P placement for soybean, but unfortunately few were done with no-tillage soil management. Borges and Mallarino (2000) found no differences in no-tillage soybean yield due to fertilizer P placement method when comparing deep banding, shallow bands applied at planting, or surface broadcasting. Again, these experiments were carried out on a great variety of Iowa soils, under a wide range in soil test P levels and under widely varying rainfall distribution patterns. Although Borges and Mallarino (2000) did not see any yield response, they found higher P uptake early in crop development with the two banded P treatments.

Buah et al. (2000) observed no difference, either in soybean leaf P concentrations or grain yields, when fertilizer P was banded or broadcast. However, soil test P was very high in this experiment and there was no response to the mere application of P fertilizer. In a group of experiments to study the effect of P fertilizer placement with different tilled systems (no-tillage was not included), Bharati et al. (1986) reported no differences in the soybean grain yield response to P among the different tillage systems. Again, this experiment was done at high levels of soil test P.

Ham and Caldwell (1978) found no effect of P fertilizer placement on soybean yields on soils that were very responsive to P addition. Ham et al. (1973) reported that soybean grain yields responded better to broadcast than banded P in a dry year, while in a more humid year, the banded plus broadcast P placement combination was superior. Rehm (1986), studying irrigated soybean in Nebraska, found that P broadcast and incorporated into the upper layer of the soil resulted in greater leaf P concentrations at early bloom and higher grain yields than were observed for banded P, even with low soil test P levels and low fertilizer P application rates. In another study, carried out on Canadian soils, Bullen et al. (1983) found soybean to be responsive to the application of banded P 2.5 cm below the seed, while broadcast P application caused little response to P addition.

As has been shown, there have been several different types of experiments done with the objective of studying the effect of P fertilizer placement on soybean and corn nutrition. Among those trials done with soybean, it is clear that the question of whether P stratification in conservation tillage systems will negatively or positively influence soybean P nutrition is still unanswered. This is a very important issue to growers producing soybean on P limited soils who have been using no-tillage soil management for a significant length of time.

Objective and Hypotheses

The objective of this study was to examine the effect of topsoil (0-20cm) phosphorus stratification on P nutrition of soybean under field conditions.

The hypotheses to be tested in this study are:

1 - Soil P stratification in the upper layers of the soil would affect soybean P nutrition by reducing P uptake.

2 - Higher soil P availability would compensate for the negative effect of P stratification on soybean P uptake.

3 – The use of starter P would compensate for the negative effect of P stratification on soybean P uptake.

CHAPTER 2

MATERIALS AND METHODS

QUICKSAND SITE

The experiment was located at the Robinson Forest Research and Education Center near Quicksand, Kentucky. The soil was silt loam textured, a Nolin-Grisby complex, occasionally flooded, and consisting of very deep, well-drained soils formed in alluvium on flood plains along the narrow, elongated valleys of the middle and north forks of the Kentucky River. Slopes range from 0 to 4 percent. The Nolin soils (fine-silty, mixed, mesic Dystric Fluventic Eutrochrepts) make up about 50 percent of the complex, and the Grisby soils (coarse-loamy, mixed, mesic Dystric Fluventic Eutrochrepts) are about 35 percent. Many other soils make up the rest of the complex.

Typically, the surface layer of the Nolin soils is brown silt loam about 25 cm thick. The subsoil extends to a depth of about 100 cm. The upper part, to a depth of about 75 cm, is dark yellowish-brown silt loam and the lower part is brown silt loam. This soil is high in natural fertility and is moderate in organic matter content.

Permeability is moderate and available water holding capacity is high. The root zone is very deep and is very easily penetrated by roots. There is a seasonal high water table at a depth of 90 to 180 cm.

The surface layer of the Grisby soil is dark yellowish-brown loam about 25 cm thick. The subsoil, to a depth of about 115 cm, is yellowish-brown loam. This soil is high in natural fertility and low to moderate in organic matter content. Permeability is moderately rapid and the available water holding capacity is high. The root zone is very deep and there is a seasonal high water table at a depth of 100 to 180 cm (USDA-NRCS and KAES, 1998)

Corn was grown using minimum tillage on the area where the experiment was conducted for the two years previous to this experiment. The area was subsoiled to a depth of 45 cm, on 76-cm centers, in one of the two years previous to this experiment. Table 2.1 illustrates the initial fertility of the surface soil (0 to 15 cm) at this location. Organic matter levels were high, pH was a bit low, and other fertility parameters were adequate.

Table 2.1: *Initial soil fertility information (0 to 15 cm) – Quicksand, 2001.*

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)***
3.6	5.6	13	95	1250	105	3.2

Treatments consisted of two levels of P stratification, and five levels of soil P availability. Stratification treatments were high and low stratification, denoted as HS and LS, respectively. These stratification levels were created either with no-tillage or moldboard plowing, respectively. Secondary tillage (disking three times) was used in both systems, to destroy remaining surface residues in no-tillage (HS) treatments and to incorporate fertilizers and to create a more desirable seedbed in moldboard plowed (LS) areas. Residues were destroyed in the no-tillage treatments in order to remove differences in soil moisture conservation, via differences in soil surface evaporation, as a factor in the study. In the second year, the entire experimental area was planted without tillage in order to maintain the existing stratification.

The five levels of soil P availability were created by broadcast application of 0, 16.8, 33.6, 50.4 and 67.3 kg P/ha before planting the first year's soybean crop, and denoted as P levels P1, P2, P3, P4, and P5, respectively. One half of the P fertilizer was applied prior to primary tillage, or its absence, and the second half was applied just prior to secondary tillage. This resulted in available soil test P levels (averaged over the surface 0 to 20 cm depth) of 10, 11, 15, 19 and 20 ppm of Mehlich III (Mehlich, 1984) extractable soil P in samples taken at the end of the first year of cropping.

The experiment was laid out in five completely randomized blocks, with a split-plot treatment arrangement. The tillage-stratification treatments were the main plots, and the five levels of available soil P were randomly assigned to subplots. The sub-plot size was 4.27 m (8 rows) wide by 6.10 m long.

Soybean (Pioneer 94B01, maturity group IV) was planted on 29 May, 2001 and on 22 May, 2002, using a Tye no-till drill at a density of 400,000 seeds/ha in both years. The row spacing was 53.3 cm, and each plot had 8 rows. Other fertilizer materials were added according to University of Kentucky recommendations (Anonymous, 2000).

Weed control was appropriate for the weed species present and consisted of both pre-emergence and post-emergence applications.

Whole plant samples were taken by harvesting all plants in 50 cm of row at R1 and R5 (Fehr and Caviness, 1977). Dry matter and tissue nutrient concentrations were determined after plant organs such as leaves, stems and pods-plus-seeds (when present) were separated. The individual organ tissue samples were analyzed for nitrogen (N), P, K, magnesium (Mg) and zinc (Zn). At crop maturity, grain yield was determined by combine harvest of the center two rows of each plot and a seed sample was taken and analyzed for N, P, K, Mg and Zn.

After plant/grain sample collection and organ separation, tissues were dried at 60 C, weighed and then ground to pass a 0.5mm screen opening. The tissue P was determined with an automated version of the Fiske and Subbarow (1925) method, after a micro-Kjeldahl wet acid digestion. The tissue K, Mg and Zn determinations were done by atomic emission or absorption after dry ashing, using apple leaf (1515) as a standard reference material.

Soil samples were taken after crop harvest by compositing 10 cores per plot. Cores were taken to a depth of 20 cm and separated into 2.5-cm increments prior to compositing. Bioavailable P, K, calcium (Ca), Mg and Zn were determined with the Mehlich III extractant (Mehlich, 1984) and both soil and buffer pH were determined according to procedures used by the University of Kentucky’s Regulatory Services Soil Test Laboratory. Soil carbon and nitrogen were determined by combustion using a LECO CN – 2000 Carbon Nitrogen Analyzer. Soil organic matter was calculated by multiplying soil carbon values by 1.72.

All data were statistically evaluated using appropriate analysis of variance procedures (SAS, 1993). When there was a significant effect due to stratification, or to the level of available P, and this latter factor did not interact with stratification, an LSD test was used to separate treatment means.

Rainfall and Temperature

In the 2001 season, rainfall was enough so that the crop was without visual symptom of drought stress during the whole cropping cycle (Figure. 2.1). In the 2002 season, rainfall was considerably lower than in 2001 (Figure 2.2), especially during late July, all of August and early September (days 65 to 110 after planting). This stressful period coincided with the medium-late (R3 to R7, Fehr and Caviness, 1977) reproductive stages of soybean, which is most sensitive to stress (Hardman and Brun, 1971; Jiang and Egli, 1995; Vasilas et al., 1995).

The average daily temperature was about normal for this location and well within the optimum range for soybean production (Figure 2.3). In 2002, the average daily temperature was higher than normal for the period at this location (Figure 2.4), but remained within the optimum range for soybean production. It is probable that these higher temperatures, and the reduced rainfall, could have caused mild water stress during the late reproductive stages of the crop. Table 2.2 shows the dates and corresponding days after planting for each time the crop was sampled.

Table 2.2. *Dates of tissue sampling and grain harvest – Quicksand, 2001 and 2002.*

Sampling stage	***Date***		***Days after planting***	
	2001	***2002***	***2001***	***2002***

Stage R1	07/16/2001	07/11/2002	48	50
Stage R5	08/24/2001	08/14/2002	87	84
Harvest	10/18/2001	10/08/2002	142	139

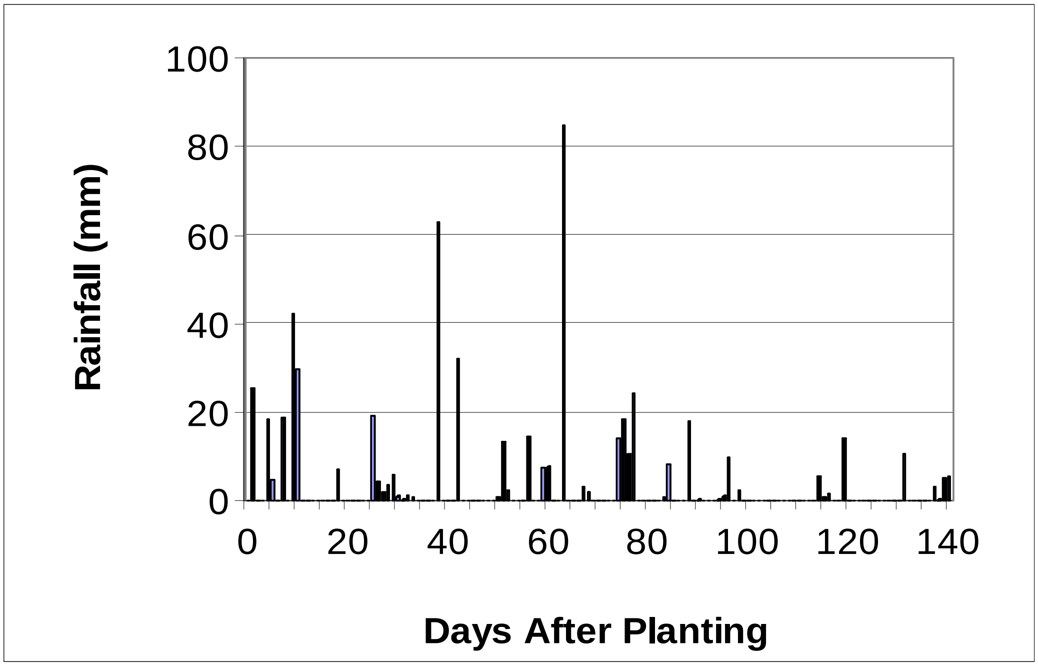

Figure 2.1: *2001 crop growing season rainfall – Quicksand.*

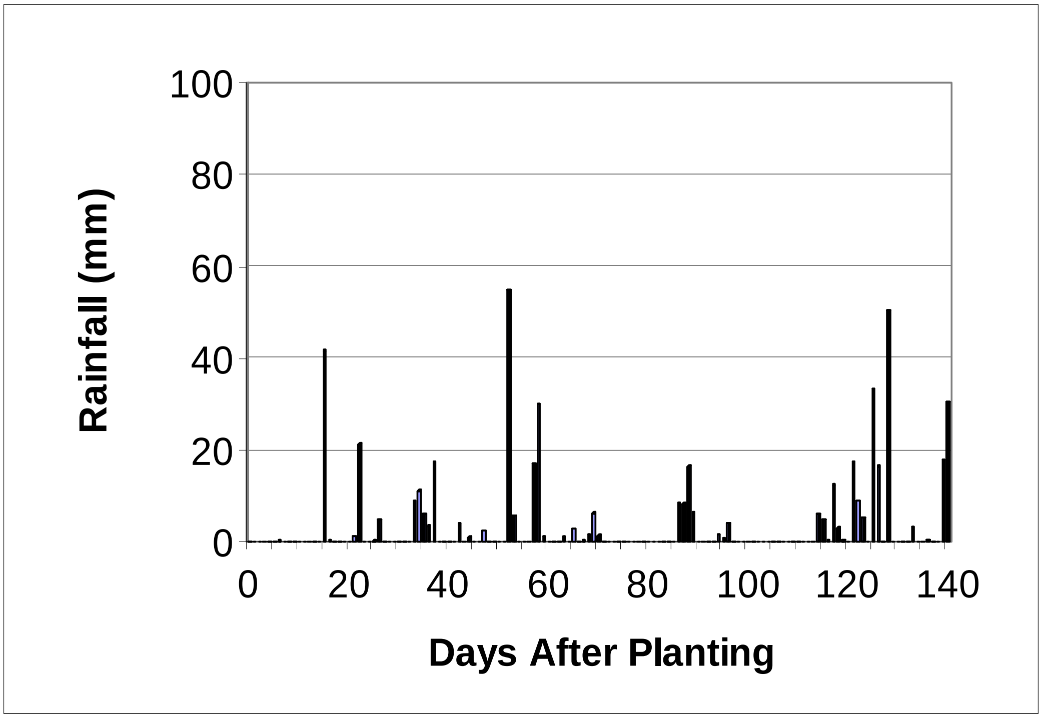

Figure 2.2: *2002 crop growing season rainfall – Quicksand.*

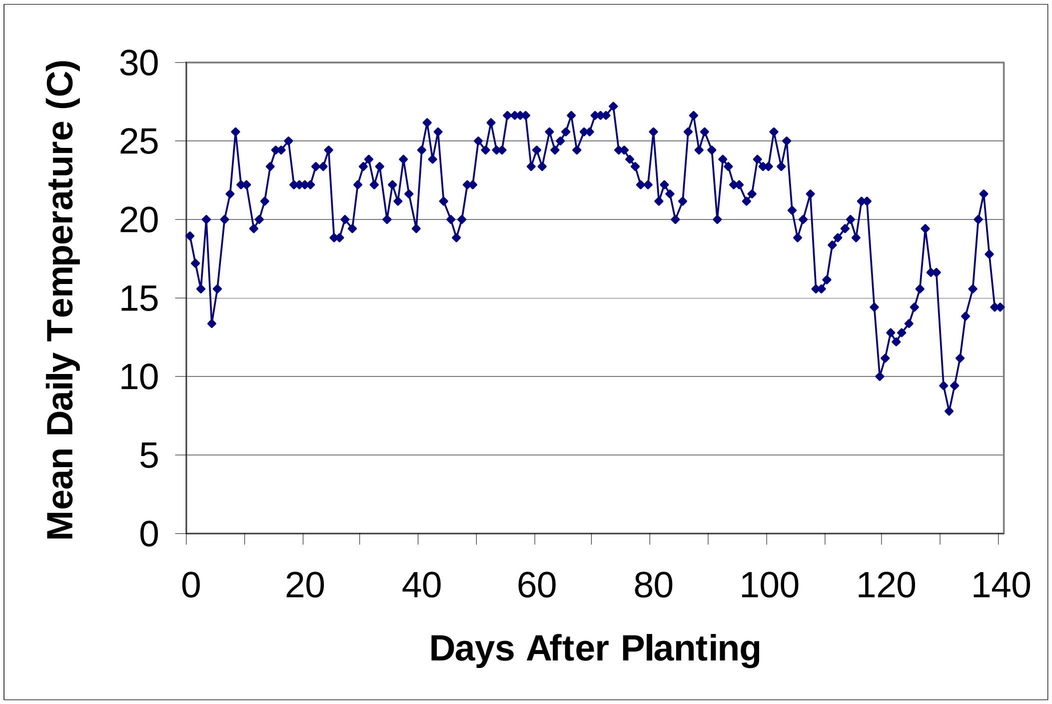

Figure 2.3: *2001 crop growing season average daily temperature – Quicksand.*

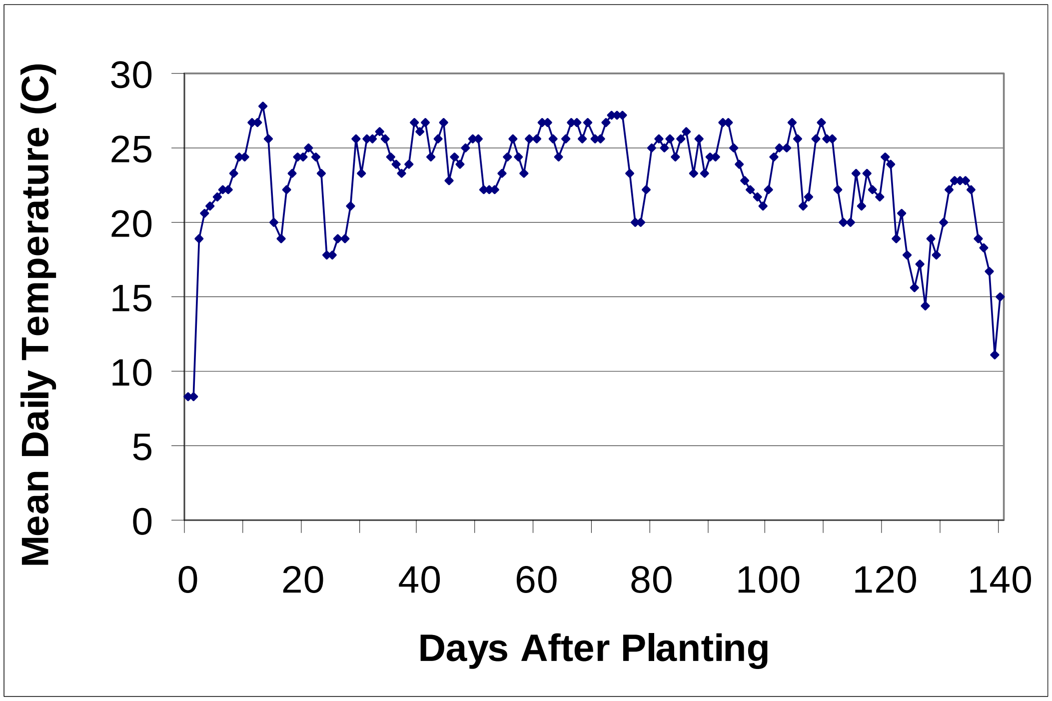

Figure 2.4: *2002 crop growing season average daily temperature – Quicksand.*

PRINCETON SITE

The experiment was located at the West Kentucky Research and Education Center near Princeton, Kentucky. The soil was a Sadler silt loam (fine-silty, mixed, mesic Glossic Fragiudalf). This series consists of moderately well-drained upland soils, and is usually found on gentle slopes of 2 to 6 percent. The upper part of the profile developed in loess, and the lower part in residuum weathered from sandstone, shale and siltstone. The surface layer of this soil is dark grayish-brown, friable silt loam 15 to 20 cm. thick. The upper part of the subsoil is yellowish-brown silt loam or silty clay loam. At a depth of about 40 cm, the subsoil is yellowish-brown, friable and has some light brownish-gray mottles. This soil has a heavy silt loam fragipan at a depth of about 55 cm. The soil is moderately high in both natural fertility and available moisture supply capacity and is strongly acid in the surface layer, unless limed (USDA and KAES, 1966).

The experimental area where the experiment was conducted had been kept in weedy grass sod, except for one year, since a four-year (1988-1991) experiment where corn was grown at four levels of available P (established with fertilizer and manure P) and in the presence and absence of hairy vetch. The soil was limed to give a pH of 6.8 in that trial. The one-year exception occurred in 1997 when another experiment, designed to test the interaction between water and phosphorus stress on soybean growth and development characteristics, was carried out in this experimental area. The plot layout was the same as that used in the first experiment.

We also used the plot layout from the first experiment to take advantage of the existing differences in available soil P levels. Table 2.3 illustrates the initial fertility of the 'existing' available soil P treatments. Organic matter was low, available K was low, and other fertility parameters were generally adequate.

Table 2.3: *Initial soil fertility information (0 to 20 cm) – 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)*
P1	1.7	6.6	3.5	56	1450	74	0.68
P2	1.8	6.6	4.5	50	1460	72	0.67
P3	1.8	6.5	8.3	54	1460	64	0.68
P4	2.3	6.8	19.0	70	1740	82	1.26

Treatments consisted of two levels of stratification, two levels of starter P fertilizer, and the four levels of "existing" soil P availability. Stratification treatments were created with moldboard plowing (low stratification – LS) and chisel plowing (high stratification – HS) of the existing sparse sod/weeds. Secondary tillage (disking three times) was used in both systems, to destroy remaining surface residues in the chisel plowed (HS) treatments and to create a more desirable seedbed in the entire experimental areas. Residues were destroyed in the chisel plowed treatments in order to remove differences in soil moisture conservation, via differences in soil surface evaporation, as a factor in the study. In the second year, the entire experimental area was planted without tillage in order to maintain the existing stratification.

The two levels of starter P fertilizer were applied in the row at planting, consisted of 0 and 10 kg P/ha, and were denoted as no starter (S0) and starter (S1). The four levels of original soil test P were 3.5, 4.5, 8.3, and 19.0 mg P/kg and were denoted as available soil P levels P1, P2, P3 and P4, respectively. As the experiment was conducted for two growing seasons, the starter P treatment was repeated in the second year, but available soil P levels were not modified by added P amendments.

The experimental design was laid out in four randomized blocks, with a factorial split plot arrangement of treatments. The main plot factorial consisted of available soil P by stratification (4 P levels by 2 stratification levels) and the 2 rates of starter P were the subplots. The plot size was 3.05 m (4 rows) wide by 12.2 m long.

Soybean (Pioneer 94B01, maturity group IV) was planted on 8 May, 2001 and 17 June, 2002, at a density of 300,000 seeds/ha in 2001 and 350,000 seeds/ha in 2002, at a row spacing of 76 cm. Other fertilizer materials were added according to University of Kentucky recommendations (Anonymous, 2000). Weed control was appropriate for the weed species present and consisted of both pre-emergence and post-emergence applications.

Plant tissue sampling, processing and analyses were done as described for the Quicksand site. Soil sampling and analyses were also done as described for the Quicksand site, except that only the main plot factorial treatments (available soil P level by stratification), and not the subplot treatments (rate of starter P) were sampled.

All data were statistically evaluated using appropriate analysis of variance procedures (SAS, 1993). When there was a significant effect due to the level of available P, and this factor did not interact with other treatment factors, an LSD test was used to separate treatment means.

Rainfall and Temperature

Rainfall during the 2001 growing season was generally good for soybean grain production (Figure 2.5). The crop suffered from drought stress during vegetative and early reproductive growth stages, but had plenty of moisture during the middle to late reproductive stages. During the 2002 season the rainfall had a pattern almost opposite to that seen in 2001 (Figure 2.6). Moisture was very good for crop growth and development until middle to late reproductive stages of the crop, when it became deficient. When tissue samples were taken at R5, corresponding to 73 days after planting, the crop was starting to show visible drought stress symptoms. From that point onwards the 2002 crop received very little rain until a few days before maturity (96 days after planting – Figure 2.6). The crop was under drought stress during a period in development when it needs high growth rates to maximize grain yield (Hardman and Brun, 1971; Jiang and Egli, 1995; Vasilas et al., 1995). Table 2.4 shows the dates and corresponding days after planting for each time the crop was sampled.

Table 2.4 *Dates of tissue sampling and grain harvest – Princeton, 2001 and 2002.*

Sampling stage	***Date***		***Days after planting***	
	2001	***2002***	***2001***	***2002***
Stage R1	06/26/2001	08/01/2002	49	45
Stage R5	07/31/2001	08/28/2002	84	73
Harvest	10/01/2001	10/22/2002	145	128

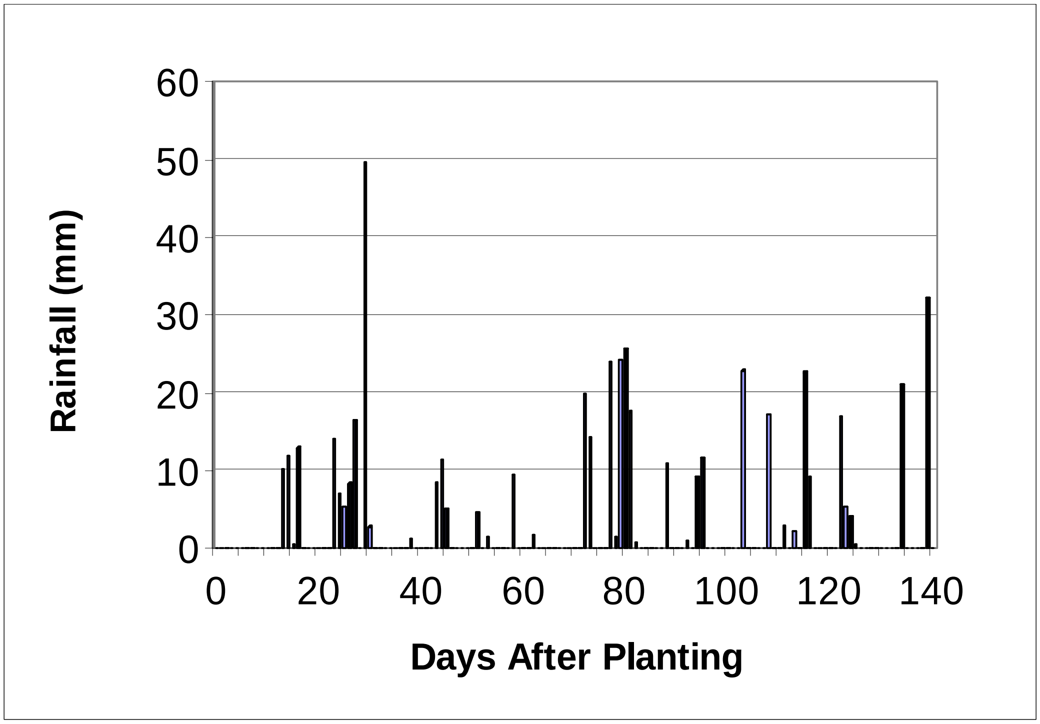

Figure 2.5: *2001 crop growing season rainfall – Princeton.*

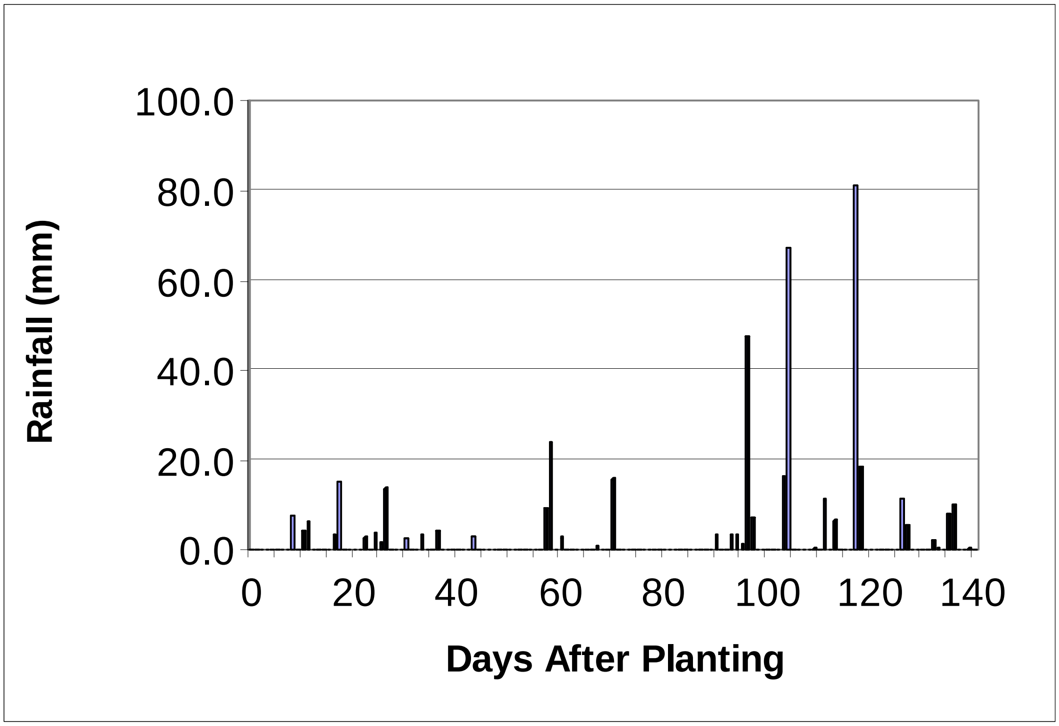

Figure 2.6: *2002 crop growing season rainfall – Princeton.*

Average daily air temperatures during the 2001 season (Figure 2.7) were near normal for this site and are within the optimum range of temperatures for soybean growth and development. During the 2002 season (Figure 2.8), average daily air temperatures were higher than normal for this area. These higher temperatures, combined with the lack of rainfall during this period, are believed to have stressed the soybean crop.

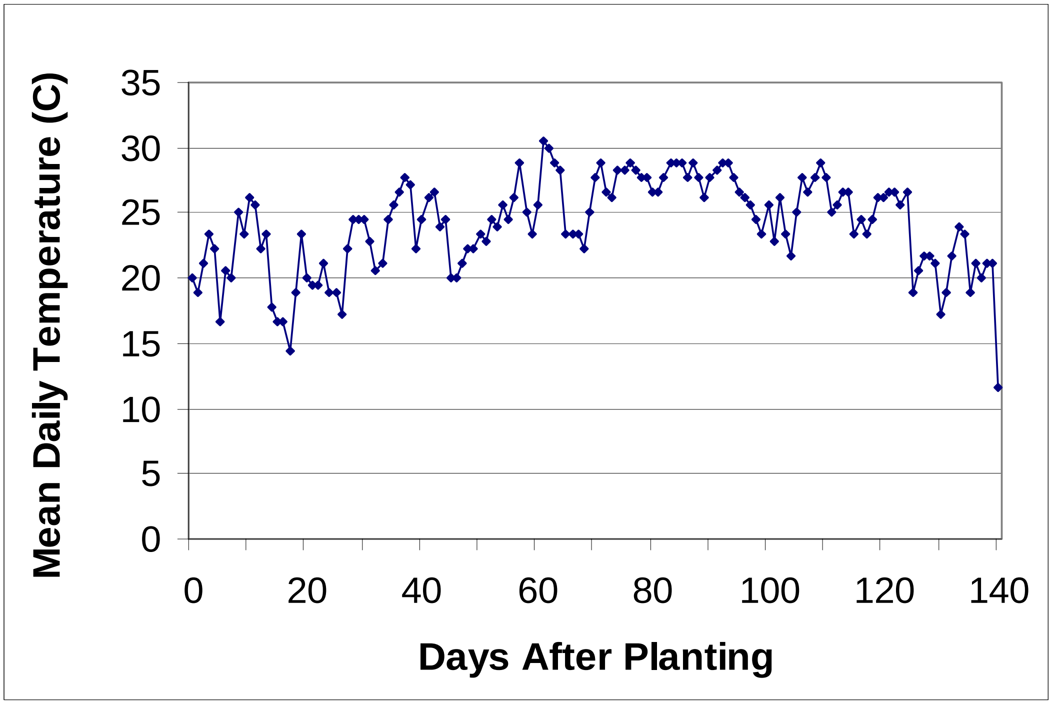

Figure 2.7: *2001 crop growing season average daily temperature – Princeton.*

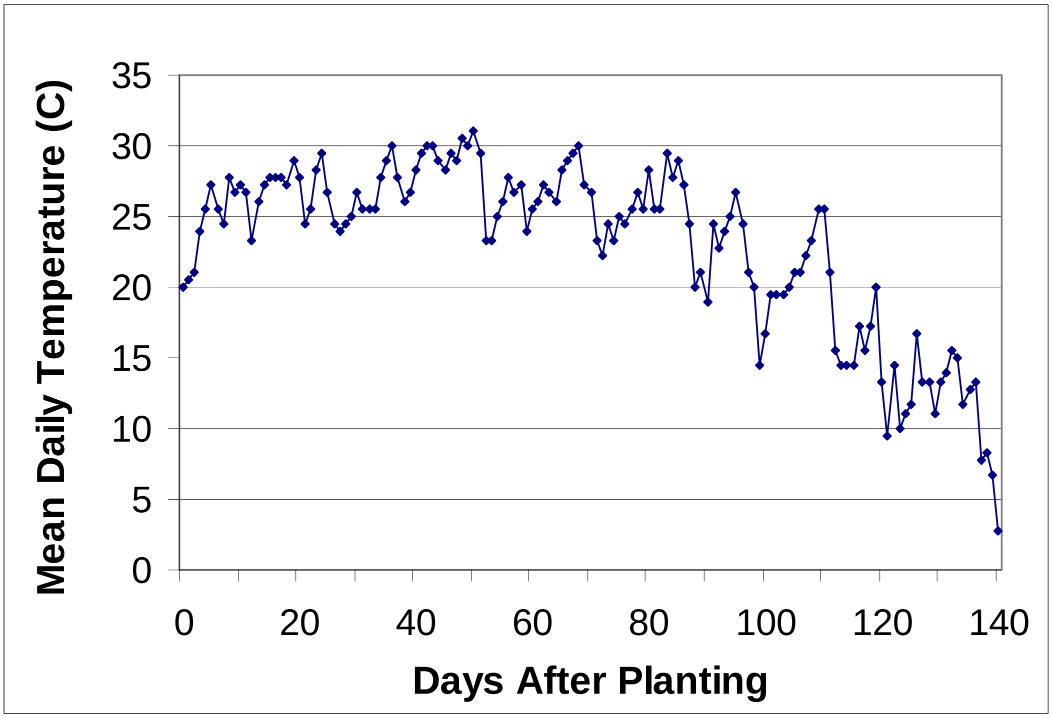

Figure 2.8: *2002 crop growing season average daily temperature – Princeton.*

CHAPTER 3

RESULTS AND DISCUSSION - QUICKSAND

This site was initially characterized by medium levels of soil test P and as having a high yield potential due to a usually excellent moisture supply to the crop and temperature and radiation levels assumed to be adequate for high grain yields. The tillage did influence stratification on Mehlich III P at the P1, P3 and P5 available soil P levels (Figures 3.1, 3.2 and 3.3). Tillage greatly affected soil P stratification in these plots.

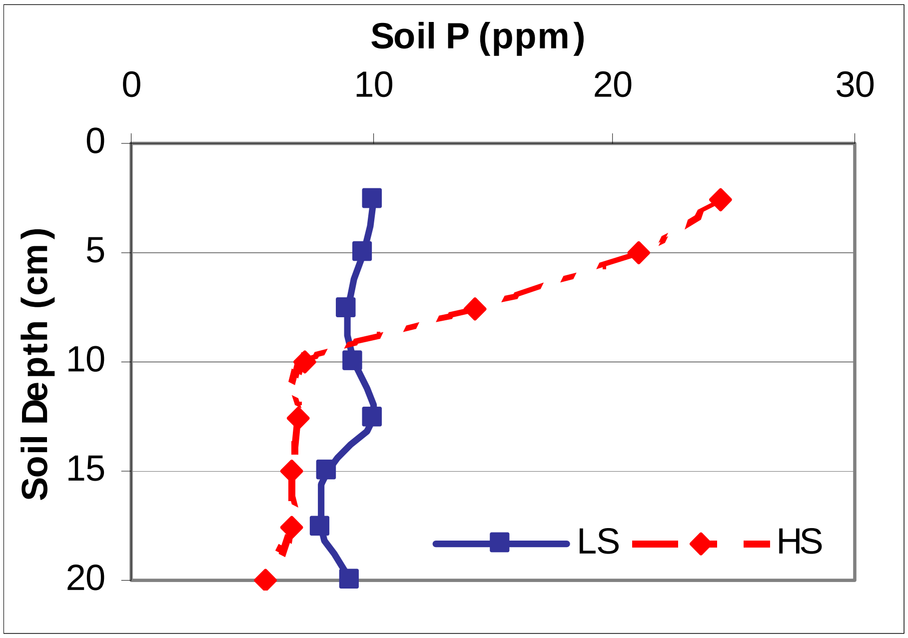

Figure 3.1: *Soil P (level P1) stratification – Quicksand, 2001. LS – low stratification; HS – high stratification.*

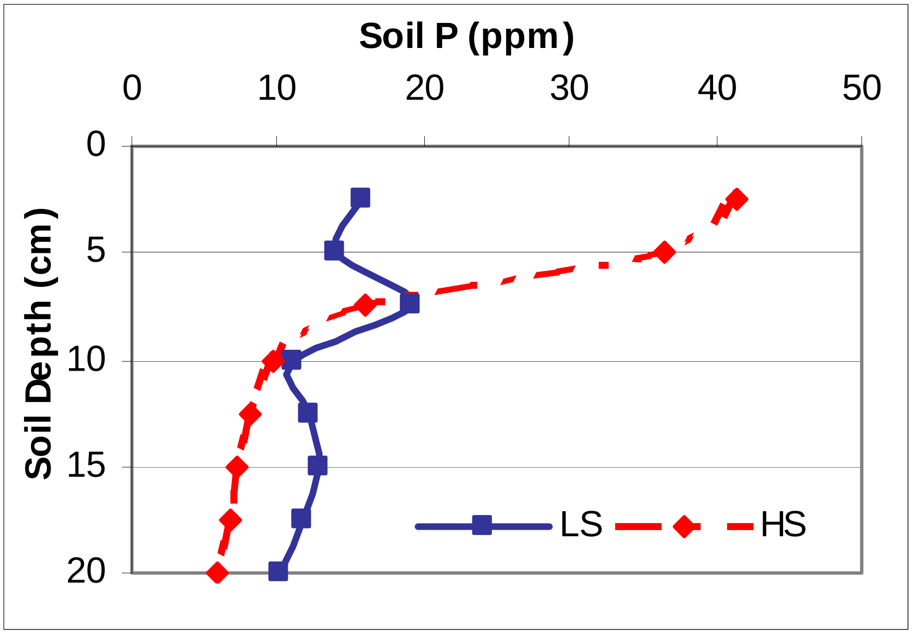

Figure 3.2: *Soil P (level P3) stratification – Quicksand, 2001. LS – low stratification; HS – high stratification.*

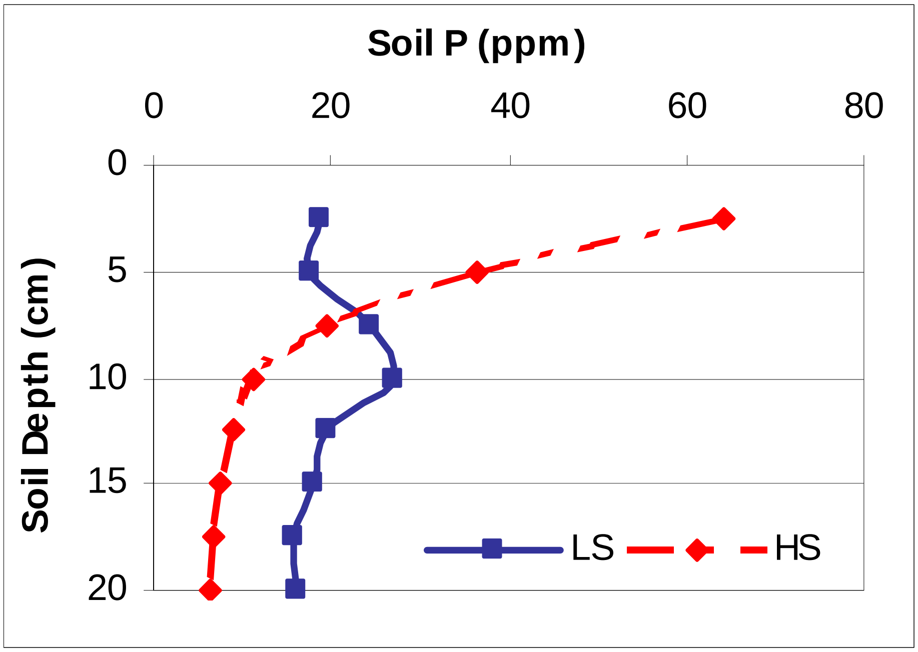

Figure 3.3: *Soil P (level P5) stratification – Quicksand, 2001. LS – low stratification; HS – high stratification.*

Dry Matter Production

Dry matter production at R1 and R5 was generally not increased by improved soil P availability at this location (Table 3.1). There was an inconsistent response at R1 in 2001. Dry matter production at both R1 and R5 sampling dates was affected by tillage-stratification in the 2001 season, but not in 2002 (Table 3.1). In 2001, the low stratification treatment produced 40 and 15% more dry matter at R1 and R5, respectively, than did the high stratification treatment. There was no interaction between stratification and soil P availability, so this difference due to stratification did not appear to be due to better phosphorus nutrition. It is most likely due to a better seedbed condition and consequent early growth and/or plant establishment in the low stratification treatment. The plant population was lower on the high stratification treatment.

Table 3.1: *Dry matter production at R1 and R5 – Quicksand, 2001 and 2002.*

Source of Variation	*Dry Matter Production at R1 (kg/ha)*		*Dry Matter Production at R5 (kg/ha)*	
	2001	***2002***	***2001***	***2002***
Stratification:				
High (HS)	1760 b	2680 a	9590 b	8720 a
Low (LS)	2460 a	2900 a	10980 a	8100 a
Soil P Level:				
P 1	2040 ab	3040 a	9930 a	7640 a
P 2	2290 a	2580 a	10030 a	8360 a
P 3	1760 b	2890 a	9470 a	8820 a
P 4	2310 a	2790 a	11880 a	8320 a
P 5	2160 ab	2650 a	10110 a	8920 a
Stratification by Soil P Level Interaction	NS†	NS	NS	NS

†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.

It is not strange that a difference in dry matter production that started very early in the crop's lifecycle is still a difference at later stages in that lifecycle. According to the interpretation of Hunt (1978) the crop growth rate of a crop (CGR) is the absolute growth or accumulation of dry matter in a certain amount of time over a certain area. If the same crop, at very early stages of growth, has areas with lower CGR due to reduced plant stand (less radiation interception) or to reduced growth of the plants (due to lower soil moisture content), these areas will never have the same dry matter at the same time as the ones that started with higher CGR. For this explanation it is assumed, as it is the same crop in both situations, that all plants have potentially the same leaf area ratio (LAR), the same net assimilation rate (NAR) and the same relative growth rate (RGR), (Hunt, 1978).

Phosphorus Nutrition

Leaf P Concentration and Soybean P Uptake

At R1, neither stratification nor differences in soil P levels caused differences in leaf P concentrations in either of the two cropping seasons, nor was there any interaction between the two treatment factors on leaf P (Table 3.2). Leaf P concentrations at R1 were high both years. These values are higher than those reported by Flannery (1989); EMBRAPA (1998); and Martins (personal communication, cited by Yamada, 1999) as critical for maximum soybean grain production.

At R5 , a critical developmental stage in soybean grain production, where maximum radiation interception and crop photosynthesis rates are needed to maximize grain yield (Hardman and Brun, 1971; Jiang and Egli, 1995; Vasilas et.al., 1995), neither stratification, soil P levels, or their interaction caused differences in leaf P concentrations in the 2001 season (Table 3.2). Soil P level caused small differences in the 2002 season (Table 3.2). The difference in R5 leaf P consisted of about 6% lower leaf P at the lowest soil P level. The difference in response between the two years was caused either by the removal of P in the previous crop, or due to less organic P mineralization due to use of the no-tillage management system in the second year. Even though no critical leaf P concentration values have been established for soybean at this developmental stage, the levels reached at the four highest soil P levels in this experiment were sufficient for high grain yield.

Table 3.2: *Soybean leaf P at R1 and R5 – Quicksand, 2001 and 2002.*

Source of Variation	***Leaf P Concentration at R1 (%)***		***Leaf P Concentration at R5 (%)***	
	2001	***2002***	***2001***	***2002***
Stratification:				
High (HS)	0.39 a	0.36 a	0.33 a	0.33 a
Low (LS)	0.37 a	0.37 a	0.32 a	0.33 a
Soil P Level:				
P 1	0.38 a	0.37 a	0.32 a	0.32 b
P 2	0.37 a	0.36 a	0.32 a	0.34 a
P 3	0.39 a	0.37 a	0.32 a	0.34 a
P 4	0.38 a	0.37 a	0.33 a	0.34 a
P 5	0.39 a	0.38 a	0.33 a	0.34 a
Stratification by Soil P Level Interaction	NS[†]	NS	NS	NS

[†] 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.

Total P uptake was affected by stratification and soil P level at R1 in the 2001 season, but not in 2002 (Table 3.3). There was no interaction between the treatment factors in either year. This effect is entirely a result of the dry matter response (Table 3.1) discussed previously. The greater dry matter production, with nearly equal tissue P concentrations, produced greater uptake of P.

Table 3.3: *Soybean P uptake at R1 and R5 – Quicksand, 2001 and 2002.*

Source of Variation	***Total P Uptake at R1 (kg/ha)***		***Total P Uptake at R5 (kg/ha)***	
	2001	***2002***	***2001***	***2002***
Stratification:				
High (HS)	5.6 b	8.7 a	34.6 a	29.1 a
Low (LS)	7.4 a	9.5 a	31.6 a	27.4 a
Soil P Level:				
P 1	6.0 bc	9.6 a	31.4 a	23.9 b
P 2	6.9 ab	8.0 a	30.9 a	27.7 ab
P 3	5.6 c	9.5 a	31.1 a	29.4 ab
P 4	7.1 a	9.3 a	38.8 b	28.6 ab
P 5	6.9 ab	9.2 a	33.6 a	31.6 a
Stratification by Soil P Level Interaction	NS[†]	NS	NS	NS

[†] 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.

In 2002, there were no differences in P uptake due to either treatment factor at R1, but there was a significant benefit of available soil P on soybean P uptake at R5 (Table 3.3). Again, no interaction between the treatment factors, on P uptake at R1 or R5, was found. The lowest soil P level, associated with a significantly lower R5 leaf P concentration (Table 3.2), and a non-significant 10% reduction in R5 dry matter (Table 3.1), also caused a significantly lower total R5 P uptake in 2002. Here, the lower P uptake is related to reductions in both dry matter and tissue P concentration and it is assumed that the non-significant decline in dry matter is due to a higher random variation in this variate, which increased the variation within treatments and decreased the sensitivity of the analysis of variance.

Grain P Concentration

At this site, stratification did not affect grain P concentration in either year, while soil test P level affected it only in 2002, when the lowest soil test P level resulted in a lower grain P concentration than all other soil P levels. Interactions between these two factors were not significant in either of the 2 years (Table 3.4).

Table 3.4: Grain P concentration – *Quicksand, 2001 and 2002***.**

Source of Variation	***Grain P Concentration (%)*** 2001	***Grain P Concentration (%)*** 2002
Stratification:		
High (HS)	0.59 a	0.68 a
Low (LS)	0.59 a	0.66 a
Soil P Level:		
P 1	0.60 a	0.65 b
P 2	0.59 a	0.68 a
P 3	0.59 a	0.67 a
P 4	0.58 a	0.67 a
P 5	0.59 a	0.69 a
Stratification by Soil P Level Interaction	NS[†]	NS

[†] 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.

Other Nutrients

Even though the main objective of this research was to analyze the effect of stratification on the P nutrition of soybeans, the behavior of some other nutrients with low soil mobility, such as potassium, zinc and magnesium, was also analyzed. Potassium and Zn were added to the entire experimental area before planting and after the stratification-tillage treatments were established. Consequently, differences in the soil profile distribution of these two nutrients are due to the interaction of the stratification tillage treatments with the existing amounts and distributions of available forms. These nutrients (K, Mg, Zn) are somewhat stratified in the upper layers in both stratification treatments (Figures 3.4, 3.5, 3.6), but K and Zn stratification were considerably stronger in the “high” stratification treatment.

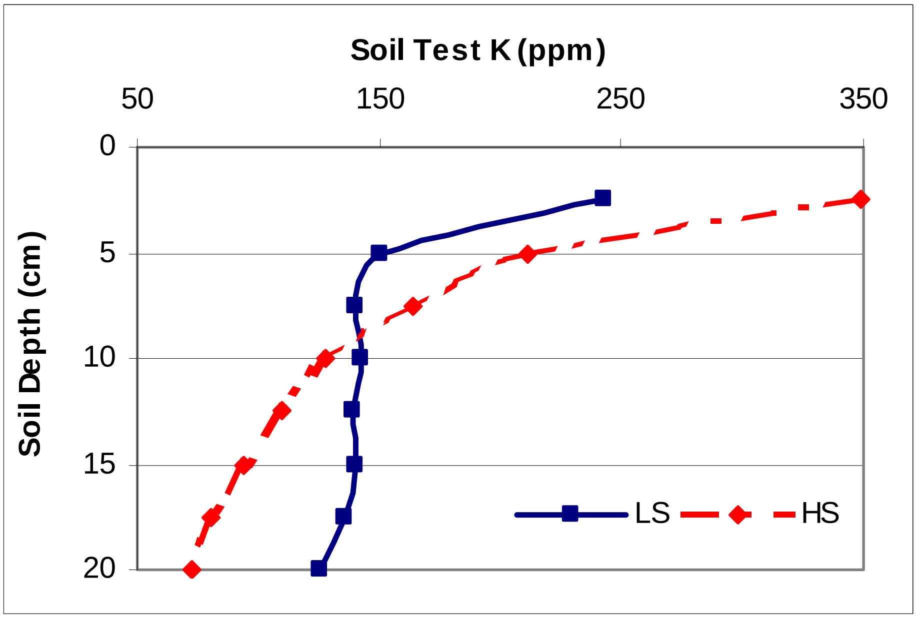

Figure 3.4: *Soil K distribution – Quicksand, 2001. LS – low stratification; HS – high stratification.*

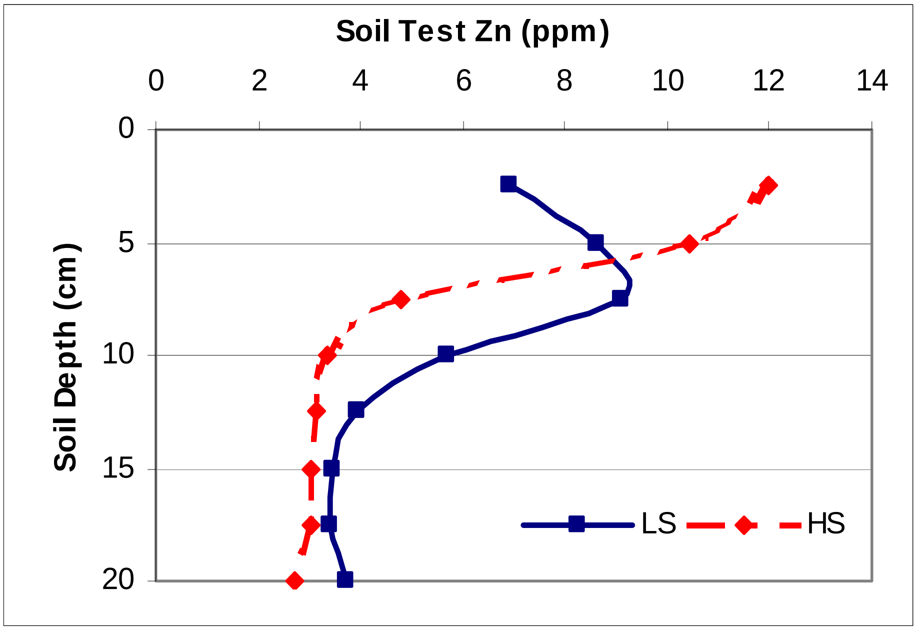

Figure 3.5: *Soil Zn distribution – Quicksand, 2001. LS – low stratification; HS – high stratification.*

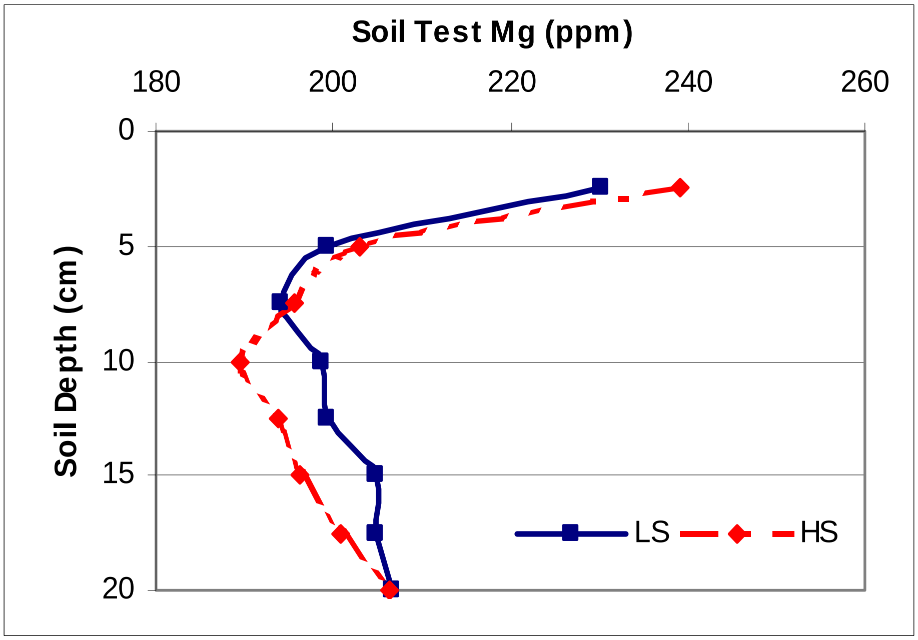

Figure 3.6: *Soil Mg distribution – Quicksand, 2001. LS – low stratification; HS – high stratification.*

Leaf Potassium

Leaf K concentration was only affected by stratification at R5 in the 2001 season (Table 3.5). High stratification resulted in 5% higher leaf K. At R1 in 2001 there was a non-significant 6% increase in leaf K with high stratification. There was no stratification effect on leaf K in 2002. Soil P level did not affect leaf K in either season. The cause of the seasonal difference in the leaf K response to stratification was not clear. It may be due to a nutrient dilution effect caused by the higher dry matter production observed in the low stratification treatments in 2001. The leaf K concentrations observed at R1, in both years, are high enough to support high soybean yields, according to established critical levels (Flannery, 1989; EMBRAPA, 1998 and Martins personal communication-cited by Yamada, 1999).

Table 3.5: *Soybean leaf K at R1 and R5 – Quicksand, 2001 and 2002.*

Source of Variation	***Leaf K Concentration at R1 (%)***		***Leaf K Concentration at R5 (%)***	
	2001	***2002***	***2001***	***2002***
Stratification:				
High (HS)	2.00 a	1.83 a	1.88 a	1.84 a
Low (LS)	1.88 a	1.81 a	1.80 b	1.84 a
Soil P Level:				
P 1	2.00 a	1.83 a	1.85 a	1.85 a
P 2	1.85 a	1.80 a	1.83 a	1.84 a
P 3	1.97 a	1.79 a	1.86 a	1.87 a
P 4	1.93 a	1.87 a	1.85 a	1.85 a
P 5	1.95 a	1.81 a	1.81 a	1.82 a
Stratification by Soil P Level Interaction	NS[†]	NS	NS	NS

[†] 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.

Grain K Concentration

Neither stratification, soil P level, nor their interaction caused differences in seed K concentration in either season. (Table 3.6).

Table 3.6: Grain K concentration – *Quicksand, 2001 and 2002***.**

Source of Variation	***Grain K Concentration (%)***	
	2001	***2002***
Stratification:		
High (HS)	2.01 a	2.14 a
Low (LS)	2.03 a	2.12 a
Soil P Level:		
P 1	2.03 a	2.11 a
P 2	2.00 a	2.12 a
P 3	2.01 a	2.15 a
P 4	2.03 a	2.15 a
P 5	2.02 a	2.12 a
Stratification by Soil P Level Interaction	NS[†]	NS

[†]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.

Leaf Magnesium

Neither stratification, soil P level, nor their interaction caused differences in leaf Mg concentrations at R1 and R5 in either season (Table 3.7). The leaf Mg concentrations observed at R1 were all higher than "critical" concentrations reported by Flannery, 1989; EMBRAPA, 1998 and Martins (personal communication - cited by Yamada, 1999).

Table 3.7: *Soybean leaf Mg at R1 and R5 – Quicksand, 2001 and 2002***.**

Source of Variation	***Leaf Mg Concentration at R1 (%)***		***Leaf Mg Concentration at R5 (%)***	
	2001	***2002***	***2001***	***2002***
Stratification:				
High (HS)	0.43 a	0.48 a	0.27 a	0.30 a
Low (LS)	0.46 a	0.46 a	0.28 a	0.31 a
Soil P Level:				
P 1	0.43 a	0.47 a	0.29 a	0.31 a
P 2	0.45 a	0.47 a	0.28 a	0.31 a
P 3	0.45 a	0.47 a	0.27 a	0.31 a
P 4	0.44 a	0.46 a	0.27 a	0.30 a
P 5	0.45 a	0.45 a	0.27 a	0.29 a
Stratification by Soil P Level Interaction	NS[†]	NS	NS	NS

[†] 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.

Grain Mg Concentration

Neither stratification, soil P levels, nor their interaction caused differences in grain Mg concentration in either season (Table 3.8).

Table 3.8: *Grain Mg concentration – Quicksand, 2001 and 2002***.**

Source of Variation	***Grain Mg Concentration (%)*** ***2001***	***2002***
Stratification:		
High (HS)	0.19 a	0.24 a
Low (LS)	0.19 a	0.24 a
Soil P Level:		
P 1	0.20 a	0.24 a
P 2	0.19 a	0.24 a
P 3	0.19 a	0.24 a
P 4	0.19 a	0.24 a
P 5	0.19 a	0.24 a
Stratification by Soil P Level Interaction	NS†	NS

†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.

Leaf Zinc

Leaf Zn concentration was not affected at R1, in either year, by the experimental treatments (Table 3.9). At R5, in both years, only the soil P level affected leaf Zn. This effect consisted of a decreasing leaf Zn concentration as the soil P level increased. There was no interaction between stratification and soil P level on leaf Zn concentrtions. The antagonistic effect of soil P on the Zn nutrition of plants is well known (Tisdale et al., 1993). Even though there was a significant difference in Zn leaf concentration among P treatments, all were well above the critical level for maximum soybean grain yield (Flannery, 1989; EMBRAPA, 1998; and Martins (personal communication - cited by Yamada, 1999).

Table 3.9: *Soybean leaf Zn at R1 and R5 – Quicksand, 2001 and 2002***.**

Source of Variation	***Leaf Zn Concentration at R1 (ppm)***		***Leaf Zn Concentration at R5 (ppm)***	
	2001	***2002***	***2001***	***2002***
Stratification:				
High (HS)	86.5 a	94.3 a	107.2 a	122.0 a
Low (LS)	82.4 a	97.9 a	105.8 a	114.1 a
Soil P Level:				
P 1	85.1 a	98.0 a	115.0 a	127.7 a
P 2	84.4 a	97.2 a	105.6 b	115.2 b
P 3	86.6 a	94.0 a	109.0 ab	117.4 b
P 4	83.2 a	93.6 a	101.8 b	116.7 b
P 5	82.8 a	97.7 a	102.0 b	113.2 b
Stratification by Soil P Level Interaction	NS[†]	NS	NS	NS

[†] 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.

Grain Zn Concentration

Neither stratification, soil P levels, nor their interaction caused differences in grain Zn concentration in 2001 season (Table 3.10), while increasing soil test P level reduced the Zn concentration of the grain in 2002. This was similar to the observed effect of soil P on leaf Zn in 2002 (Table 3.9). A significant soil test P by stratification interaction was observed in 2002 affecting grain Zn concentration (Table 3.10). The interaction consisted in a reduction in grain Zn concentration as the soil test P level increased in the low stratification treatment, while in the high stratification treatment the grain Zn concentration was similar for all the soil test P levels.

Table 3.10: *Grain Zn concentration – Quicksand, 2001 and 2002.*

Source of Variation	***Grain Zn Concentration (ppm)*** ***2001***	***2002***
Stratification:		
High (HS)	51.1 a	55.1 a
Low (LS)	51.7 a	54.9 a
Soil P Level:		
P 1	51.7 a	55.9 a
P 2	51.7 a	55.2 b
P 3	51.0 a	55.1 bc
P 4	51.2 a	54.3 c
P 5	51.5 a	54.4 c
Stratification by Soil P Level Interaction	NS[†]	**

[†] 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.

Grain Yield

At this site, neither stratification, soil P level, or their interaction, affected grain yield in the 2001 season (Table 3.11). It seems that all soil P levels under study, regardless of stratification, could provide soybean plants with enough P for the maximum grain yield attainable under this experiment's environmental conditions. These environmental conditions were very good, and yields were very high. It is also evident that earlier differences in R1 and R5 dry matter and leaf K concentrations, due to stratification, and in leaf Zn concentration, due to soil P level, did not affect soybean grain yield. Average yield in 2002 was considerably lower than in 2001. Among the factors affecting yield during this season were water stress during late reproductive growth stages and an infection of "Frogeye leaf spot" caused by the fungus *Cercospora* *sojina*, observed at R5 and confirmed by the University of Kentucky Disease Diagnostic Lab. In the 2002 season, the only factor that affected yield was stratification (Table 3.11). The low stratification environment produced 12% higher yield. As no difference in the several crop P nutrition indices already studied was observed, this yield difference is credited to some factor other than phosphorus nutrition. It is assumed that this difference was caused either by better moisture supply to the crop or by lower Frogeye leaf spot disease pressure in the low stratification treatment.

Table 3.11: *Grain Yield – Quicksand, 2001 and 2002***.**

Source of Variation	***Grain Yield (kg/ha)***	
	2001	***2002***
Stratification:		
High (HS)	4300 a	2990 b
Low (LS)	4280 a	3430 a
Soil P Level:		
P 1	4430 a	3240 a
P 2	4150 a	2970 a
P 3	4160 a	3400 a
P 4	4340 a	3190 a
P 5	4390 a	3250 a
Stratification by Soil P Level Interaction	NS[†]	NS

[†] 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.

CHAPTER 4

RESULTS AND DISCUSSION - PRINCETON

This site was characterized by very low to medium levels of soil test P. This soil has a fragipan at a depth of 55 to 60 cm, which limits root exploration and plant water and nutrient supply. Temperatures were optimum for soybean grain production, although temperatures were a bit higher than normal in 2002. The lack of rainfall in the 2002 season caused late drought stress in crop, which probably reduced grain yield. Even though the 2002 crop was planted in mid-June, it did not suffer from extreme low temperatures prior to harvest.

The average (0 to 20 cm) soil fertility parameters in the existing soil P treatments, determined after soybean harvest, are illustrated in Table 4.1. The influence of tillage induced stratification treatments on soil test P (at each P level) is illustrated in Figures 4.1, 4.2, 4.3 and 4.4.

Table 4.1: *Average (0-20 cm) soil fertility parameters – Princeton, 2001.*

Soil	***Organic***	***pH***	***Mehlich***	***Mehlich***	***Mehlich***	***Mehlich***	***Mehlich***

Test P Level	Matter (%)	(H_2O)	III P (mg/kg)	III K (mg/kg)	III Ca (mg/kg)	III Mg (mg/kg)	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

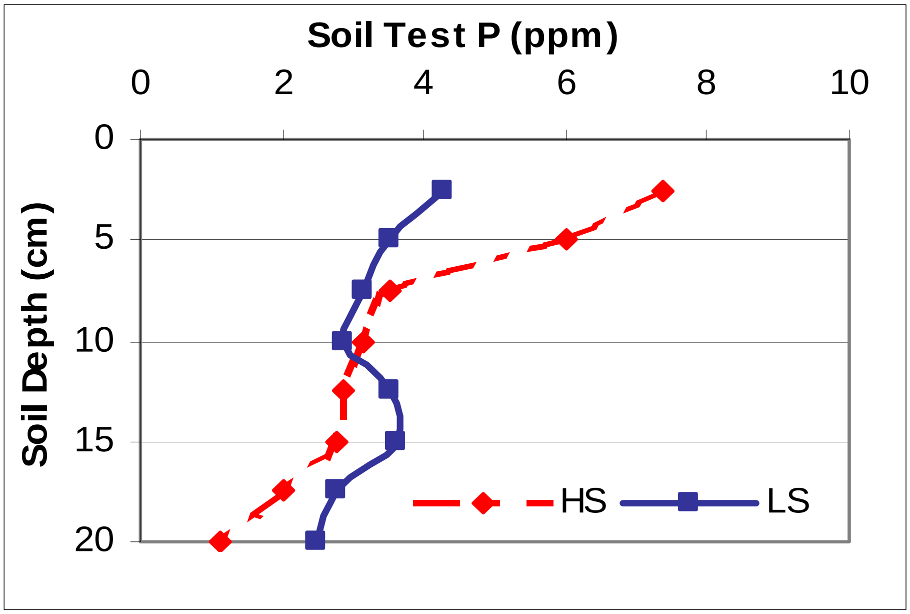

Figure 4.1: *Soil test P (Level P 1) stratification – Princeton, 2001. LS – low stratification; HS – high stratification.*

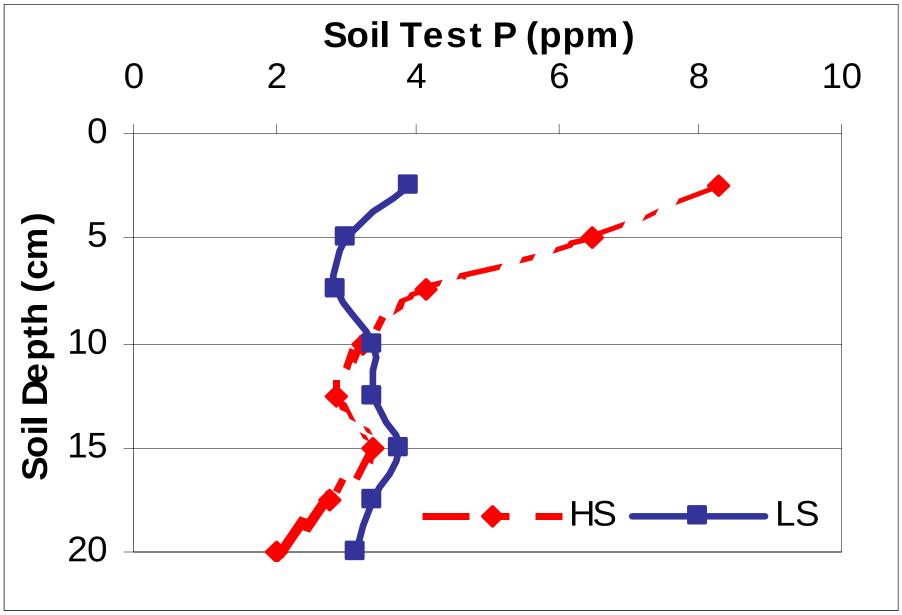

Figure 4.2: *Soil test P (Level P 2) stratification – Princeton, 2001. LS – low stratification; HS – high stratification.*

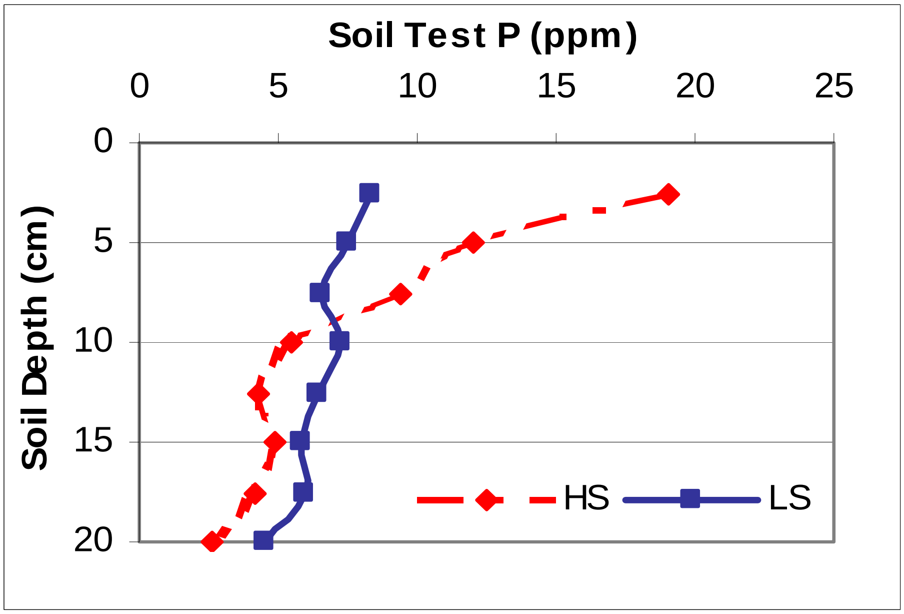

Figure 4.3: *Soil test P (Level P 3) stratification – Princeton, 2001. LS – low stratification; HS – high stratification.*

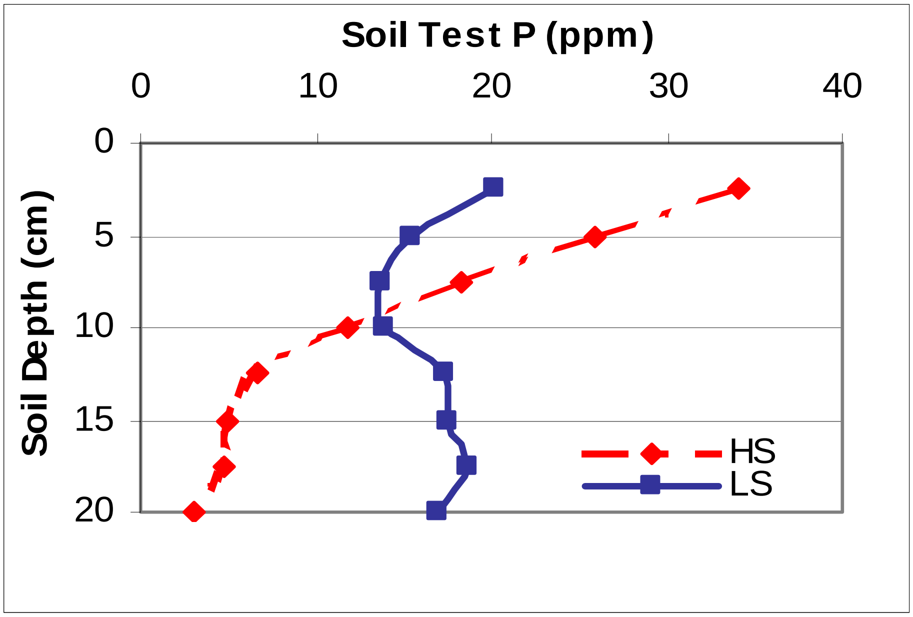

Figure 4.4: *Soil test P (Level P 4) stratification – Princeton, 2001. LS – low stratification; HS – high stratification.*

Dry Matter Production

Dry matter production was affected by stratification only at R1 in 2001, by the use of starter P at R1 in 2002, and by soil test P levels at both R1 and R5 in both years (Table 4.2). No interaction among treatment factors was observed at either R1 or R5 in either season. Low stratification increased R1 dry matter by 28% over the high stratification treatment in the 2001 season. This effect was mainly due to the better seedbed conditions and improved plant emergence present in the low stratification (moldboard plowed) treatment. The use of in-row starter P increased dry matter production by 13% only at R1 in 2002. The seasonal difference in the R1 dry matter response to starter P is not easily explained. The amount of P added, as starter, was not enough to significantly increase R5 dry matter production in either season. As will be discussed later, starter P usually increased the soybean leaf P concentration. The level of available P consistently and positively affected soybean dry matter production at both R1 and R5, in both years (Table 4.2). This response was expected, given the values of available soil P levels in the experiment.

Phosphorus Nutrition

Leaf P Concentration

In the 2001 season, leaf P concentrations at R1 were positively affected by the main effects of increasing soil test P level and the use of starter P (Table 4.3). At R5 in the 2001 season, and at R1 in 2002, leaf P concentrations were similarly responsive to the main effects of soil test P and starter P, but were also positively influenced by greater P stratification (Table 4.3). At R5 in 2002, leaf P responded only to available soil P level.

Table 4.2: *Soybean dry matter at R1 and R5 – Princeton, 2001 and 2002***.**

Source of Variation	***Dry Matter at R1 (kg/ha)***		***Dry Matter at R5 (kg/ha)***	
	2001	***2002***	***2001***	***2002***

Stratification:				
High (HS)	614 b	2330 a	3740 a	4810 a
Low (LS)	785 a	2230 a	3880 a	4810 a
Starter P:				
No (S0)	699 a	2140 b	3860 a	4920 a
Yes (S1)	700 a	2420 a	3750 a	4700 a
Soil P level:				
P 1	588 c	2070 c	3200 c	4180 c
P 2	631 bc	2020 c	3460 bc	4490 bc
P 3	751 ab	2370 b	3900 b	4980 b
P 4	830 a	2660 a	4670 a	5600 a
Stratification by P Level	NS[†]	NS	NS	NS
Stratification by Starter	NS	NS	NS	NS
Starter by P Level	NS	NS	NS	NS
Stratification by Starter by P Level	NS	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; means within a box followed by the same letter are not significantly different at the 90% level of confidence.

It is evident that stratification never lowered (sometimes raised) this index of soybean P nutrition, even when the crop was under drought stress.

An interaction between stratification and use of starter P on R5 leaf P was observed in the 2001 season (Figure 4.5). Regardless of soil test P level, stratification was beneficial to soybean P nutrition 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 as effective as starter P in improving soybean P nutrition. In the 2002 season, however, the treatment factors that interacted to affect the R1 leaf P concentration of soybean were soil test P level and the use of starter. In this interaction, the use of starter increased leaf P concentration when soil test P levels were low, but the effect diminished to nothing as the soil test P increased (Figure 4.6).

Table 4.3: *Soybean leaf P concentration at R1 and R5 – Princeton, 2001 and 2002.*

Source of Variation	*Leaf P at R1 (%)*		*Leaf P at R5 (%)*	
	2001	***2002***	***2001***	***2002***
Stratification:				
High (HS)	0.29 a	0.31 a	0.26 a	0.21 a
Low (LS)	0.29 a	0.30 b	0.24 b	0.20 a
Starter P:				
No (S0)	0.28 b	0.30 b	0.24 b	0.20 a
Yes (S1)	0.30 a	0.31 a	0.26 a	0.21 a
Soil P level:				
P 1	0.26 b	0.26 d	0.21 c	0.17 c
P 2	0.27 b	0.28 c	0.21 c	0.18 c
P 3	0.32 a	0.32 b	0.27 b	0.22 b
P 4	0.33 a	0.35 a	0.31 a	0.26 a
Stratification by P Level	NS[†]	NS	NS	NS
Stratification by Starter	NS	NS	**	NS
Starter by P Level	NS	**	NS	NS
Stratification by Starter by P Level	NS	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; means within a box followed by the same letter are not significantly different at the 90% level of confidence.

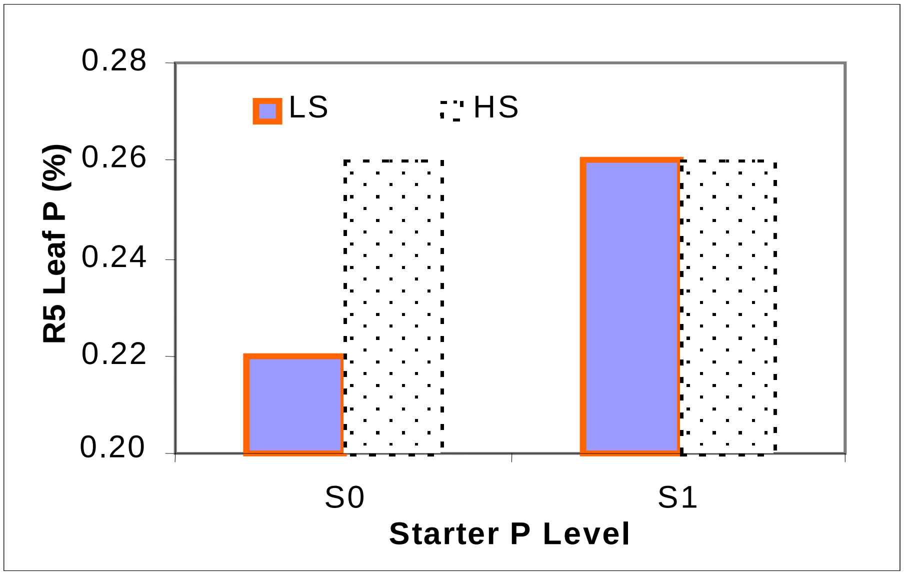

Figure 4.5: *P stratification by P starter interaction on R5 leaf P concentration in 2001.*

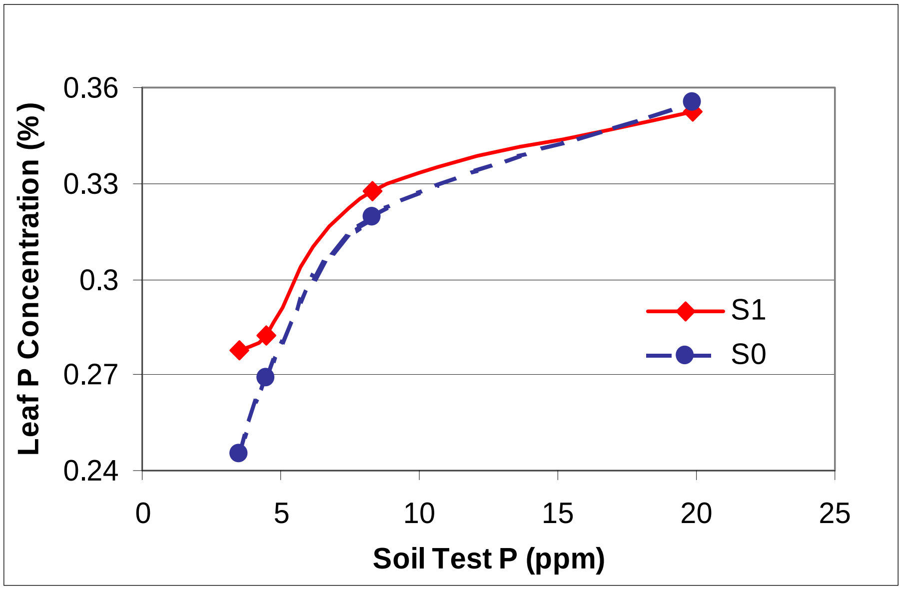

Figure 4.6: *Soil test P level by P starter interaction on R1 leaf P concentration in 2002.*

Total Phosphorus Uptake

Phosphorus uptake was affected by the main effect of soil test P at R1 and R5 in both seasons, by the use of starter P only at R1 in the 2002 season, and by stratification only at R1, regardless of season (Table 4.4). There was a non-significant trend for greater P uptake with use of starter P in the 2001 season, and a significantly negative effect of stratification at R1 in the same season. This latter effect was likely due to the previously discussed effect of stratification treatments on soybean dry matter at R1 in 2001 (Table 4.2), as there were no observed effects of stratification on leaf P at this sampling time (Table 4.3).

Table 4.4: *Soybean P uptake at R1 and R5 – Princeton, 2001 and 2002***.**

	Total P Uptake at R1 (kg/ha)		***Total P Uptake at R5 (kg/ha)***	
Source of Variation	***2001***	***2002***	***2001***	***2002***
Stratification:				
High (HS)	1.62 b	6.39 a	9.10 a	9.50 a
Low (LS)	2.14 a	5.78 b	8.82 a	9.81 a
Starter P:				
No (S0)	1.80 a	5.60 b	8.72 a	9.82 a
Yes (S1)	1.96 a	6.57 a	9.20 a	9.50 a
Soil P level:				
P 1	1.35 b	4.27 c	5.60 b	6.73 c
P 2	1.48 b	4.52 c	6.24 b	6.99 c
P 3	2.16 a	6.71 b	12.05 a	9.96 b
P 4	2.53 a	8.84 a	11.96 a	14.95 a
Stratification by P Level	NS[†]	NS	NS	NS
Stratification by Starter	NS	NS	**	NS
Starter by P Level	NS	NS	NS	NS
Stratification by Starter by P Level	NS	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. means within a box followed by the same letter are not significantly different at the 90% level of confidence.

An interaction between stratification and use of P starter was observed in P uptake at R5 in 2001 (Figure 4.7). The interaction was similar to that observed for R5 leaf P concentration in 2001 and indicated that, regardless of soil test P level, stratification was beneficial to soybean P nutrition when no starter P was applied.

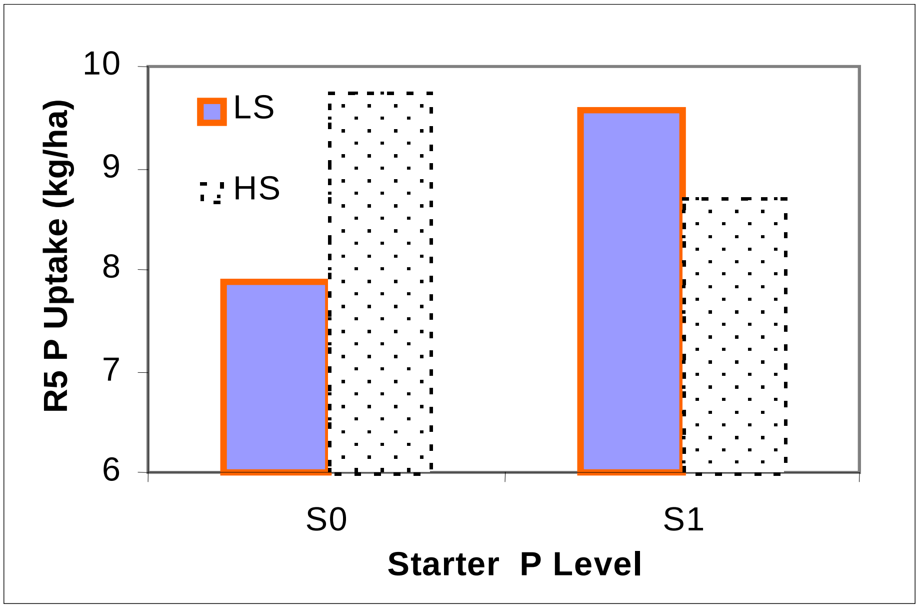

Figure 4.7: *P stratification by P starter interaction on P uptake at R5 in 2001.*

Grain P concentration

Grain P concentration in 2001 and in 2002 was influenced by all three main effects (Table 4.5). In 2001, high stratification increased grain P concentration by 7%, the use of starter raised it by 11%, and greater soil test P increased grain P by nearly 50% (Table 4.5), while in 2002 these increases, for the same factors, were 4%, 9% and 35%, respectively. There were no interactions among the main effects on grain P concentrations in 2001 (Table 4.5). In 2002, there was an interaction between starter P and stratification (Table 4.5, Figure 4.8). In this interaction, grain P was much more responsive to the use of starter where soil P was not highly stratified, said in other way, grain P levels were greater with the high P stratification, when no starter was used (Figure 4.8).

Table 4.5: *Soybean grain P concentration – Princeton, 2001 and 2002***.**

Source of Variation	***Grain P concentration (%)***	
	2001	***2002***
Stratification:		
High (HS)	0.49 a	0.50 a
Low (LS)	0.46 b	0.48 b
Starter P:		
No (S0)	0.45 b	0.47 b
Yes (S1)	0.50 a	0.51 a
Soil P level:		
P 1	0.39 c	0.43 c
P 2	0.42 c	0.44 c
P 3	0.51 b	0.51 b
P 4	0.58 a	0.58 a
Stratification by P Level	NS[†]	NS
Stratification by Starter	NS	*
Starter by P Level	NS	NS
Stratification by Starter by P Level	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. means within a box followed by the same letter are not significantly different at the 90% level of confidence.

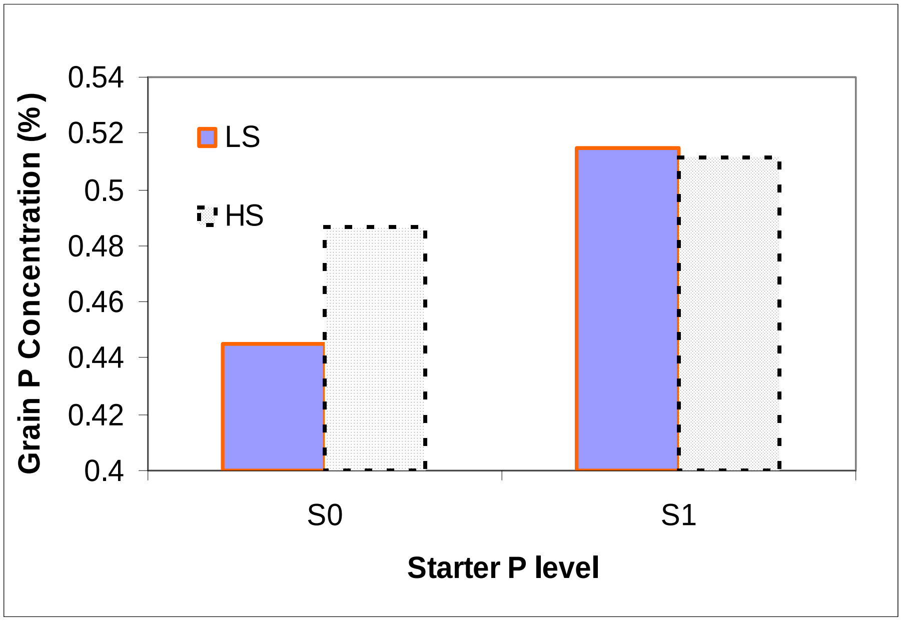

Figure 4.8 *Starter by stratification interaction on soybean grain P concentration – Princeton, 2002.*

OTHER NUTRIENTS

Even though the main objective of the work was to analyze the effect of stratification on the P nutrition of soybean, crop response to the availability of other low mobility nutrients, such as potassium, zinc and magnesium, was also examined. Potassium and Zn were added to the entire experimental area before planting, but after the tillage-stratification treatments were in place. Consequently, there was no large difference in the distribution of these nutrients within the topsoil (0 to 20 cm) profile (Figures 4.9, 4.10 and 4.11). It is evident that K and Zn are strongly stratified, regardless of stratification treatment. Available Mg is much more homogeneously distributed in the low stratification treatment.

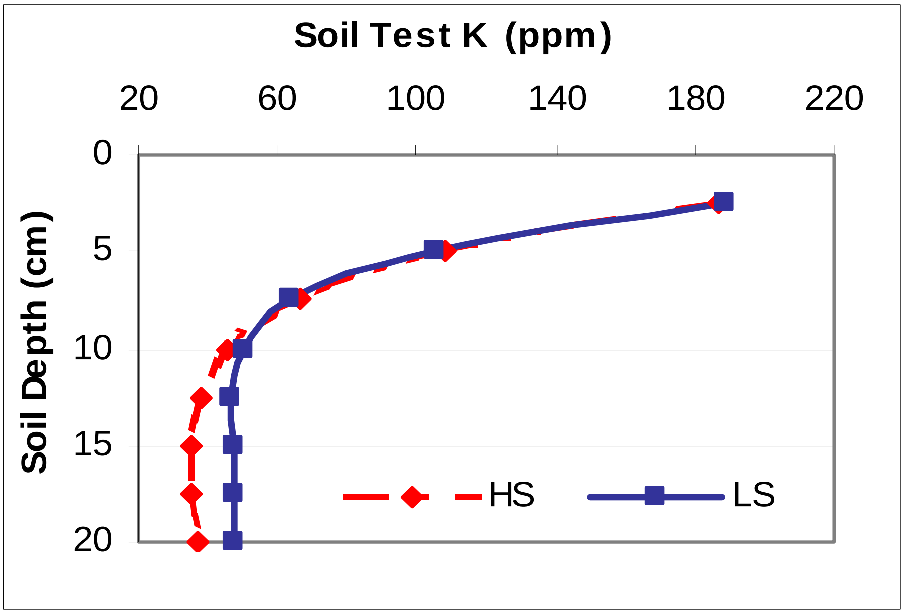

Figure 4.9: *Available soil K distribution – Princeton, 2001. LS – low stratification; HS – high stratification.*

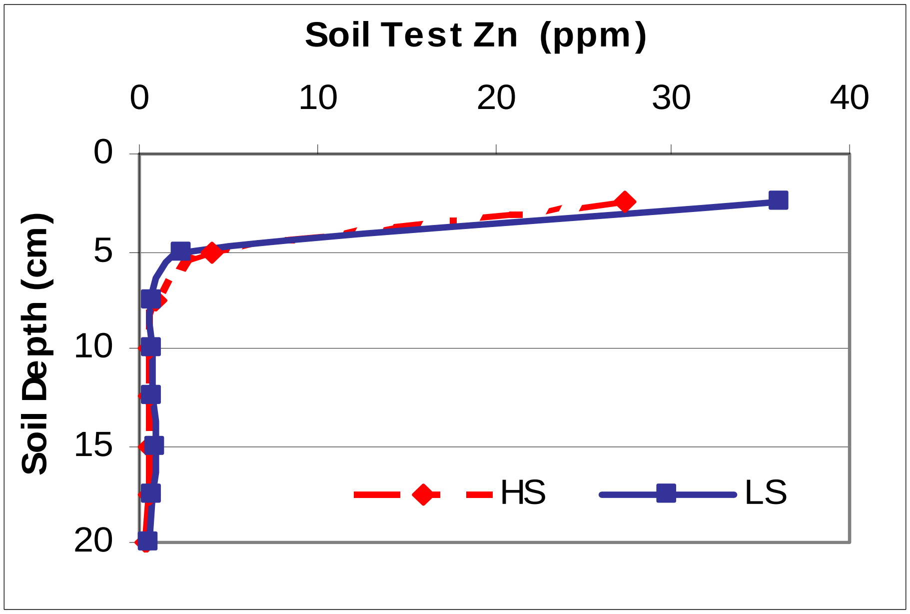

Figure 4.10: *Available soil Zn distribution – Princeton, 2001. LS – low stratification; HS – high stratification.*

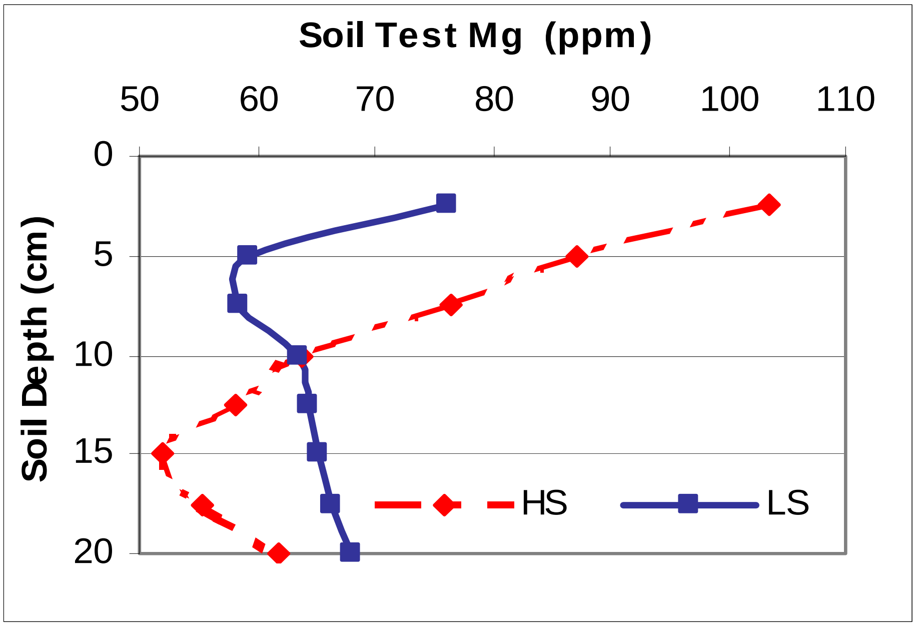

Figure 4.11: *Available soil Mg distribution – Princeton, 2001. LS – low stratification; HS – high stratification.*

Potassium Nutrition

Leaf K concentrations were increased by high stratification only at R5 in 2001 (Table 4.6). Leaf K was not positively affected by the use of starter P at any time; there was a negative response to starter at R5 in 2002. Increasing soil test P did not affect leaf K at R1 in either of the two seasons studied, while negatively affected it at R5 in both 2001 and 2002 (Table 4.6). Leaf K concentration was lower as the soil test P level increased, and given that dry matter production increased with the increase in soil test P level, the results suggest that the difference observed in leaf K concentration at R5 can be due to a dry matter dilution effect. At early stages of crop development, when dry matter was low, the available potassium was enough to maintain equal leaf K concentrations, regardless of the soil test P levels. At R5, when dry matter production was much higher, the soil could not provide enough potassium to maintain equal leaf K concentrations at all soil test P levels. It is evident from Table 4.6 that the dilution effect appears for P1, P2 and P3, but not for P4. This difference in behavior at P4 is likely related to the fact that P4 had significantly higher soil test K levels than the other soil P level treatments at the start of the experiment. At R1, there was also an increase in dry matter with greater soil P, but the dilution influence of this response on leaf K was not observed. In 2001 this was because R1 dry matter production was so low. In 2002, the relative differences in R1 dry matter production among the soil P level treatments were much smaller than those observed at R5.

Table 4.6: *Soybean leaf K concentration at R1 and R5 – Princeton, 2001 and 2002.*

Source of Variation	***Leaf K at R1 (%)***		***Leaf K at R5 (%)***	
	2001	***2002***	***2001***	***2002***
Stratification:				
High (HS)	1.84 a	1.17 a	1.57 a	1.07 a
Low (LS)	1.75 a	1.08 a	1.41 b	1.01 a
Starter P:				
No (S0)	1.77 a	1.15 a	1.47 a	1.10 a
Yes (S1)	1.81 a	1.04 a	1.51 a	0.98 b
Soil P level:				
P 1	1.84 a	1.19 a	1.65 a	1.13 a
P 2	1.75 a	1.13 a	1.50 b	1.06 ab
P 3	1.71 a	1.05 a	1.36 c	1.00 b
P 4	1.87 a	1.15 a	1.46 bc	0.98 b
Stratification by P Level	NS[†]	NS	NS	NS
Stratification by Starter	NS	NS	NS	NS
Starter by P Level	NS	**	NS	NS
Stratification by Starter by P Level	NS	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; means within a box followed by the same letter are not significantly different at the 90% level of confidence.

There was a significant interaction between use of starter and soil P level on leaf K concentration at R1 in 2002 (Table 4.6, Figure 4.12). The explanation for this interaction is not clear, though it seems that when starter was used at soil P levels P1 and P2 leaf K was lower than when it was not used. Just the opposite was observed at soil P levels P3 and P4. It is also evident from Figure 4.12 that leaf K generally decreased between soil P level P1 and P3, while increasing between P3 and P4.

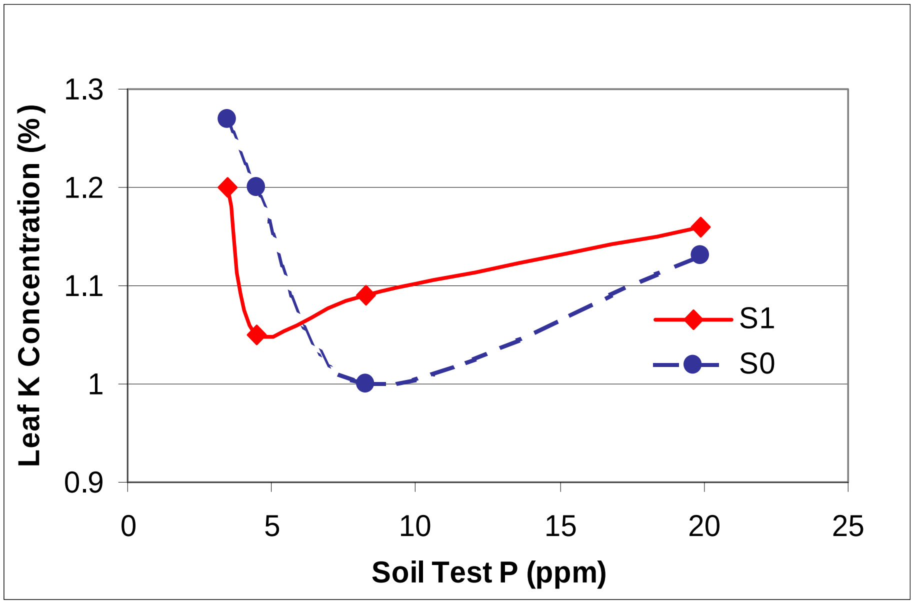

Figure 4.12: *Soil P level by starter P interaction on leaf K at R1 – Princeton, 2002.*

Grain K Concentration

In the 2001 season grain K concentration was affected only by soil P level, and was higher for the highest soil test P levels. This was not in agreement with observed trends in leaf K with increasing available soil P (Table 4.7). In the 2002 season, grain K was affected by starter P and by soil test P level (Table 4.7). The use of starter P resulted in higher grain K concentrations as did the highest soil test P level (Table 4.7). An interaction between stratification and starter P was also observed on grain K (Table 4.7).

Table 4.7: Soybean grain K concentration – Princeton, 2001 and 2002**.**

Source of Variation	***Grain K Concentration (%)***	
	2001	***2002***
Stratification:		
High (HS)	2.05 a	1.76 a
Low (LS)	2.05 a	1.74 a
Starter P:		
No (S0)	2.03 a	1.73 b
Yes (S1)	2.07 a	1.78 a
Soil P level:		
P 1	1.99 b	1.71 b
P 2	1.98 b	1.71 b
P 3	2.08 a	1.75 b
P 4	2.13 a	1.83 a
Stratification by P Level	NS[†]	NS
Stratification by Starter	NS	**
Starter by P Level	NS	NS
Stratification by Starter by P Level	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; means within a box followed by the same letter are not significantly different at the 90% level of confidence.

Magnesium Nutrition

Leaf Mg concentration was positively affected by the use of starter P only at R5 in 2002, but was positively influenced by increasing soil test P level at all sampling dates in both years (Table 4.8). As there is no known direct effect of available P on Mg nutrition reported in the literature, the benefit is believed to be derived from the improved general status of the soybean due to reduced P deficiency. The leaf Mg concentrations observed at the lowest soil test P level at R1 in 2001, which are considerably lower than those observed at the same growth stage in 2002, are somewhat below the range of considered optimal for maximum soybean grain production by Flannery (1989); EMBRAPA (1998); and Martins (personal communication - cited by Yamada, 1999). Even though these leaf Mg concentrations are a little below those considered optimal, it is important to note that the optimal designation was for nutrient concentrations in the uppermost completely expanded trifoliates. This sampling was of all the leaves of the plant, and considering that Mg is a nutrient with high mobility within the plant (Tisdale, et al., 1993), it is highly probable that the concentration of Mg in the uppermost completely expanded trifoliates was higher than the 0.33% critical value.

An interaction between soil test P level and the use of starter on leaf Mg was observed at R1 in 2002 (Table 4.8). This interaction was confusing and not easy to explain. When starter P was used at low soil test P levels the leaf Mg concentration was higher than when no starter is used, but at higher levels of soil test P, just the opposite was observed (Figure 4.13).

Table 4.8: *Soybean leaf Mg concentration at R1 and R5 – Princeton, 2001 and 2002***.**

Source of Variation	***Leaf Mg at R1 (%)***		***Leaf Mg at R5 (%)***	
	2001	***2002***	***2001***	***2002***
Stratification:				
High (HS)	0.33 a	0.44 a	0.35 a	0.38 a
Low (LS)	0.36 a	0.44 a	0.35 a	0.38 a
Starter P:				
No (S0)	0.35 a	0.44 a	0.35 a	0.37 b
Yes (S1)	0.35 a	0.44 a	0.35 a	0.39 a
Soil P level:				
P 1	0.31 b	0.41 b	0.32 c	0.35 b
P 2	0.35 a	0.44 a	0.34 bc	0.37 b
P 3	0.38 a	0.45 a	0.37 ab	0.38 ab
P 4	0.36 a	0.46 a	0.39 a	0.42 a
Stratification by P Level	NS[†]	NS	NS	NS
Stratification by Starter	NS	NS	NS	NS
Starter by P Level	NS	**	NS	NS
Stratification by Starter by P Level	NS	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; means within a box followed by the same letter are not significantly different at the 90% level of confidence.

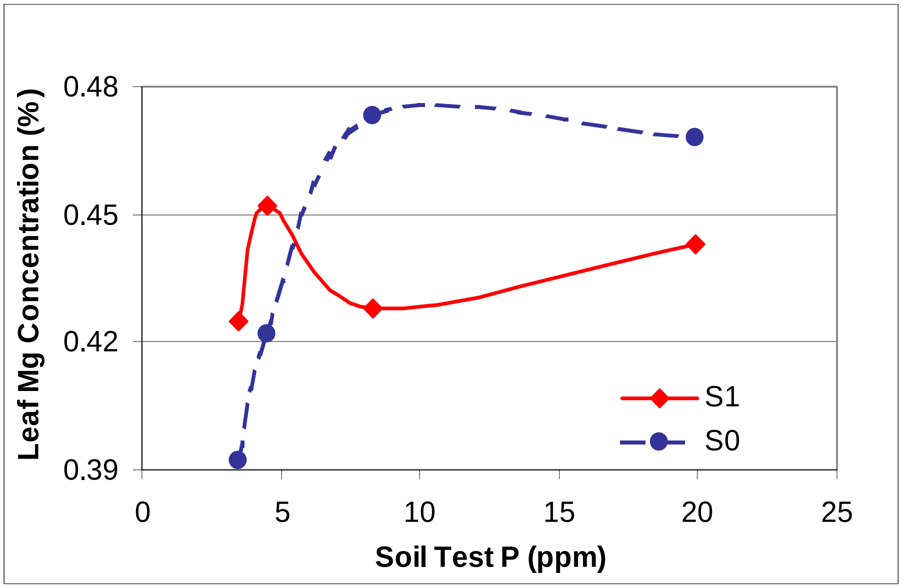

Figure 4.13: Soil P level by starter P interaction on leaf Mg at R1 – Princeton, 2002.

Grain Magnesium Concentration

Soybean grain Mg concentration was affected only by soil test P level in both years. The effect was similar to the one observed for leaf Mg concentration and consisted of higher levels of grain tissue Mg as the soil test P level increased (Table 4.9).

Table 4.9: Soybean grain Mg concentration – Princeton, 2001 and 2002**.**

Source of Variation	***Grain Mg Concentration (%)***	
	2001	***2002***

Stratification:		
High (HS)	0.13 a	0.22 a
Low (LS)	0.13 a	0.21 a
Starter P:		
No (S0)	0.13 a	0.21 a
Yes (S1)	0.13 a	0.21 a
Soil P level:		
P 1	0.12 b	0.21 b
P 2	0.12 b	0.21 b
P 3	0.13 a	0.21 b
P 4	0.13 a	0.22 a
Stratification by P Level	NS[†]	NS
Stratification by Starter	NS	NS
Starter by P Level	NS	NS
Stratification by Starter by P Level	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; means within a box followed by the same letter are not significantly different at the 90% level of confidence.

Zinc Nutrition

Leaf Zn concentration was negatively affected at R1 and R5, in both years, by soil test P level (Table 4.10). This antagonistic effect of soil phosphorus on the Zn nutrition of plants is well known (Tisdale et. al., 1993). Despite the significant difference in leaf Zn due to the soil P treatments, all leaf Zn values were well above the cited critical range for maximum soybean grain production (Flannery, 1989; EMBRAPA, 1998; Martins, personal communication - cited by Yamada, 1999). Interactions between stratification and starter P; between soil P level and starter P; and the three way interaction of stratification by soil P level by starter P on leaf Zn were observed at different times (Table 4.10). In the interaction between soil test P level and starter P, the leaf Zn at the lowest soil test P was lower with the use of starter than when starter was not used, while at the highest soil test P levels, just the opposite was observed (Figure 4.14). In the stratification by starter P interaction, the leaf Zn concentration decreased greatly when starter P was applied with low stratification, while not changing a great deal when starter was used on highly stratified soil (Figure 4.15). The three-way interaction is not illustrated, as it is not easily explained. Even with all the interactions and effects observed in leaf Zn, little attention needs to be paid, nutritionally, as these concentrations were all high and in no case even close to the critical level for soybean grain production.

Table 4.10: Soybean *leaf Zn concentration at R1 and R5 – Princeton, 2001 and 2002.*

Source of Variation	***Leaf Zn at R1 (%)***		***Leaf Zn at R5 (%)***	
	2001	***2002***	***2001***	***2002***

Stratification:				
High (HS)	38.1 a	71.5 a	71.5 a	93.3 a
Low (LS)	38.5 a	70.2 a	70.8 a	84.4 a
Starter P:				
No (S0)	38.8 a	72.0 a	72.1 a	90.4 a
Yes (S1)	37.8 a	69.7 a	70.2 a	87.3 a
Soil P level:				
P 1	40.4 a	71.9 b	84.9 a	89.3 b
P 2	40.8 a	80.2 a	84.2 a	106.5 a
P 3	36.5 b	72.1 b	59.3 b	87.9 b
P 4	35.5 b	59.4 c	56.2 b	71.6 c
Stratification by P Level	NS[†]	NS	NS	NS
Stratification by Starter	NS	*	NS	NS
Starter by P Level	**	NS	NS	NS
Stratification by 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. means within a box followed by the same letter are not significantly different at the 90% level of confidence.

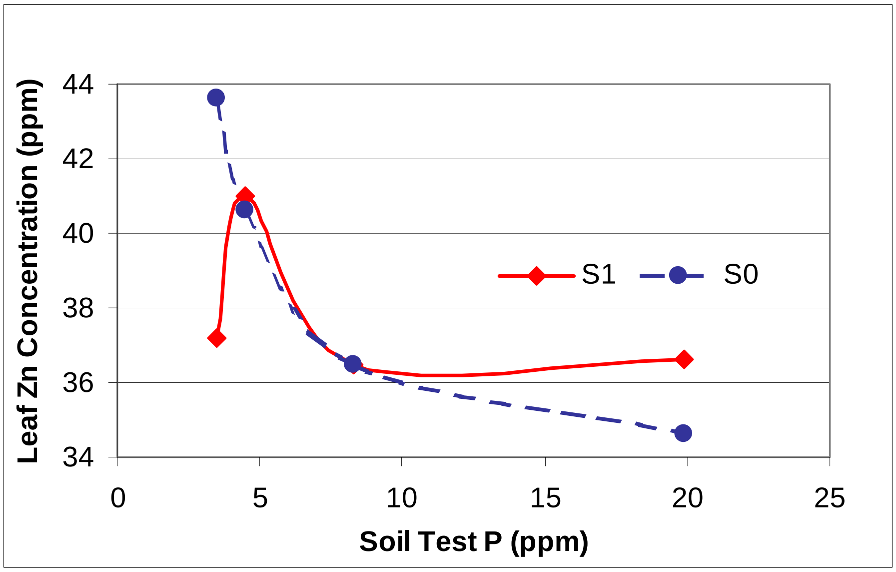

Figure 4.14: Soil P level by starter P interaction on leaf Zn at R1– Princeton, 2001.

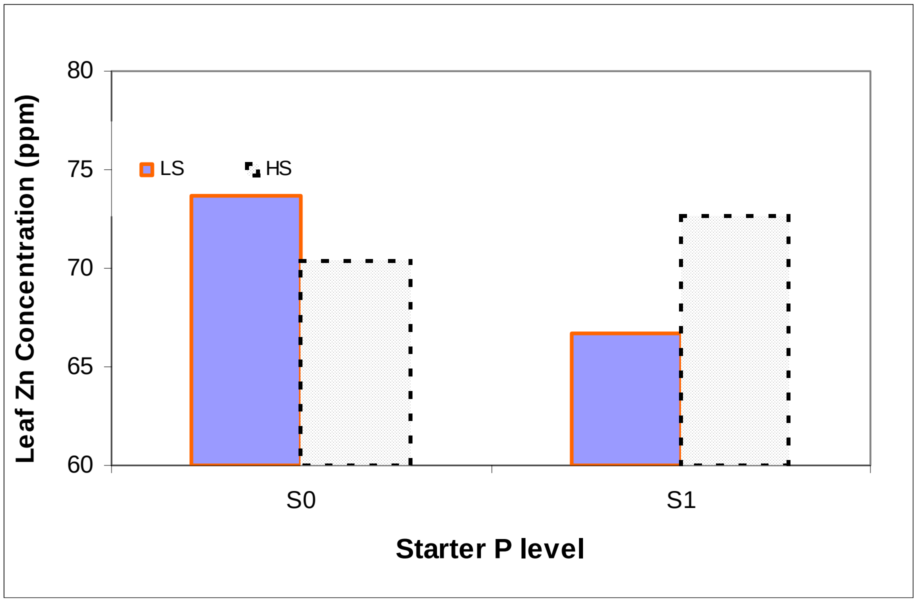

Figure 4.15: Stratification by starter P interaction on leaf Zn at R1 – Princeton, 2002.

Grain Zinc Concentration

Grain Zn concentration was negatively affected by increasing soil test P level in both years (Table 4.11). This effect was similar to what was observed for leaf Zn and is attributable to the already mentioned antagonistic effect of P on Zn nutrition of plants. The use of starter reduced grain Zn concentration in 2002. Interactions between the use of starter P and soil test P level on grain Zn concentrations were observed in both years, while interaction between stratification and soil test P level was only observed in 2001; and between stratification and starter P only in 2002 (not shown).

Table 4.11: Soybean grain Zn concentration – Princeton, 2001 and 2002**.**

Source of Variation	***Grain Zn Concentration (%)***	
	2001	***2002***
Stratification:		
High (HS)	60.1 a	62.8 a
Low (LS)	61.4 a	62.9 a
Starter P:		
No (S0)	61.5 a	63.7 a
Yes (S1)	60.0 a	62.1 b
Soil P level:		
P 1	65.7 a	64.9 a
P 2	61.9 b	64.6 a
P 3	58.4 bc	62.3 b
P 4	57.1 c	59.8 c
Stratification by P Level	*[†]	NS
Stratification by Starter	NS	*
Starter by P Level	*	**
Stratification by Starter by P Level	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; means within a box followed by the same letter are not significantly different at the 90% level of confidence.

Grain Yield

Soybean grain yields were very different between the two seasons. It is evident from Table 4.12 that the 2001 season had much higher grain yields than the 2002 season. The causes of these differences was probably the drought stress in 2002, and the fact that the crop was planted much later in 2002 than in 2001. There was likely a reduction in radiation interception during reproductive stages with this planting delay, particularly at the wider row spacing employed at this location. Stratification only affected yields during the 2002 season, when the highly stratified treatment produced 12% higher yields. The use of starter P, as well as increasing soil P availability, positively affected grain yields in both years, suggesting a good crop response to P addition (Table 4.12). In the 2001 season there was a starter P by soil test P level interaction on soybean grain yield, and a stratification by starter P interaction occurred in both years (Table 4.12, Figures 4.16, 4.17 and 4.18). In the starter P by soil test P interaction, use of starter P 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 (Figure 4.16). In the stratification by starter P interaction, observed both years, the grain yield was much more responsive to starter P with low stratification than with high stratification.

Table 4.12: *Soybean grain yield – Princeton, 2001 and 2002.*

Source of Variation	***Grain Yield (kg/ha)***	
	2001	***2002***
Stratification:		
High (HS)	2930 a	1680 a
Low (LS)	2870 a	1500 b
Starter P:		
No (S0)	2800 b	1520 b
Yes (S1)	3000 a	1650 a
Soil P level:		
P 1	2320 d	1420 c
P 2	2530 c	1540 b
P 3	3270 b	1660 a
P 4	3480 a	1730 a
Stratification by P Level	NS[†]	NS
Stratification by Starter	**	*
Starter by P Level	**	NS
Stratification by Starter by P Level	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;

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

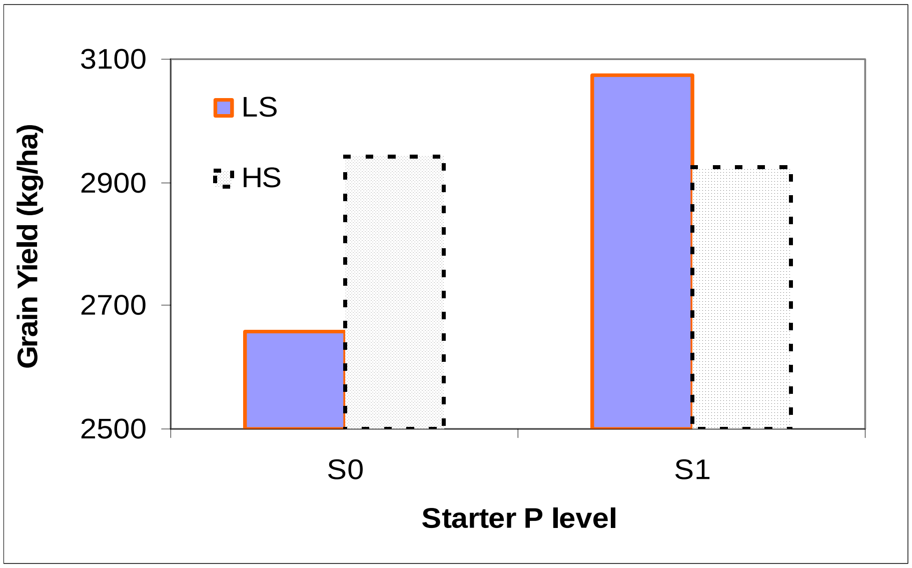

Figure 4.16: *Starter P level by soil P stratification level interaction on grain yield – Princeton, 2001.*

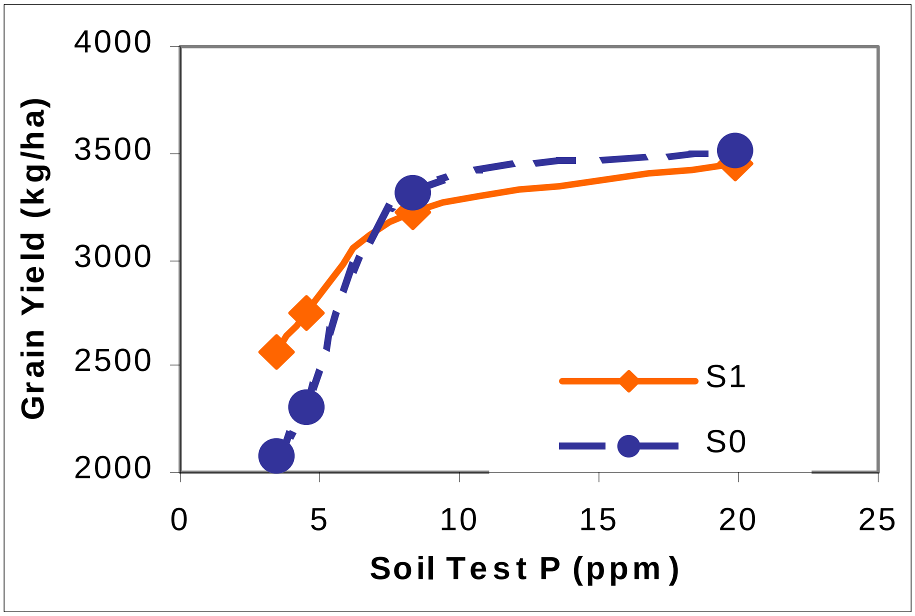

Figure 4.17: *Starter P level by soil test P interaction on grain yield – Princeton, 2001*

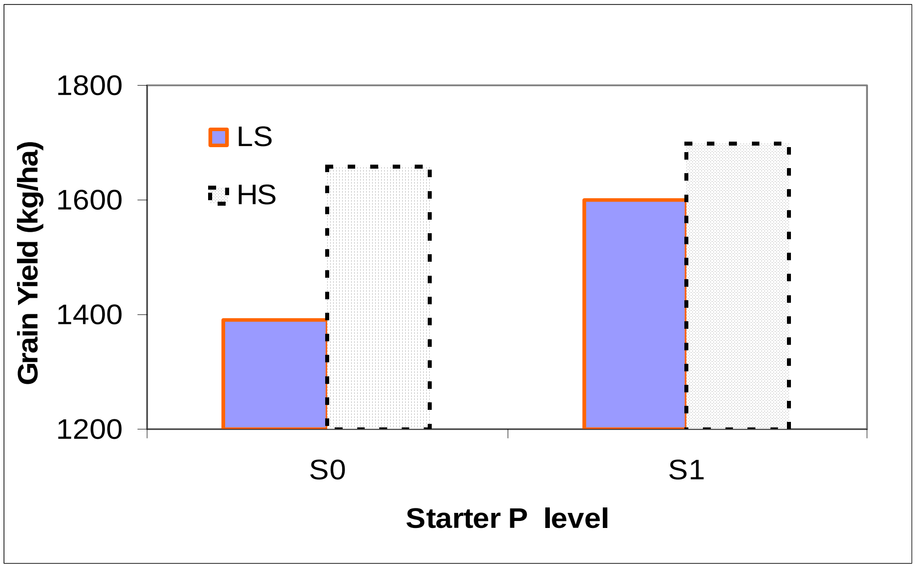

Figure 4.18: *Starter P level by soil test P interaction on grain yield – Princeton, 2002*

CHAPTER 5

FINAL ANALYSIS AND CONCLUSIONS

Soil P Stratification

The data obtained in both experiments suggest that stratification of soil P did not have much effect on soybean P nutrition, as indicated by leaf P concentrations or by total P uptake, thus the hypothesis that soil P stratification would negatively affect P nutrition of soybean was rejected. When the relative to the maximum (for each site-year) leaf P concentrations at R1 and R5 were related to soil test P for each of the soil P stratification treatments across all 4 site-years, it was found that both levels of stratification produced very similar responses in these two variates. The response function that provided the best fit, in all situations, was a quadratic-plateau (Figure 5.1). From these response functions, the soil test P levels where the maximum relative leaf P concentrations at R1 were achieved are 13.9 and 13.0 ppm P for HS and LS treatments, respectively. The hypothesis that higher available soil P would overcome the effect of soil P stratification was also rejected. When the same analysis was done for relative leaf P concentrations at R5, the quadratic-plateau response function also fitted very well (Figure 5.2). The soil test P levels that achieved maximum relative leaf P concentrations at R5 were 13.4 and 14.5 ppm for HS and LS, respectively.

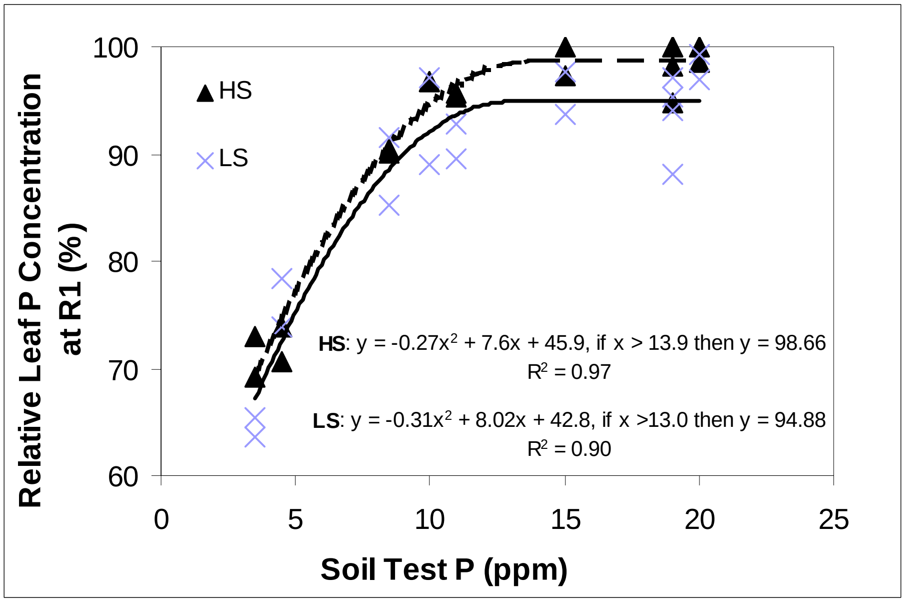

Figure 5.1: Relative leaf P at R1 as a function of soil test P for each stratification treatment. Princeton (only S0 treatments) and Quicksand, 2001 and 2002.

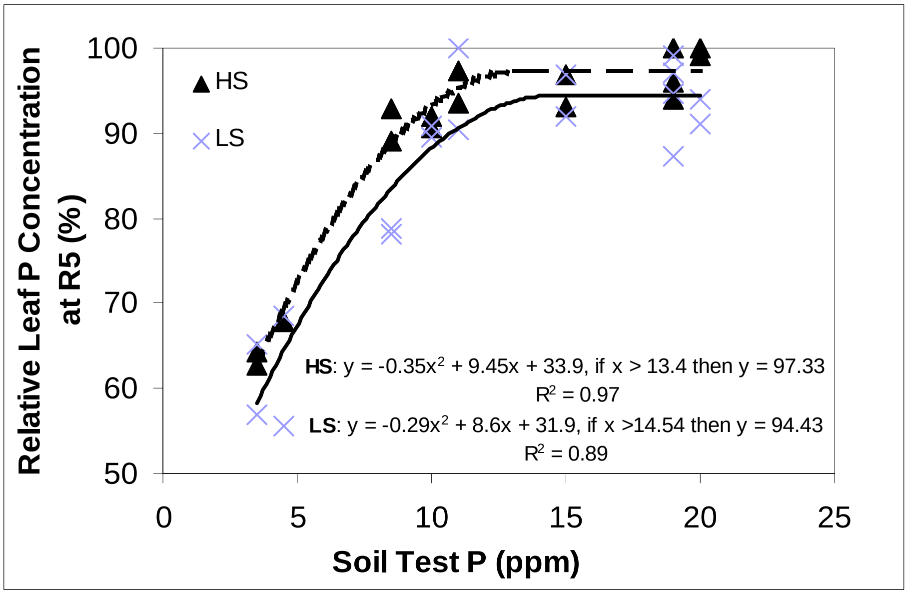

Figure 5.2: Relative leaf P at R5 as a function of soil test P for each stratification treatment. Princeton (only S0 treatments) and Quicksand, 2001 and 2002.

Total P uptake at R5 was also well related to soil test P in both stratification treatments (Figure 5.3). The quadratic-plateau response functions predict a soil test P level of 13.3 ppm to produce maximum total P uptake in the HS treatment, and 19.8 ppm in the LS treatment. The values are what we might expect, if the principle benefits of fertilizer P banding (reduced fixation and greater root contact) are to be believed, thus the hypothesis that the use of starter P would overcome the effect of stratification was rejected. The highly stratified treatment achieved maximal P uptake at lower average (0 to 20 cm) soil test P values because the upper portion of the topsoil is considerably higher in available soil P, in effect a two-dimensional band of available P. This is further supported by the several stratification by starter P interactions on soybean P nutritional parameters and on grain yield. Starter P was much less beneficial when soil P was stratified than when soil P was well mixed throughout the upper 20 cm of soil. It is evident from these data that stratification of available soil P does not negatively affect the phosphorus nutritional status of soybean.

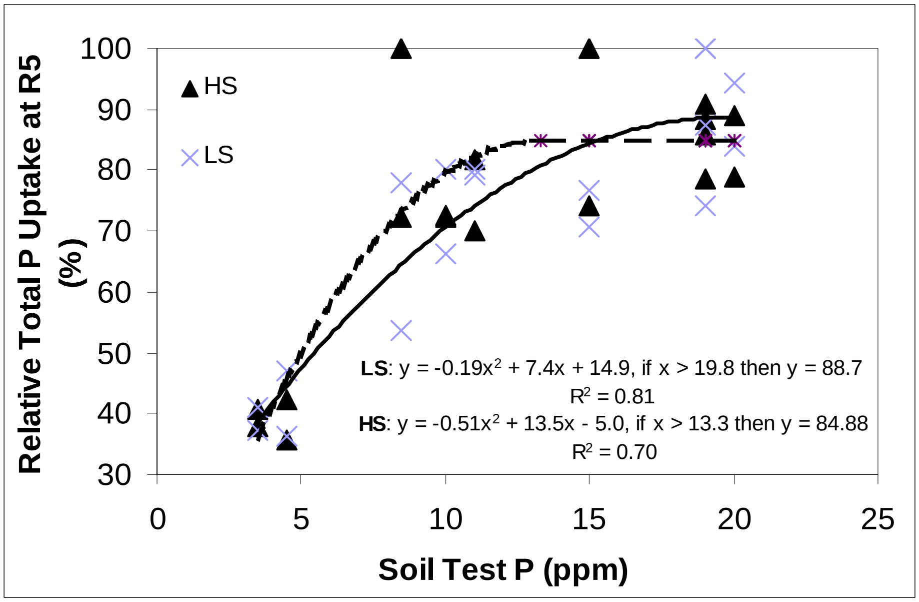

Figure 5.3: Relative total P uptake at R5 as a function of soil test P for each stratification treatment. Princeton (only S0 treatments) and Quicksand, 2001 and 2002.

APPENDIX A

COMPLIMENTARY DATA – QUICKSAND

Table A.1 *Quicksand Plot Plan.*

		Rep 1	Rep 2	Rep 3	Rep 4	Rep 5
	P1	13	28	49	19	39
	P2	12	27	47	21	36
HS	***P3***	11	26	50	20	40
	P4	9	30	46	8	38
	P5	10	29	48	7	37
	P1	1	17	34	22	43
	P2	5	15	35	6	44
LS	***P3***	4	18	32	23	45
	P4	3	16	31	24	42
	P5	2	14	33	25	41

Table A.2. *Leaf nutrient concentrations at R1 – Quicksand, 2001.*

Plot Number	N Conc. (%)	P Conc. (%)	K Conc. (%)	Mg Conc. (%)	Zn Conc. (ppm)
1	5.51	0.415	1.92	0.59	55.52
2	4.32	0.402	2.05	0.47	63.29
3	4.42	0.384	2.26	0.42	58.56
4	4.51	0.386	2.04	0.43	63.74
5	3.92	0.335	2.06	0.48	61.82
6	4.53	0.348	1.77	0.49	75.23
7	4.04	0.388	2.09	0.42	95.38
8	4.19	0.357	2.01	0.48	77.48
9	4.06	0.384	1.88	0.53	70.27
10	4.16	0.406	2.1	0.57	69.26
11	4.62	0.404	2.07	0.50	72.41
12	4.06	0.387	2.17	0.42	70.27
13	4.49	0.39	2.27	0.40	67.00
14	5.28	0.427	2.15	0.54	74.32
15	5.04	0.385	1.96	0.47	73.20
16	5.33	0.395	1.72	0.53	87.27
17	4.97	0.43	1.79	0.45	94.59
18	5.04	0.401	2.06	0.48	98.65
19	4.69	0.348	1.72	0.42	93.13
20	4.05	0.368	1.81	0.47	116.33
21	4.39	0.347	1.71	0.51	88.29
22	3.99	0.33	1.96	0.42	93.13
23	4.5	0.365	1.75	0.52	79.50
24	4.83	0.39	1.67	0.44	92.45
25	4.72	0.394	1.86	0.43	80.97
26	3.89	0.426	2.03	0.45	83.33
27	4.31	0.397	1.86	0.41	94.37
28	3.36	0.37	2.11	0.45	91.55
29	3.97	0.397	2.05	0.35	90.20
30	3.82	0.389	1.95	0.42	80.63
31	4.41	0.388	1.85	0.39	92.57
32	4.64	0.372	2.04	0.46	77.59
33	4.94	0.383	1.7	0.47	74.55
34	4.63	0.351	1.82	0.47	74.55
35	5.09	0.374	1.62	0.49	90.32
36	4.34	0.394	1.83	0.41	96.51
37	3.68	0.37	1.97	0.41	105.86
38	3.82	0.371	2.01	0.42	87.16
39	4.39	0.427	2.01	0.40	89.53
40	4.35	0.395	1.82	0.44	99.89
41	4.63	0.335	1.5	0.45	91.55
42	4.49	0.321	1.8	0.42	97.97
43	4.19	0.312	1.96	0.39	105.07
44	4.69	0.348	1.72	0.43	89.41
45	4.95	0.349	1.84	0.46	102.93
46	4.07	0.392	2.11	0.36	88.06
47	4.7	0.387	1.79	0.41	104.73
48	4.92	0.407	2.03	0.36	83.11
49	4.41	0.398	2.29	0.37	75.56
50	4.4	0.408	2.27	0.34	71.96

Table A.3. *Stem nutrient concentrations at R1 – Quicksand, 2001.*

Plot Number	N Conc. (%)	P Conc. (%)	K Conc. (%)	Mg Conc. (%)	Zn Conc. (ppm)
1	1.82	0.21	3.47	0.29	21.5
2	1.66	0.233	3.46	0.35	20.7
3	1.6	0.214	3.47	0.27	24.9
4	1.4	0.21	3.59	0.29	19.5
5	1.33	0.172	2.96	0.30	33.3
6	1.37	0.182	3.19	0.34	21.3
7	1.06	0.209	3.15	0.36	24.3
8	1.08	0.184	2.90	0.34	19.0
9	1.62	0.238	3.40	0.36	24.4
10	1.19	0.219	3.32	0.35	20.7
11	1.56	0.22	3.38	0.40	25.5
12	1.29	0.234	3.52	0.31	20.2
13	1.33	0.226	3.58	0.30	20.7
14	2.48	0.247	4.15	0.30	37.6
15	2.31	0.229	3.85	0.32	33.4
16	2.14	0.229	3.43	0.31	34.5
17	1.9	0.233	3.39	0.29	33.5
18	2.07	0.219	3.68	0.28	35.6
19	1.39	0.197	3.43	0.36	33.2
20	1.2	0.212	3.16	0.50	39.2
21	1.26	0.184	3.01	0.45	27.0
22	1.2	0.183	3.48	0.34	23.6
23	1.52	0.208	3.36	0.37	24.0
24	1.53	0.223	3.58	0.34	28.6
25	1.79	0.248	3.70	0.34	38.6
26	1.58	0.282	2.99	0.50	42.2
27	1.55	0.232	3.54	0.41	38.2
28	1.3	0.227	3.32	0.40	34.1
29	1.3	0.259	3.71	0.36	32.7
30	1.49	0.224	3.07	0.38	28.0
31	1.3	0.221	3.24	0.30	24.1
32	1.8	0.191	3.47	0.36	29.5
33	1.42	0.205	3.05	0.37	18.4
34	1.63	0.204	3.61	0.36	28.6
35	1.6	0.194	3.24	0.36	27.0
36	1.63	0.23	3.54	0.35	29.8
37	1.12	0.2	3.12	0.35	47.1
38	1.26	0.206	3.23	0.35	25.7
39	1.14	0.227	3.32	0.34	23.2
40	1.15	0.23	3.17	0.36	22.6
41	1.53	0.181	3.43	0.36	30.0
42	1.55	0.178	3.24	0.33	26.6
43	1.7	0.179	3.86	0.33	31.0
44	1.55	0.187	3.51	0.31	20.3
45	2.08	0.195	3.97	0.32	56.4
46	1.09	0.221	3.30	0.34	21.1
47	1.41	0.226	3.48	0.35	22.7
48	1.64	0.235	3.55	0.32	27.6
49	1.82	0.258	3.51	0.37	25.2
50	1.81	0.265	3.75	0.32	20.8

Table A.4. *Leaf nutrient concentrations at R5 – Quicksand, 2001.*

Plot Number	N Conc. (%)	P Conc. (%)	K Conc. (%)	Mg Conc. (%)	Zn Conc. (ppm)
1	4.58	0.345	1.94	0.267	73.80
2	4.19	0.316	1.76	0.241	75.00
3	4.52	0.334	1.89	0.224	74.28
4	4.27	0.328	1.96	0.245	75.96
5	4.19	0.305	1.67	0.304	65.63
6	4.55	0.34	1.83	0.274	52.40
7	4.92	0.414	1.60	0.303	109.86
8	4.47	0.353	1.96	0.243	82.45
9	4.45	0.31	1.72	0.275	87.02
10	4.84	0.327	1.96	0.292	80.77
11	4.66	0.325	1.92	0.275	87.26
12	4.79	0.333	1.93	0.257	82.55
13	5.04	0.332	2.07	0.286	84.62
14	4.28	0.335	1.67	0.253	101.92
15	4.59	0.354	1.87	0.308	130.53
16	4.6	0.336	1.71	0.363	105.77
17	4.72	0.343	1.92	0.291	110.10
18	4.5	0.325	1.63	0.306	106.73
19	4.51	0.324	1.79	0.278	122.60
20	4.3	0.341	2.06	0.263	104.09
21	4.04	0.317	1.88	0.295	117.55
22	3.58	0.29	1.83	0.290	162.26
23	4.09	0.318	1.78	0.291	118.51
24	4.26	0.34	1.99	0.278	133.17
25	4.13	0.318	1.76	0.275	115.14
26	4.18	0.316	1.82	0.272	130.53
27	4.39	0.332	1.78	0.283	127.64
28	4.62	0.339	1.72	0.313	115.14
29	4.58	0.345	1.87	0.258	113.70
30	4.85	0.339	1.89	0.269	101.44
31	4.41	0.346	1.93	0.237	95.67
32	4.26	0.345	1.81	0.289	108.89
33	4.02	0.306	1.71	0.291	110.34
34	4.47	0.33	1.66	0.342	126.44
35	4.32	0.321	1.83	0.326	120.19
36	4.17	0.326	1.96	0.276	121.63
37	4.4	0.333	1.99	0.229	94.47
38	4.39	0.329	1.81	0.284	112.02
39	3.77	0.302	1.91	0.221	115.14
40	3.97	0.314	1.91	0.279	112.26
41	4.26	0.315	1.83	0.272	107.93
42	4.19	0.305	1.79	0.288	107.45
43	4.26	0.293	1.95	0.318	114.66
44	3.51	0.265	1.59	0.260	109.38
45	4.03	0.298	1.73	0.286	124.28
46	3.74	0.32	1.84	0.276	118.99
47	4.34	0.33	1.92	0.252	128.13
48	4.41	0.334	1.96	0.275	101.68
49	4.22	0.319	1.96	0.266	105.29
50	4.06	0.338	1.97	0.214	121.39

Table A.5. *Stem nutrient concentrations at R5 – Quicksand, 2001.*

Plot Number	N Conc. (%)	P Conc. (%)	K Conc. (%)	Mg Conc. (%)	Zn Conc. (ppm)
1	1.45	0.318	2.25	0.20	10.98
2	1.27	0.277	1.73	0.20	8.84
3	1.09	0.267	2.06	0.17	14.53
4	1.26	0.299	2.03	0.18	9.55
5	1.05	0.223	1.59	0.21	8.43
6	0.934	0.252	1.87	0.19	9.65
7	0.882	0.299	1.60	0.21	11.48
8	1.07	0.289	1.74	0.20	10.98
9	1.12	0.222	1.65	0.20	10.98
10	1.71	0.333	2.31	0.18	12.70
11	1.72	0.325	2.21	0.20	13.72
12	1.43	0.303	2.08	0.19	10.77
13	1.65	0.351	2.54	0.17	14.02
14	1.13	0.285	1.63	0.19	10.06
15	1.37	0.322	2.03	0.20	13.72
16	1.35	0.326	1.87	0.21	12.70
17	1.26	0.321	2.00	0.19	12.09
18	1.2	0.274	1.79	0.19	12.70
19	1.23	0.319	2.06	0.20	14.02
20	1.18	0.314	2.04	0.18	11.08
21	0.877	0.252	1.70	0.23	12.40
22	0.691	0.218	1.58	0.19	12.60
23	0.982	0.295	1.88	0.20	10.47
24	1.15	0.317	2.10	0.19	13.72
25	1.01	0.272	1.92	0.20	11.38
26	1.05	0.276	1.83	0.21	13.92
27	1.07	0.293	1.96	0.22	14.94
28	1.24	0.311	1.95	0.22	12.70
29	1.16	0.323	1.87	0.20	12.70
30	1.38	0.324	2.19	0.19	13.92
31	1.43	0.298	2.03	0.20	11.79
32	1.05	0.292	1.91	0.21	10.26
33	1.1	0.28	1.78	0.21	12.30
34	1.2	0.294	1.56	0.23	13.31
35	1.11	0.25	1.82	0.21	12.60
36	1.07	0.281	1.98	0.21	12.40
37	1.14	0.298	1.78	0.19	9.65
38	1.16	0.29	1.93	0.20	12.09
39	0.864	0.274	1.88	0.18	11.38
40	0.877	0.276	1.79	0.20	10.47
41	1.08	0.249	1.80	0.20	10.47
42	1	0.237	1.61	0.21	10.06
43	1.37	0.197	2.05	0.20	12.80
44	0.827	0.19	1.52	0.20	9.96
45	0.957	0.233	1.74	0.20	11.69
46	0.934	0.271	1.53	0.20	12.60
47	1.14	0.294	2.07	0.19	13.41
48	1.33	0.322	1.98	0.19	13.11
49	1.19	0.295	2.06	0.20	13.01
50	1.25	0.339	2.20	0.19	14.33

Table A.6. *Pod nutrient concentrations at R5 – Quicksand, 2001.*

Plot Number	N Conc. (%)	P Conc. (%)	K Conc. (%)	Mg Conc. (%)	Zn Conc. (ppm)
1	3.36	0.434	2.74	0.22	43.75
2	3.27	0.412	2.44	0.22	38.09
3	3.3	0.436	2.64	0.23	39.39
4	3.36	0.436	2.77	0.23	43.75
5	3.2	0.385	2.48	0.25	39.27
6	3.06	0.414	2.50	0.24	43.63
7	2.83	0.396	2.34	0.27	44.22
8	3.19	0.425	2.44	0.23	45.75
9	3.17	0.402	2.39	0.23	43.63
10	3.88	0.481	2.68	0.22	49.29
11	3.64	0.468	2.61	0.21	46.46
12	3.37	0.437	2.53	0.22	42.81
13	3.54	0.483	2.91	0.21	50.24
14	2.96	0.414	2.47	0.22	42.33
15	3.48	0.465	2.60	0.22	49.76
16	3.31	0.439	2.55	0.23	46.23
17	3.46	0.451	2.55	0.22	46.34
18	3.13	0.446	2.51	0.24	47.64
19	3.2	0.421	2.49	0.25	50.71
20	3.35	0.43	2.50	0.25	47.76
21	3.03	0.4	2.27	0.27	44.93
22	2.7	0.393	2.38	0.28	48.94
23	3.2	0.435	2.55	0.24	45.40
24	3.19	0.441	2.58	0.24	47.29
25	3.06	0.418	2.49	0.23	45.75
26	3.12	0.398	2.48	0.27	46.11
27	3.12	0.413	2.55	0.24	47.41
28	3.25	0.431	2.58	0.24	45.17
29	3.1	0.436	2.56	0.23	44.10
30	3.41	0.457	2.59	0.24	48.35
31	3.24	0.419	2.55	0.24	42.92
32	3.2	0.424	2.40	0.24	43.51
33	3.17	0.434	2.58	0.23	44.46
34	3.01	0.417	2.39	0.24	46.46
35	3.29	0.426	2.48	0.26	49.17
36	3.18	0.415	2.66	0.25	47.17
37	3.12	0.405	2.60	0.23	43.51
38	3.22	0.419	2.49	0.25	45.75
39	2.94	0.388	2.43	0.25	44.58
40	3.08	0.392	2.42	0.25	43.28
41	2.95	0.393	2.44	0.26	42.69
42	2.91	0.379	2.35	0.25	43.40
43	3.57	0.406	2.65	0.28	49.76
44	2.59	0.354	2.45	0.25	41.51
45	2.89	0.39	2.49	0.25	43.99
46	2.95	0.416	2.58	0.25	46.70
47	3.06	0.397	2.58	0.24	45.40
48	3.15	0.423	2.69	0.22	44.81
49	3.08	0.404	2.64	0.24	44.81
50	2.98	0.407	2.71	0.24	46.82

Table A.7. *Grain nutrient concentrations – Quicksand, 2001.*

Plot Number	N Conc. (%)	P Conc. (%)	K Conc. (%)	Mg Conc. (%)	Zn Conc. (ppm)
1	5.62	0.56	2.03	0.189	50.96
2	5.88	0.62	2.05	0.188	49.15
3	5.76	0.596	2.09	0.193	48.29
4	5.84	0.597	2.07	0.194	50.53
5	5.71	0.587	2.02	0.190	49.79
6	5.55	0.583	2.03	0.194	51.60
7	5.68	0.607	2.02	0.190	53.42
8	4.95	0.52	2.01	0.185	50.64
9	5.68	0.623	2.01	0.189	47.54
10	5.57	0.516	1.96	0.184	48.18
11	5.86	0.6	2.04	0.189	47.22
12	5.83	0.606	2.03	0.187	47.86
13	5.71	0.596	2.02	0.187	49.15
14	5.89	0.613	2.09	0.198	51.92
15	5.5	0.533	1.97	0.186	51.92
16	5.21	0.584	1.96	0.193	53.74
17	5.64	0.601	2.08	0.193	52.46
18	5.55	0.62	2.03	0.187	50.43
19	5.75	0.601	2.16	0.181	51.92
20	5.77	0.604	2.02	0.192	51.82
21	5.59	0.643	2.02	0.194	51.82
22	5.71	0.634	2.04	0.199	51.92
23	5.73	0.583	2.05	0.191	50.75
24	5.68	0.612	2.12	0.186	52.14
25	5.66	0.606	2.02	0.191	52.35
26	5.62	0.596	2.01	0.185	50.85
27	5.84	0.644	2.07	0.194	52.56
28	5.88	0.612	2.04	0.194	51.28
29	6.05	0.609	2.03	0.191	50.64
30	no data	no data	no data	no data	no data
31	5.75	0.588	2.05	0.192	52.56
32	5.94	0.629	2.01	0.198	51.50
33	5.96	0.627	2.03	0.198	52.03
34	5.92	0.623	1.98	0.199	52.35
35	5.78	0.593	2.02	0.196	53.21
36	5.74	0.547	1.88	0.194	52.24
37	5.8	0.611	1.94	0.210	51.60
38	5.95	0.575	1.94	0.183	50.00
39	6.12	0.581	1.91	0.199	52.03
40	6.03	0.567	2.05	0.186	48.93
41	5.96	0.565	2.04	0.196	53.42
42	5.96	0.566	2.03	0.194	51.28
43	6.07	0.571	1.94	0.205	53.42
44	5.82	0.565	2.00	0.191	53.10
45	5.99	0.529	1.97	0.202	53.85
46	5.82	0.533	2.04	0.190	54.59
47	5.94	0.573	2.02	0.190	52.88
48	6.03	0.565	2.02	0.194	51.92
49	6	0.548	2.10	0.204	53.74
50	5.99	0.625	1.90	0.207	53.95

Table A.8. *Leaf nutrient concentrations at R1 – Quicksand, 2002.*

Plot Number	N Conc. (%)	P Conc. (%)	K Conc. (%)	Mg Conc. (%)	Zn Conc. (ppm)
1	5.13	0.373	2.02	0.41	72.99
2	5.43	0.377	1.80	0.41	76.56
3	5.3	0.392	1.83	0.40	73.33
4	4.97	0.378	1.81	0.43	83.82
5	4.9	0.341	1.59	0.52	85.49
6	5.09	0.334	1.87	0.44	98.10
7	4.93	0.364	1.78	0.54	115.18
8	4.8	0.36	1.85	0.57	95.76
9	5.16	0.384	1.81	0.53	75.11
10	4.93	0.362	1.74	0.48	80.80
11	5.25	0.384	1.86	0.42	76.12
12	5.01	0.402	1.84	0.43	91.85
13	5.21	0.394	1.90	0.43	83.48
14	5.4	0.403	1.84	0.38	98.21
15	4.9	0.385	1.88	0.44	112.72
16	4.55	0.378	1.77	0.48	121.09
17	5.25	0.391	1.81	0.47	96.65
18	4.83	0.366	1.75	0.49	107.25
19	5.47	0.383	2.02	0.59	103.13
20	5.3	0.38	1.76	0.51	76.67
21	4.62	0.344	1.70	0.53	90.40
22	4.8	0.349	1.92	0.49	98.44
23	4.62	0.345	1.82	0.52	97.54
24	4.26	0.346	1.97	0.49	110.60
25	4.66	0.363	1.79	0.47	116.41
26	4.77	0.349	1.75	0.48	111.94
27	4.62	0.346	1.80	0.50	94.98
28	4.92	0.382	1.90	0.46	88.95
29	5.05	0.402	1.85	0.42	92.52
30	5.27	0.406	2.01	0.40	85.94
31	4.91	0.367	1.92	0.43	76.90
32	5.3	0.385	1.74	0.46	83.93
33	5.19	0.38	1.78	0.44	91.74
34	4.86	0.353	1.60	0.44	106.25
35	5.02	0.35	1.82	0.47	99.22
36	5.05	0.362	1.84	0.48	93.08
37	5.01	0.395	1.86	0.45	104.35
38	5.3	0.379	1.79	0.50	87.50
39	5.09	0.339	1.79	0.48	92.30
40	4.71	0.349	1.53	0.58	112.61
41	4.99	0.349	1.62	0.45	101.90
42	5.09	0.349	2.01	0.43	107.70
43	5.23	0.365	1.85	0.45	108.59
44	5.04	0.342	1.83	0.43	114.17
45	5.03	0.366	1.98	0.44	101.00
46	4.34	0.32	1.70	0.41	102.23
47	4.98	0.343	1.81	0.47	92.08
48	4.59	0.362	2.02	0.44	99.00
49	5.01	0.34	1.82	0.43	120.42
50	4.94	0.372	1.94	0.39	88.73

Table A.9. *Stem nutrient concentrations at R1 – Quicksand, 2002.*

Plot Number	N Conc. (%)	P Conc. (%)	K Conc. (%)	Mg Conc. (%)	Zn Conc. (ppm)
1	1.93	0.328	3.92	0.33	24.6
2	1.91	0.359	3.94	0.38	27.0
3	1.81	0.335	4.19	0.35	24.0
4	1.66	0.3	3.46	0.37	24.7
5	1.71	0.247	2.84	0.49	25.4
6	1.59	0.261	3.49	0.45	34.9
7	1.42	0.283	3.19	0.48	34.8
8	1.49	0.25	3.23	0.52	32.9
9	1.64	0.266	3.16	0.49	28.3
10	1.78	0.303	3.38	0.39	27.2
11	1.75	0.305	4.01	0.40	28.0
12	1.62	0.362	3.92	0.38	27.2
13	1.81	0.362	4.15	0.35	32.6
14	1.83	0.375	3.93	0.37	35.4
15	1.48	0.325	3.57	0.42	30.6
16	1.39	0.311	3.11	0.42	27.7
17	1.86	0.312	3.9	0.41	33.5
18	1.43	0.254	3.1	0.41	35.9
19	2.09	0.253	3.27	0.48	43.0
20	1.74	0.259	3.14	0.46	26.9
21	1.55	0.249	2.8	0.46	30.8
22	1.5	0.229	3.03	0.44	31.7
23	1.43	0.231	3.08	0.43	25.2
24	1.38	0.261	3.22	0.38	26.1
25	1.47	0.301	3.44	0.43	28.0
26	1.55	0.274	3.23	0.41	33.1
27	1.71	0.254	3.50	0.46	33.9
28	1.71	0.305	3.72	0.44	31.1
29	1.62	0.36	3.91	0.37	26.6
30	2.15	0.361	4.00	0.29	33.8
31	2.03	0.324	4.06	0.34	30.3
32	2.04	0.357	3.91	0.38	30.1
33	1.75	0.319	4.00	0.41	29.8
34	1.63	0.277	3.54	0.44	33.8
35	1.73	0.268	3.66	0.45	35.1
36	1.7	0.277	3.89	0.45	34.7
37	1.54	0.312	3.34	0.40	32.3
38	1.86	0.27	3.28	0.43	35.6
39	1.65	0.23	3.58	0.44	31.6
40	1.65	0.255	2.95	0.48	37.3
41	1.76	0.278	3.87	0.41	32.5
42	1.57	0.256	3.99	0.41	31.9
43	1.66	0.272	3.77	0.39	36.3
44	1.53	0.248	3.80	0.41	32.8
45	1.76	0.301	3.86	0.38	32.8
46	1.43	0.266	3.49	0.33	25.7
47	1.61	0.228	3.47	0.41	30.0
48	1.49	0.294	3.76	0.38	30.5
49	1.46	0.243	3.55	0.42	34.2
50	1.75	0.329	4.01	0.33	27.7

Table A.10. *Leaf nutrient concentrations at R5 – Quicksand, 2002.*

Plot Number	N Conc. (%)	P Conc. (%)	K Conc. (%)	Mg Conc. (%)	Zn Conc. (ppm)
1	4.75	0.34	1.80	0.268	89.62
2	4.76	0.348	1.82	0.274	91.27
3	4.69	0.331	1.79	0.275	82.78
4	4.88	0.351	1.80	0.294	95.87
5	4.97	0.358	1.73	0.332	98.35
6	4.91	0.344	1.85	0.317	118.63
7	4.72	0.341	1.89	0.313	132.19
8	4.52	0.333	1.81	0.302	138.44
9	4.44	0.329	1.66	0.342	107.78
10	4.88	0.355	1.77	0.281	97.29
11	4.58	0.345	1.88	0.277	102.12
12	4.87	0.36	1.76	0.271	96.46
13	4.93	0.341	1.81	0.271	92.45
14	4.87	0.33	1.73	0.292	99.76
15	5.11	0.37	1.86	0.287	101.89
16	4.7	0.338	1.88	0.321	118.51
17	4.49	0.317	1.71	0.346	133.96
18	4.72	0.332	1.87	0.310	106.84
19	4.65	0.317	1.99	0.340	137.50
20	4.6	0.319	1.72	0.355	117.92
21	4.86	0.338	1.65	0.358	110.73
22	4.71	0.304	1.75	0.365	130.31
23	4.84	0.315	1.79	0.336	120.75
24	4.97	0.35	1.93	0.311	119.58
25	4.5	0.314	1.77	0.314	120.40
26	4.76	0.353	1.85	0.298	146.34
27	4.78	0.334	1.92	0.334	120.99
28	4.98	0.348	1.90	0.275	143.04
29	4.96	0.356	1.87	0.288	125.12
30	4.87	0.325	1.73	0.296	111.91
31	4.93	0.337	1.81	0.293	97.05
32	4.9	0.354	1.77	0.297	104.48
33	4.89	0.34	1.78	0.290	103.07
34	4.69	0.32	1.91	0.313	128.54
35	4.85	0.349	1.77	0.316	116.04
36	4.82	0.343	1.86	0.302	141.75
37	4.77	0.365	1.89	0.290	133.49
38	4.89	0.332	1.82	0.313	111.32
39	4.71	0.307	1.81	0.293	117.10
40	4.74	0.337	1.83	0.352	118.63
41	4.3	0.305	1.85	0.298	119.34
42	4.4	0.332	2.10	0.303	135.50
43	4.43	0.315	1.97	0.288	135.97
44	4.32	0.32	2.03	0.303	126.53
45	4.37	0.331	2.06	0.310	137.15
46	4.7	0.349	1.94	0.286	143.51
47	4.67	0.32	1.95	0.297	120.87
48	4.25	0.306	1.80	0.293	110.50
49	4.19	0.299	1.92	0.294	133.84
50	4.44	0.333	2.16	0.289	123.70

Table A.11. *Stem nutrient concentrations at R5 – Quicksand, 2002.*

Plot Number	N Conc. (%)	P Conc. (%)	K Conc. (%)	Mg Conc. (%)	Zn Conc. (ppm)
1	1.46	0.386	2.50	0.25	12.29
2	1.52	0.363	2.89	0.34	15.02
3	1.51	0.317	2.67	0.29	14.29
4	1.63	0.36	2.48	0.27	17.65
5	1.77	0.262	2.38	0.41	19.33
6	1.52	0.231	2.37	0.38	16.81
7	1.38	0.263	2.10	0.34	15.65
8	1.31	0.264	2.38	0.33	17.33
9	1.4	0.314	2.34	0.32	14.50
10	1.47	0.347	2.72	0.32	15.23
11	1.55	0.346	2.50	0.31	13.97
12	1.5	0.35	2.67	0.34	14.29
13	1.71	0.385	3.01	0.27	15.76
14	1.53	0.348	2.33	0.25	12.61
15	1.58	0.385	2.55	0.30	15.13
16	1.78	0.373	2.79	0.28	19.12
17	1.43	0.308	2.46	0.28	17.75
18	1.58	0.289	2.37	0.37	17.33
19	1.5	0.246	2.43	0.35	16.70
20	1.54	0.246	2.02	0.39	14.92
21	1.37	0.253	2.37	0.41	17.75
22	1.25	0.179	2.15	0.31	14.60
23	1.63	0.238	2.24	0.39	19.33
24	1.47	0.275	2.46	0.34	15.97
25	1.46	0.304	2.59	0.30	17.65
26	1.32	0.314	2.35	0.28	17.02
27	1.37	0.27	2.21	0.33	16.07
28	1.25	0.311	2.42	0.27	17.33
29	1.53	0.383	2.56	0.28	17.12
30	1.56	0.353	2.60	0.30	16.49
31	1.8	0.354	2.87	0.25	16.60
32	1.55	0.346	2.68	0.32	13.66
33	1.48	0.351	2.62	0.33	15.34
34	1.47	0.255	2.47	0.32	17.02
35	1.57	0.261	2.47	0.41	18.38
36	1.27	0.292	2.39	0.33	16.18
37	1.29	0.339	2.36	0.32	15.55
38	1.51	0.253	2.49	0.37	14.92
39	1.49	0.211	2.23	0.38	15.97
40	1.37	0.246	2.19	0.36	14.39
41	1.41	0.288	2.34	0.33	14.29
42	1.52	0.311	2.53	0.37	17.33
43	1.41	0.274	2.60	0.31	17.75
44	1.46	0.305	2.50	0.31	16.28
45	1.41	0.261	2.37	0.35	17.44
46	1.47	0.298	2.62	0.30	20.27
47	1.59	0.224	2.38	0.34	17.33
48	1.55	0.326	2.89	0.33	16.70
49	1.58	0.269	2.36	0.31	20.06
50	1.37	0.299	2.80	0.26	17.44

Table A.12. *Pod nutrient concentrations at R5 – Quicksand, 2002.*

Plot Number	N Conc. (%)	P Conc. (%)	K Conc. (%)	Mg Conc. (%)	Zn Conc. (ppm)
1	3.49	0.461	2.74	0.38	43.87
2	3.55	0.467	2.73	0.39	46.46
3	3.63	0.45	2.84	0.38	47.88
4	3.53	0.46	2.58	0.40	49.17
5	3.57	0.439	2.46	0.42	51.42
6	3.47	0.419	2.48	0.44	49.41
7	3.41	0.425	2.47	0.44	47.41
8	3.4	0.431	2.55	0.44	47.17
9	3.48	0.445	2.58	0.43	44.10
10	3.57	0.461	2.53	0.41	47.17
11	3.45	0.438	2.61	0.39	45.99
12	3.46	0.472	2.57	0.41	45.99
13	3.6	0.483	2.59	0.40	45.99
14	3.36	0.433	2.63	0.38	41.86
15	3.46	0.461	2.72	0.41	46.82
16	3.7	0.482	2.75	0.42	52.48
17	3.59	0.46	2.64	0.40	47.29
18	3.77	0.468	2.44	0.42	45.64
19	3.46	0.406	2.44	0.43	45.28
20	3.65	0.416	2.40	0.45	45.52
21	3.55	0.449	2.44	0.45	49.06
22	3.44	0.407	2.40	0.45	48.35
23	3.54	0.416	2.34	0.44	48.47
24	3.5	0.446	2.45	0.40	47.76
25	3.69	0.457	2.51	0.44	46.93
26	3.53	0.442	2.53	0.44	49.29
27	3.7	0.443	2.41	0.44	49.06
28	3.51	0.437	2.49	0.42	49.88
29	3.57	0.451	2.58	0.40	46.93
30	3.64	0.466	2.60	0.40	48.70
31	3.44	0.459	2.75	0.41	44.93
32	3.57	0.464	2.64	0.39	45.99
33	3.53	0.456	2.68	0.41	47.29
34	3.44	0.424	2.56	0.41	47.76
35	3.5	0.417	2.44	0.42	47.17
36	3.32	0.425	2.54	0.40	46.70
37	3.25	0.436	2.53	0.42	47.52
38	3.42	0.425	2.44	0.43	47.88
39	3.42	0.374	2.40	0.48	45.99
40	3.47	0.427	2.40	0.44	48.58
41	3.39	0.417	2.45	0.46	45.52
42	3.41	0.426	2.58	0.41	48.58
43	3.29	0.404	2.52	0.40	49.17
44	3.42	0.435	2.60	0.42	50.83
45	3.21	0.394	2.48	0.44	49.88
46	3.42	0.439	2.56	0.42	54.60
47	3.58	0.413	2.47	0.45	47.52
48	3.41	0.424	2.55	0.43	46.70
49	3.57	0.415	2.54	0.41	50.47
50	3.21	0.417	2.62	0.40	49.53

Table A.13. *Grain nutrient concentrations – Quicksand, 2002.*

Plot Number	N Conc. (%)	P Conc. (%)	K Conc. (%)	Mg Conc. (%)	Zn Conc. (ppm)
1	5.93	0.649	2.20	0.240	51.81
2	5.89	0.667	2.13	0.243	50.69
3	5.99	0.682	2.22	0.245	50.83
4	5.98	0.681	2.22	0.244	52.92
5	5.81	0.667	2.12	0.245	52.64
6	5.66	0.662	2.13	0.243	57.50
7	5.74	0.722	2.12	0.246	56.81
8	6.07	0.707	2.13	0.252	56.25
9	5.86	0.687	2.12	0.249	51.94
10	5.91	0.695	2.15	0.242	50.97
11	5.93	0.694	2.14	0.241	52.08
12	6.05	0.701	2.15	0.242	51.39
13	6.19	0.707	2.19	0.243	52.64
14	6.03	0.684	2.15	0.236	54.17
15	6.08	0.714	2.22	0.239	53.47
16	5.8	0.631	2.16	0.238	54.03
17	5.88	0.681	2.14	0.240	55.00
18	5.9	0.673	2.15	0.245	54.72
19	6.1	0.674	2.17	0.250	55.97
20	6.04	0.704	2.23	0.249	56.67
21	5.75	0.698	2.10	0.255	57.50
22	5.91	0.605	2.05	0.253	59.03
23	5.9	0.632	2.02	0.235	55.97
24	5.89	0.654	2.09	0.245	55.00
25	6.07	0.702	2.07	0.258	55.14
26	5.94	0.66	2.13	0.243	56.53
27	5.74	0.711	2.09	0.258	54.86
28	5.9	0.699	2.14	0.239	54.86
29	6.01	0.717	2.12	0.236	55.14
30	6.18	0.712	2.20	0.239	54.72
31	6.11	0.687	2.14	0.234	54.31
32	5.97	0.697	2.19	0.236	53.19
33	6.16	0.706	2.15	0.238	53.75
34	5.97	0.673	2.12	0.238	58.75
35	6.15	0.685	2.10	0.243	55.69
36	6	0.686	2.17	0.242	56.25
37	5.9	0.708	2.14	0.249	55.56
38	5.95	0.686	2.13	0.246	53.47
39	6.1	0.631	2.07	0.238	55.97
40	6.11	0.678	2.14	0.241	55.83
41	5.12	0.591	2.08	0.245	55.56
42	5.98	0.652	2.12	0.240	55.56
43	5.71	0.58	2.07	0.240	57.36
44	6.24	0.632	2.02	0.242	56.67
45	no data	no data	no data	no data	no data
46	5.36	0.629	2.16	0.244	56.67
47	5.36	0.632	2.14	0.239	56.25
48	6.08	0.695	2.13	0.241	56.39
49	5.35	0.616	2.08	0.239	56.39
50	5.61	0.648	2.19	0.242	57.64

APPENDIX B

COMPLIMENTARY DATA – PRINCETON

Table B.1 *Princeton Plot Plan.*

			Rep 1	Rep 2	Rep 3	Rep 4
		P1	3	22	52	44
		P2	1	21	50	41
	S1	**P3**	4	24	49	42
		P4	2	23	51	43
HS						
		P1	14	27	61	37
		P2	16	28	63	40
	S0	**P3**	13	25	64	39
		P4	15	26	62	38
		P1	32	12	34	56
		P2	30	11	33	55
	S1	**P3**	31	10	36	54
		P4	29	9	35	53
LS						
		P1	17	5	47	57
		P2	19	6	48	58
	S0	**P3**	18	7	45	59
		P4	20	8	46	60

Table B.2. *Leaf nutrient concentrations at R1 – Princeton, 2001.*

Plot Number	N Conc. (%)	P Conc. (%)	K Conc. (%)	Mg Conc. (%)	Zn Conc. (ppm)
1	4.31	0.319	1.91	0.287	44.8
2	3.4	0.278	1.59	0.398	32.5
3	3.83	0.256	1.9	0.322	34.8
4	3.31	0.293	2.18	0.347	30.9
5	3.24	0.184	1.83	0.376	44.0
6	4.09	0.215	1.41	0.411	36.2
7	3.56	0.296	1.65	0.437	40.5
8	2.56	0.318	2.45	0.317	28.1
9	3.78	0.347	2.09	0.281	27.2
10	3.96	0.336	1.87	0.344	47.9
11	4.27	0.271	1.84	0.318	33.0
12	4.16	0.26	1.74	0.306	30.2
13	3.3	0.276	1.54	0.330	26.7
14	3.74	0.281	2.24	0.249	46.0
15	3.94	0.334	2.14	0.322	32.3
16	3.49	0.205	1.93	0.261	48.2
17	3	0.19	1.77	0.254	45.2
18	3.92	0.344	1.92	0.309	38.8
19	3.01	0.308	1.85	0.414	37.9
20	2.81	0.317	1.61	0.427	39.4
21	3.7	0.314	1.95	0.344	38.5
22	4.29	0.263	1.94	0.316	35.9
23	2.99	0.235	2.16	0.297	42.8
24	3.43	0.355	1.72	0.393	35.6
25	3.35	0.322	1.95	0.317	28.0
26	3.96	0.361	1.72	0.422	34.1
27	2.87	0.195	1.75	0.297	36.8
28	3.1	0.255	2.26	0.253	33.8
29	4	0.4	1.93	0.430	39.9
30	4.25	0.289	1.58	0.384	43.3
31	3.13	0.364	2.1	0.354	35.6
32	4.28	0.358	1.9	0.324	41.5
33	3.38	0.251	1.56	0.328	37.8
34	3.35	0.284	1.82	0.297	42.1
35	3.74	0.382	1.63	0.492	35.1
36	3.05	0.29	1.49	0.378	28.7
37	3.14	0.233	1.86	0.274	32.5
38	3.43	0.326	2.12	0.344	27.9
39	3.88	0.296	1.9	0.402	46.9
40	3.98	0.224	2.1	0.337	39.3
41	3.71	0.205	1.91	0.362	53.6
42	3.16	0.273	1.35	0.487	37.5
43	3.52	0.361	1.78	0.376	29.9
44	3.22	0.242	1.71	0.250	30.8
45	3.38	0.336	1.55	0.305	33.8
46	3.57	0.349	1.61	0.390	34.2
47	3.7	0.283	1.88	0.282	49.2
48	3.7	0.295	1.69	0.354	39.6
49	3.6	0.325	1.66	0.289	39.7
50	3.55	0.287	1.76	0.261	43.0
51	4.29	0.345	2.06	0.296	41.1
52	3.53	0.345	1.99	0.347	39.9
53	4.13	0.312	1.78	0.315	42.4
54	4.73	0.347	1.62	0.518	36.2
55	3.86	0.27	1.74	0.410	34.2
56	3.68	0.215	1.66	0.354	42.4
57	3.74	0.217	1.89	0.297	49.4
58	3.29	0.259	1.53	0.406	45.1
59	3.18	0.28	1.39	0.467	39.4
60	3.58	0.225	1.49	0.350	35.0
61	3.96	0.294	1.54	0.386	46.0
62	4.46	0.351	1.78	0.324	46.1
63	3.42	0.285	0.964	0.428	44.7
64	3.85	0.34	1.38	0.360	38.0

Table B.3. *Stem nutrient concentrations at R1 – Princeton, 2001.*

Plot Number	N Conc. (%)	P Conc. (%)	K Conc. (%)	Mg Conc. (%)	Zn Conc. (ppm)
1	1.910	0.216	2.030	0.252	24.8
2	1.380	0.186	1.360	0.377	17.6
3	1.390	0.135	1.700	0.292	20.1
4	1.510	0.202	2.180	0.31	16.4
5	1.730	0.128	1.800	0.262	21.6
6	1.970	0.132	1.500	0.307	20.9
7	1.890	0.172	1.740	0.363	20.7
8	1.240	0.239	2.290	0.302	11.9
9	1.670	0.261	2.380	0.285	13.3
10	2.130	0.242	1.850	0.238	21.9
11	2.180	0.179	1.490	0.178	19.2
12	1.600	0.162	1.460	0.219	15.8
13	1.140	0.148	1.310	0.301	13
14	1.590	0.165	2.460	0.255	25.6
15	1.540	0.247	2.390	0.3	17.5
16	1.730	0.143	2.060	0.306	32.4
17	1.410	0.121	1.810	0.275	21.7
18	1.500	0.241	2.220	0.321	19.4
19	1.360	0.194	1.900	0.351	15.8
20	1.400	0.229	1.690	0.373	16.8
21	1.640	0.219	2.010	0.337	18.7
22	1.880	0.162	2.480	0.294	18.3
23	1.520	0.167	2.370	0.314	22.4
24	1.460	0.257	1.880	0.344	15.5
25	1.440	0.219	1.840	0.335	14.2
26	1.730	0.257	1.800	0.347	15.3
27	1.450	0.122	1.500	0.305	20.3
28	1.260	0.145	2.190	0.291	17.7
29	1.580	0.295	1.820	0.42	20.5
30	1.370	0.164	1.700	0.354	17.5
31	1.630	0.286	1.900	0.333	21.9
32	1.630	0.231	2.310	0.332	22.5
33	1.430	0.147	1.390	0.325	15.3
34	1.330	0.190	1.930	0.315	17.8
35	1.760	0.295	1.620	0.37	17.8
36	1.390	0.191	1.540	0.349	14.7
37	1.320	0.127	1.730	0.252	14.8
38	1.190	0.258	2.060	0.279	11
39	1.540	0.156	1.750	0.247	21.2
40	1.830	0.151	1.710	0.203	22.7
41	1.550	0.113	1.930	0.319	23.6
42	1.810	0.241	1.780	0.429	20.2
43	1.380	0.260	1.750	0.3	12.4
44	1.230	0.128	1.340	0.235	16.2
45	1.220	0.221	1.810	0.335	14.7
46	1.030	0.223	1.350	0.319	11.8
47	1.600	0.181	2.070	0.317	21.9
48	1.270	0.184	1.530	0.35	16.7
49	1.470	0.217	1.710	0.325	22.7
50	1.710	0.188	1.690	0.266	25.9
51	1.890	0.270	2.290	0.283	26.5
52	1.600	0.258	1.920	0.288	18.8
53	1.880	0.209	2.010	0.33	20.9
54	2.310	0.252	2.210	0.354	24.6
55	2.050	0.179	1.820	0.284	17.4
56	1.730	0.137	1.350	0.273	23.4
57	1.660	0.127	1.770	0.26	32.4
58	1.800	0.180	1.400	0.399	25.7
59	1.810	0.201	1.050	0.369	19.2
60	1.380	0.118	1.430	0.347	20
61	2.030	0.200	1.500	0.354	27.8
62	1.830	0.210	1.720	0.273	27.6
63	1.790	0.206	0.689	0.29	22.7
64	1.530	0.186	1.010	0.346	20

Table B.4. *Leaf nutrient concentrations at R5 – Princeton, 2001.*

Plot Number	N Conc. (%)	P Conc. (%)	K Conc. (%)	Mg Conc. (%)	Zn Conc. (ppm)
1	4.02	0.266	1.77	0.389	52.3
2	4.65	0.344	1.62	0.442	49.1
3	4.32	0.203	1.74	0.313	89.7
4	4.43	0.25	1.61	0.341	64.5
5	3.62	0.154	1.62	0.307	87.8
6	3.79	0.153	1.28	0.366	93.9
7	4.31	0.215	1.27	0.392	70.8
8	4.66	0.276	1.62	0.309	48.0
9	4.58	0.306	1.49	0.282	41.7
10	4.48	0.266	1.41	0.339	60.6
11	4.64	0.233	1.73	0.331	92.8
12	4.85	0.264	1.37	0.356	55.6
13	4.53	0.262	1.49	0.274	55.8
14	4.1	0.205	1.34	0.363	83.0
15	4.57	0.332	1.83	0.326	63.6
16	3.81	0.205	1.71	0.297	105.5
17	4.13	0.205	1.48	0.325	74.5
18	4.02	0.254	1.31	0.333	63.6
19	4.3	0.216	1.33	0.303	67.5
20	4.41	0.271	1.24	0.446	55.8
21	4.03	0.21	1.62	0.287	78.0
22	4.18	0.212	1.87	0.271	88.1
23	4.48	0.31	1.70	0.319	58.3
24	4.51	0.292	1.33	0.365	56.7
25	4.53	0.292	1.52	0.383	64.5
26	4.56	0.325	1.57	0.374	41.7
27	4.15	0.205	1.54	0.300	74.5
28	4.21	0.235	1.56	0.304	70.8
29	4.54	0.317	1.29	0.403	43.1
30	4.1	0.22	1.39	0.354	65.9
31	4.4	0.296	1.16	0.393	52.0
32	4.13	0.216	1.61	0.320	69.7
33	4.19	0.231	1.56	0.409	88.8
34	4.31	0.239	1.63	0.359	82.0
35	4.21	0.309	1.22	0.504	61.4
36	4.5	0.298	1.35	0.358	41.7
37	3.91	0.235	1.70	0.326	89.4
38	4.42	0.3	1.37	0.334	49.7
39	4.68	0.301	1.52	0.367	53.0
40	4.07	0.196	1.81	0.339	87.0
41	4.22	0.205	1.43	0.315	101.4
42	4.42	0.295	1.48	0.424	49.4
43	4.4	0.301	1.28	0.406	47.7
44	4.17	0.233	1.56	0.335	75.5
45	4.22	0.293	1.39	0.327	58.4
46	4.36	0.296	1.22	0.356	50.8
47	4.21	0.224	1.93	0.336	80.5
48	4.03	0.2	1.20	0.382	68.4
49	3.86	0.281	1.39	0.354	65.3
50	3.96	0.23	1.50	0.301	88.6
51	4.05	0.332	1.78	0.355	74.8
52	4.13	0.211	1.66	0.311	100.5
53	4.48	0.304	1.48	0.372	66.3
54	4.32	0.261	1.21	0.373	76.1
55	3.94	0.181	1.32	0.317	100.8
56	3.69	0.164	1.71	0.251	107.7
57	3.52	0.145	1.66	0.247	94.8
58	3.52	0.141	1.41	0.239	104.4
59	4	0.237	1.06	0.480	60.0
60	4.19	0.273	1.20	0.471	80.5
61	3.63	0.18	1.90	0.326	105.2
62	4.25	0.322	1.41	0.500	66.1
63	4.12	0.234	1.28	0.456	80.8
64	4.21	0.285	1.26	0.453	56.1

Table B.5. *Stem nutrient concentrations at R5 – Princeton, 2001.*

Plot Number	N Conc. (%)	P Conc. (%)	K Conc. (%)	Mg Conc. (%)	Zn Conc. (ppm)
1	1.580	0.173	2.63	0.25	21.6
2	1.500	0.316	2.69	0.28	15.5
3	1.470	0.112	2.30	0.24	26.1
4	1.370	0.131	2.09	0.26	12.7
5	1.290	0.081	1.59	0.22	15.3
6	1.340	0.070	1.08	0.27	16.3
7	1.440	0.110	1.33	0.31	9.1
8	1.650	0.224	2.28	0.37	9.5
9	1.500	0.314	2.17	0.23	3.6
10	1.340	0.175	1.92	0.24	5.7
11	1.290	0.115	1.96	0.22	15.9
12	1.470	0.146	1.59	0.28	7.8
13	1.420	0.210	1.92	0.26	7.4
14	1.350	0.103	1.76	0.28	17.6
15	1.470	0.338	2.61	0.22	15.0
16	1.420	0.117	2.34	0.23	32.2
17	1.480	0.100	2.01	0.26	17.8
18	1.800	0.223	1.67	0.28	11.4
19	1.540	0.111	1.56	0.28	11.4
20	1.660	0.201	1.33	0.35	8.1
21	1.470	0.124	1.89	0.23	11.4
22	1.410	0.113	2.30	0.25	17.2
23	1.650	0.291	2.51	0.20	12.1
24	1.610	0.231	2.42	0.28	10.6
25	1.470	0.209	2.15	0.27	11.2
26	1.660	0.325	2.23	0.25	8.3
27	1.530	0.105	1.90	0.27	13.8
28	1.530	0.140	2.32	0.23	14.0
29	1.720	0.291	1.90	0.27	7.0
30	1.450	0.135	1.61	0.27	9.1
31	1.710	0.266	1.53	0.30	9.5
32	1.610	0.132	2.06	0.25	14.8
33	1.470	0.139	1.72	0.26	15.3
34	1.480	0.135	2.01	0.28	19.9
35	1.660	0.295	1.57	0.34	11.9
36	1.600	0.267	1.62	0.26	4.7
37	1.570	0.146	2.32	0.24	21.0
38	1.480	0.290	2.15	0.29	6.6
39	1.600	0.234	2.34	0.25	14.2
40	1.420	0.101	2.29	0.27	37.1
41	1.500	0.106	1.99	0.25	20.8
42	1.700	0.231	2.46	0.30	14.2
43	1.680	0.284	1.88	0.30	8.3
44	1.480	0.138	2.28	0.26	14.0
45	1.850	0.299	2.18	0.26	14.2
46	1.430	0.180	1.39	0.26	10.6
47	1.460	0.122	1.94	0.28	14.0
48	1.430	0.107	1.37	0.30	10.6
49	1.390	0.263	1.97	0.24	10.4
50	1.330	0.146	1.86	0.24	17.2
51	1.450	0.320	2.61	0.24	15.9
52	1.200	0.113	1.92	0.23	22.2
53	1.640	0.310	2.26	0.25	14.0
54	1.620	0.194	1.59	0.29	15.9
55	1.350	0.097	1.37	0.28	20.1
56	1.390	0.087	1.60	0.22	24.2
57	1.270	0.072	1.45	0.19	18.4
58	1.290	0.073	1.32	0.22	22.2
59	1.380	0.140	1.23	0.38	16.5
60	1.710	0.197	1.73	0.35	24.8
61	1.260	0.096	2.06	0.22	20.8
62	1.730	0.270	2.40	0.32	23.7
63	1.640	0.136	1.57	0.32	22.9
64	1.430	0.188	1.40	0.26	10.0

Table B.6. *Pod nutrient concentrations at R5 – Princeton, 2001.*

Plot Number	N Conc. (%)	P Conc. (%)	K Conc. (%)	Mg Conc. (%)	Zn Conc. (ppm)
1	3.080	0.385	2.44	0.41	62.4
2	3.440	0.478	2.50	0.37	57.9
3	0.024	0.317	2.00	0.37	64.9
4	0.029	0.350	2.29	0.38	51.7
5	2.810	0.232	2.04	0.32	49.8
6	2.830	0.221	1.64	0.13	50.9
7	3.350	0.305	2.04	0.35	45.2
8	3.310	0.365	2.57	0.30	46.5
9	3.290	0.401	2.54	0.25	42.2
10	3.300	0.358	2.52	0.33	44.9
11	3.000	0.292	2.50	0.33	55.5
12	3.230	0.320	2.20	0.30	42.2
13	3.020	0.344	2.38	0.30	44.1
14	2.980	0.297	2.19	0.35	54.9
15	3.220	0.431	2.71	0.31	51.1
16	2.800	0.293	2.31	0.36	68.9
17	3.020	0.285	2.24	0.35	49.2
18	3.520	0.367	2.36	0.30	45.2
19	3.110	0.298	2.27	0.34	44.9
20	3.420	0.375	2.18	0.33	46.2
21	3.230	0.326	2.44	0.32	50.1
22	3.140	0.319	2.33	0.36	54.9
23	3.340	0.445	2.94	0.30	51.9
24	3.110	0.394	2.58	0.34	47.8
25	3.180	0.406	2.58	0.36	52.2
26	3.300	0.450	2.77	0.31	45.5
27	3.120	0.300	2.33	0.36	53.8
28	3.210	0.356	2.62	0.32	54.4
29	3.380	0.415	2.47	0.30	43.7
30	3.210	0.329	2.24	0.33	44.1
31	3.380	0.427	2.24	0.30	45.7
32	3.170	0.323	2.34	0.36	50.1
33	2.930	0.291	2.10	0.30	49.8
34	3.150	0.323	2.18	0.37	54.7
35	3.550	0.427	2.37	0.30	47.1
36	3.450	0.392	2.42	0.31	41.7
37	3.290	0.344	2.46	0.36	59.6
38	3.300	0.411	2.65	0.33	44.4
39	3.390	0.423	2.67	0.34	50.5
40	2.960	0.274	2.25	0.37	56.5
41	3.110	0.287	2.38	0.36	56.4
42	3.340	0.419	2.57	0.37	50.1
43	3.440	0.414	2.48	0.33	47.4
44	3.180	0.319	2.40	0.33	50.5
45	3.500	0.402	2.47	0.30	45.2
46	3.480	0.400	2.15	0.30	42.8
47	3.260	0.318	2.23	0.33	49.5
48	3.200	0.276	1.98	0.33	43.7
49	3.100	0.411	2.37	0.30	45.7
50	3.020	0.312	2.23	0.35	48.4
51	2.990	0.456	2.50	0.38	61.5
52	2.820	0.259	2.25	0.33	51.4
53	3.400	0.401	2.62	0.32	47.4
54	3.310	0.337	2.24	0.33	45.9
55	3.110	0.278	2.06	0.34	54.9
56	2.900	0.230	1.94	0.31	47.4
57	2.690	0.194	1.90	0.30	45.9
58	2.670	0.197	1.85	0.30	50.5
59	3.020	0.308	1.99	0.38	50.5
60	3.270	0.365	2.26	0.39	58.2
61	2.790	0.241	2.12	0.31	51.1
62	3.210	0.434	2.71	0.41	74.6
63	3.310	0.330	2.16	0.39	58.2
64	3.240	0.385	2.22	0.37	48.9

Table B.7. *Grain nutrient concentrations – Princeton, 2001.*

Plot Number	N Conc. (%)	P Conc. (%)	K Conc. (%)	Mg Conc. (%)	Zn Conc. (ppm)
1	6.22	0.47	1.88	0.128	66.3
2	6.15	0.60	2.09	0.134	64.0
3	6.63	0.43	1.91	0.129	69.0
4	6.50	0.52	2.04	0.132	63.8
5	6.24	0.36	1.91	0.119	71.9
6	6.16	0.37	1.92	0.129	69.0
7	6.22	0.49	1.99	0.134	57.9
8	5.60	0.58	2.14	0.136	55.6
9	5.92	0.63	2.11	0.141	56.5
10	5.95	0.50	1.92	0.131	62.0
11	6.07	0.37	1.83	0.120	68.5
12	6.32	0.37	1.88	0.122	65.9
13	6.41	0.52	2.03	0.130	63.8
14	5.87	0.37	1.91	0.124	68.5
15	6.15	0.56	1.93	0.130	61.0
16	6.14	0.38	1.87	0.126	66.1
17	6.35	0.36	1.98	0.120	98.8
18	6.51	0.48	1.99	0.131	60.4
19	6.73	0.40	1.91	0.129	61.9
20	6.27	0.56	2.07	0.141	54.4
21	6.49	0.40	1.99	0.123	63.9
22	6.37	0.40	1.95	0.128	62.9
23	6.43	0.62	2.02	0.133	60.0
24	6.22	0.59	2.12	0.132	59.0
25	6.07	0.45	2.01	0.129	63.3
26	5.96	0.56	2.04	0.134	58.9
27	6.04	0.35	1.85	0.122	62.3
28	6.09	0.38	1.99	0.125	60.8
29	6.57	0.61	2.11	0.131	55.3
30	6.31	0.44	1.96	0.125	58.1
31	6.09	0.54	2.63	0.131	59.4
32	6.34	0.38	1.94	0.120	60.0
33	6.44	0.47	2.00	0.131	57.1
34	6.47	0.46	2.10	0.128	57.6
35	6.52	0.57	2.12	0.129	59.4
36	6.59	0.60	2.10	0.132	50.4
37	6.27	0.42	2.06	0.125	60.1
38	6.22	0.54	2.15	0.139	53.0
39	6.29	0.57	2.24	0.137	54.0
40	6.20	0.48	2.11	0.132	53.8
41	6.49	0.43	2.02	0.128	62.3
42	6.26	0.48	2.02	0.195	57.9
43	6.45	0.59	2.14	0.131	54.9
44	6.23	0.41	2.11	0.123	57.3
45	6.16	0.46	2.03	0.133	55.0
46	6.69	0.61	2.26	0.139	52.8
47	6.52	0.35	2.00	0.121	60.4
48	6.69	0.36	1.98	0.118	61.8
49	6.49	0.55	2.11	0.129	56.0
50	6.53	0.54	2.20	0.132	55.5
51	6.36	0.59	2.22	0.127	56.5
52	6.55	0.47	2.15	0.132	56.8
53	6.49	0.56	2.23	0.133	56.0
54	6.46	0.55	2.15	0.131	59.5
55	6.49	0.46	2.23	0.126	61.4
56	6.35	0.34	2.03	0.117	67.5
57	6.21	0.32	2.03	0.114	70.1
58	6.43	0.33	1.94	0.114	63.9
59	6.05	0.40	1.95	0.122	58.1
60	6.51	0.53	2.19	0.126	59.5
61	6.47	0.43	2.15	0.123	61.9
62	6.58	0.60	2.28	0.133	55.4
63	6.32	0.38	1.93	0.122	59.6
64	6.62	0.49	1.99	0.127	54.0

Table B.8. *Leaf nutrient concentrations at R1 – Princeton, 2002.*

Plot Number	N Conc. (%)	P Conc. (%)	K Conc. (%)	Mg Conc. (%)	Zn Conc. (ppm)
1	4.63	0.288	1.12	0.534	71.9
2	5.08	0.343	1.51	0.391	56.0
3	4.89	0.281	1.04	0.490	60.5
4	5.31	0.349	1.26	0.438	68.1
5	4.86	0.236	1.25	0.386	63.9
6	4.82	0.255	1.23	0.396	66.5
7	5.02	0.294	0.97	0.436	57.7
8	5.09	0.357	1.73	0.345	37.5
9	5.26	0.364	1.59	0.347	43.3
10	5.06	0.288	1.31	0.439	56.6
11	4.84	0.292	1.23	0.402	58.4
12	4.95	0.318	0.96	0.465	47.2
13	4.91	0.344	1.07	0.485	52.2
14	4.49	0.233	1.33	0.396	68.1
15	5.3	0.357	1.31	0.399	67.7
16	4.63	0.24	1.48	0.373	97.2
17	4.91	0.263	1.25	0.408	77.9
18	4.98	0.33	1.01	0.429	85.4
19	4.86	0.298	0.91	0.497	74.7
20	4.5	0.338	0.80	0.643	68.6
21	5.09	0.285	1.25	0.375	95.0
22	5.23	0.291	1.27	0.421	76.0
23	5.17	0.362	1.30	0.416	71.2
24	5.29	0.347	1.09	0.416	103.6
25	5.28	0.344	1.01	0.496	78.2
26	5.2	0.357	1.07	0.468	47.5
27	4.95	0.258	1.28	0.401	62.6
28	5	0.278	1.38	0.375	87.1
29	4.83	0.348	0.84	0.521	52.4
30	4.74	0.274	0.91	0.471	80.6
31	4.96	0.322	0.88	0.369	51.8
32	4.81	0.276	0.98	0.392	59.5
33	4.79	0.295	0.86	0.508	99.5
34	4.82	0.267	1.18	0.383	62.2
35	5.14	0.344	0.89	0.528	66.7
36	5.25	0.34	1.01	0.443	45.2
37	4.88	0.271	1.19	0.437	70.7
38	5.29	0.369	1.23	0.456	46.6
39	3.96	0.288	1.25	0.478	60.3
40	4.97	0.301	1.30	0.501	62.0
41	5.32	0.294	0.94	0.505	64.8
42	5.17	0.346	1.11	0.452	69.5
43	4.8	0.339	1.03	0.470	45.4
44	5.09	0.293	1.00	0.449	52.9
45	4.77	0.298	0.85	0.458	85.4
46	5.04	0.346	0.88	0.487	54.9
47	4.76	0.254	1.18	0.397	91.7
48	4.81	0.276	1.06	0.409	67.8
49	5.22	0.327	1.13	0.395	100.0
50	4.81	0.284	1.09	0.393	77.9
51	5.08	0.35	1.06	0.447	74.5
52	4.98	0.277	1.04	0.468	75.4
53	5.26	0.368	1.06	0.427	80.3
54	5.06	0.304	0.94	0.475	83.7
55	4.89	0.247	1.04	0.429	89.6
56	4.67	0.22	1.39	0.332	90.1
57	4.66	0.199	1.27	0.357	97.7
58	4.87	0.246	1.23	0.406	101.5
59	4.99	0.317	0.85	0.504	82.0
60	5.35	0.346	1.06	0.442	65.9
61	5.03	0.247	1.38	0.354	93.3
62	5.27	0.375	0.96	0.504	71.8
63	4.99	0.259	1.04	0.425	88.0
64	5.3	0.341	0.95	0.501	73.2

Table B.9. *Stem nutrient concentrations at R1 – Princeton, 2002.*

Plot Number	N Conc. (%)	P Conc. (%)	K Conc. (%)	Mg Conc. (%)	Zn Conc. (ppm)
1	1.700	0.176	1.319	0.53	27.14
2	2.000	0.313	2.805	0.41	25.36
3	1.710	0.150	1.267	0.49	24.64
4	2.110	0.288	2.306	0.49	28.93
5	1.710	0.131	1.433	0.37	25.36
6	1.830	0.139	1.371	0.36	27.50
7	1.820	0.185	1.205	0.45	24.88
8	1.870	0.322	3.729	0.30	15.71
9	2.070	0.330	3.178	0.36	18.21
10	1.880	0.178	1.953	0.42	20.12
11	1.800	0.170	1.558	0.35	23.69
12	1.920	0.198	1.184	0.46	21.90
13	1.940	0.257	1.807	0.51	24.29
14	1.540	0.121	2.057	0.39	27.62
15	2.040	0.311	2.483	0.42	28.33
16	1.540	0.131	2.462	0.35	46.19
17	1.810	0.156	1.828	0.40	31.19
18	1.920	0.263	1.402	0.46	34.05
19	1.850	0.197	1.080	0.50	30.83
20	1.840	0.309	0.841	0.51	27.98
21	1.950	0.183	2.244	0.38	32.02
22	1.830	0.162	2.025	0.45	26.43
23	2.080	0.351	2.399	0.48	26.90
24	2.090	0.281	1.984	0.53	37.26
25	2.130	0.281	1.890	0.54	28.10
26	2.090	0.342	2.025	0.52	20.71
27	1.640	0.141	2.025	0.38	22.50
28	1.760	0.165	2.576	0.36	29.52
29	1.880	0.301	1.025	0.55	21.19
30	1.740	0.166	1.163	0.49	26.31
31	1.950	0.256	1.031	0.41	22.14
32	1.910	0.164	1.184	0.39	24.17
33	2.100	0.193	1.070	0.52	39.17
34	1.900	0.160	1.610	0.40	26.07
35	2.080	0.262	1.205	0.56	27.98
36	2.210	0.256	1.465	0.53	20.60
37	1.850	0.143	1.880	0.44	27.14
38	2.170	0.324	2.701	0.46	22.98
39	2.150	0.264	2.337	0.48	25.12
40	1.780	0.175	2.285	0.44	26.43
41	2.100	0.226	1.818	0.60	28.21
42	2.050	0.262	2.181	0.51	29.05
43	2.000	0.296	1.994	0.46	21.90
44	1.870	0.190	1.610	0.49	22.02
45	2.000	0.222	0.977	0.47	32.38
46	2.120	0.278	1.319	0.55	24.76
47	1.930	0.147	1.745	0.39	32.86
48	1.980	0.171	1.589	0.50	30.48
49	2.200	0.276	2.057	0.48	43.45
50	1.950	0.195	1.859	0.46	31.90
51	2.200	0.305	1.849	0.49	29.05
52	1.930	0.156	1.548	0.50	27.98
53	2.180	0.300	1.776	0.49	28.33
54	1.940	0.196	1.402	0.49	27.74
55	1.870	0.143	1.454	0.47	31.79
56	1.660	0.117	1.548	0.32	30.83
57	1.870	0.118	1.797	0.36	41.43
58	1.710	0.140	1.724	0.42	38.81
59	2.020	0.233	1.184	0.54	33.21
60	1.940	0.283	1.652	0.53	23.69
61	1.710	0.136	2.493	0.36	37.50
62	2.130	0.333	1.693	0.54	26.07
63	1.740	0.143	1.444	0.45	30.12
64	1.980	0.219	1.517	0.51	30.12

Table B.10. *Leaf nutrient concentrations at R5 – Princeton, 2002.*

Plot Number	N Conc. (%)	P Conc. (%)	K Conc. (%)	Mg Conc. (%)	Zn Conc. (ppm)
1	4.15	0.176	1.11	0.381	89.4
2	4.37	0.281	1.27	0.333	65.969
3	3.91	0.185	0.97	0.386	74.670
4	4.23	0.224	0.85	0.400	73.238
5	3.81	0.138	1.37	0.267	86.564
6	4.09	0.152	1.41	0.217	94.934
7	4.05	0.199	1.15	0.341	58.480
8	4.41	0.289	1.49	0.281	60.903
9	4.37	0.285	1.58	0.272	66.189
10	4.14	0.209	1.04	0.356	63.767
11	4.24	0.184	0.89	0.393	78.304
12	4.13	0.171	1.05	0.345	76.652
13	4.43	0.238	1.08	0.370	93.172
14	3.83	0.147	0.99	0.365	86.564
15	4.22	0.263	1.23	0.324	71.256
16	3.84	0.161	1.20	0.339	115.419
17	3.79	0.155	1.26	0.297	115.198
18	3.93	0.23	0.99	0.387	96.696
19	3.88	0.193	0.91	0.473	111.454
20	3.84	0.255	0.64	0.569	77.863
21	4	0.197	1.26	0.359	94.824
22	4.26	0.191	1.14	0.375	95.485
23	4.14	0.256	1.00	0.408	81.938
24	4.22	0.236	1.25	0.332	119.824
25	4.31	0.244	0.97	0.430	102.863
26	4.07	0.281	0.91	0.481	70.154
27	3.85	0.162	1.26	0.314	90.859
28	3.98	0.192	1.36	0.329	94.053
29	3.89	0.253	0.65	0.519	87.115
30	3.93	0.2	0.98	0.400	114.648
31	3.89	0.232	0.84	0.419	65.308
32	3.75	0.179	1.11	0.353	73.348
33	3.87	0.176	0.96	0.370	123.899
34	3.79	0.183	0.85	0.409	86.674
35	3.94	0.272	0.68	0.536	62.996
36	3.93	0.226	0.89	0.394	64.427
37	3.8	0.171	1.32	0.312	97.137
38	4.14	0.247	1.19	0.346	49.119
39	4.28	0.25	0.98	0.443	59.692
40	4.02	0.196	1.25	0.370	160.352
41	3.97	0.177	0.93	0.390	101.101
42	3.68	0.165	0.95	0.369	118.833
43	3.82	0.254	0.72	0.470	56.498
44	4.02	0.236	0.87	0.500	97.687
45	3.89	0.189	1.11	0.394	73.018
46	3.76	0.254	1.05	0.365	49.449
47	3.9	0.257	1.08	0.359	43.722
48	4.04	0.216	1.01	0.406	100.881
49	3.81	0.235	0.82	0.435	103.744
50	3.55	0.187	1.12	0.345	92.841
51	3.54	0.235	0.84	0.432	106.608
52	3.38	0.182	1.19	0.353	96.035
53	3.62	0.241	0.85	0.421	80.507
54	3.6	0.193	0.89	0.400	89.207
55	3.58	0.168	0.86	0.390	98.348
56	3.39	0.143	0.97	0.375	93.722
57	3.24	0.116	1.19	0.334	109.141
58	3.33	0.14	0.90	0.423	117.181
59	3.82	0.188	0.99	0.369	108.921
60	3.39	0.215	0.77	0.481	72.137
61	3.54	0.161	1.42	0.271	105.396
62	3.6	0.229	0.84	0.426	87.335
63	3.22	0.145	0.82	0.401	116.630
64	3.21	0.218	1.22	0.275	115.749

Table B.11. *Stem nutrient concentrations at R5 – Princeton, 2002.*

Plot Number	N Conc. (%)	P Conc. (%)	K Conc. (%)	Mg Conc. (%)	Zn Conc. (ppm)
1	1.650	0.072	0.75	0.33	14.5
2	1.570	0.246	1.33	0.30	11.1
3	1.570	0.086	0.64	0.35	10.2
4	1.670	0.124	0.56	0.39	8.5
5	1.580	0.062	0.82	0.24	13.1
6	1.540	0.065	0.86	0.24	15.2
7	1.580	0.116	0.85	0.33	8.1
8	1.570	0.296	1.82	0.29	9.3
9	1.630	0.294	2.06	0.29	9.3
10	1.730	0.122	0.84	0.37	9.6
11	1.560	0.077	0.51	0.32	10.5
12	1.740	0.080	0.67	0.29	12.8
13	1.740	0.137	0.85	0.37	11.5
14	1.410	0.062	0.57	0.29	11.5
15	1.720	0.231	1.17	0.33	9.3
16	1.520	0.072	0.75	0.30	17.7
17	1.830	0.075	0.84	0.31	21.3
18	1.500	0.193	0.82	0.40	12.8
19	1.520	0.110	0.84	0.38	16.8
20	1.720	0.199	0.42	0.50	12.6
21	1.550	0.097	0.98	0.32	12.5
22	1.550	0.082	0.79	0.39	12.1
23	1.620	0.219	0.86	0.40	9.2
24	1.720	0.138	1.03	0.37	12.8
25	1.660	0.146	0.75	0.44	10.7
26	1.580	0.238	0.69	0.44	9.3
27	1.480	0.073	0.85	0.30	11.7
28	1.670	0.092	1.29	0.32	13.2
29	1.530	0.230	0.42	0.44	11.8
30	1.660	0.108	0.71	0.38	14.1
31	1.490	0.164	0.62	0.36	8.8
32	1.720	0.086	0.79	0.33	11.6
33	1.810	0.090	0.58	0.37	17.3
34	1.640	0.085	0.47	0.38	12.2
35	1.640	0.228	0.43	0.45	10.8
36	1.670	0.166	0.71	0.38	10.8
37	1.540	0.089	1.06	0.29	12.0
38	1.700	0.209	1.10	0.34	7.7
39	1.720	0.174	0.71	0.41	8.7
40	1.500	0.094	1.14	0.37	18.4
41	1.650	0.090	0.59	0.36	14.1
42	1.750	0.088	0.58	0.33	21.7
43	1.620	0.188	0.38	0.39	10.2
44	1.590	0.193	0.62	0.36	14.8
45	1.650	0.096	0.69	0.37	9.6
46	1.560	0.226	0.86	0.37	7.1
47	1.700	0.229	0.77	0.36	7.8
48	1.690	0.109	0.63	0.37	10.8
49	1.550	0.164	0.44	0.38	12.6
50	1.640	0.094	0.71	0.33	11.7
51	1.450	0.211	0.55	0.40	13.2
52	1.450	0.096	0.86	0.34	12.8
53	1.580	0.240	0.65	0.42	10.8
54	1.650	0.116	0.66	0.35	12.3
55	1.380	0.082	0.46	0.33	12.2
56	1.680	0.071	0.51	0.30	14.1
57	1.850	0.066	0.63	0.33	24.4
58	1.760	0.072	0.43	0.35	18.7
59	1.410	0.100	0.65	0.34	14.7
60	1.570	0.200	0.49	0.39	10.1
61	1.470	0.079	1.01	0.27	14.1
62	1.400	0.209	0.65	0.42	14.1
63	1.490	0.083	0.74	0.31	10.8
64	1.420	0.119	0.52	0.37	13.1

Table B.12. *Pod nutrient concentrations at R5 – Princeton, 2002.*

Plot Number	N Conc. (%)	P Conc. (%)	K Conc. (%)	Mg Conc. (%)	Zn Conc. (ppm)
1	2.860	0.200	1.64	0.48	41.1
2	3.070	0.315	1.95	0.40	45.9
3	3.080	0.231	1.52	0.47	38.8
4	3.110	0.253	1.51	0.48	38.2
5	2.980	0.178	1.64	0.48	47.9
6	2.950	0.181	1.67	0.47	43.5
7	3.030	0.234	1.75	0.47	31.0
8	3.340	0.337	2.26	0.41	34.5
9	3.190	0.313	2.25	0.42	38.3
10	3.220	0.251	1.67	0.48	34.0
11	3.100	0.212	1.52	0.49	32.7
12	3.020	0.199	1.65	0.48	35.6
13	3.260	0.261	1.76	0.47	46.5
14	3.040	0.195	1.63	0.52	39.1
15	3.290	0.303	1.90	0.43	32.9
16	2.940	0.183	1.61	0.49	42.7
17	3.060	0.199	1.63	0.47	42.6
18	3.030	0.282	1.80	0.46	36.4
19	3.080	0.244	1.73	0.48	39.3
20	3.510	0.311	1.36	0.48	36.5
21	3.260	0.257	1.74	0.43	35.3
22	3.190	0.223	1.69	0.48	34.8
23	3.320	0.316	1.81	0.43	33.1
24	3.190	0.255	1.80	0.47	35.3
25	3.210	0.263	1.74	0.49	33.9
26	3.210	0.301	1.64	0.48	31.3
27	2.910	0.198	1.78	0.48	35.5
28	3.100	0.233	1.89	0.46	37.7
29	3.430	0.327	1.44	0.49	34.6
30	3.240	0.249	1.68	0.49	40.0
31	3.130	0.287	1.61	0.46	30.8
32	2.950	0.214	1.63	0.48	35.8
33	3.140	0.224	1.59	0.47	40.0
34	3.200	0.223	1.51	0.50	37.6
35	3.480	0.341	1.42	0.47	34.1
36	3.430	0.305	1.73	0.46	32.7
37	3.100	0.228	1.93	0.48	38.8
38	3.350	0.315	2.01	0.45	31.5
39	3.110	0.274	1.76	0.48	32.3
40	3.250	0.247	1.89	0.48	43.2
41	3.160	0.223	1.65	0.49	39.2
42	3.130	0.203	1.48	0.47	41.3
43	3.390	0.307	1.30	0.44	33.1
44	3.370	0.300	1.62	0.47	38.3
45	3.270	0.237	1.68	0.47	33.1
46	3.270	0.322	1.94	0.46	28.7
47	3.600	0.333	1.90	0.45	29.8
48	3.260	0.251	1.69	0.48	34.6
49	3.390	0.297	1.85	0.51	35.7
50	3.150	0.240	1.62	0.48	37.9
51	3.400	0.324	1.57	0.48	36.5
52	3.000	0.244	1.72	0.47	36.0
53	3.140	0.311	1.73	0.47	33.7
54	3.480	0.292	1.58	0.48	36.5
55	3.430	0.234	1.55	0.49	38.0
56	3.180	0.210	1.48	0.49	38.6
57	3.130	0.182	1.49	0.52	46.3
58	3.090	0.185	1.30	0.50	43.5
59	3.420	0.270	1.87	0.52	41.4
60	3.480	0.325	1.63	0.48	34.0
61	3.190	0.226	1.93	0.49	40.4
62	3.280	0.315	1.63	0.49	34.3
63	3.090	0.205	1.61	0.48	43.2
64	3.370	0.278	1.61	0.48	38.5

Table B.13. *Grain nutrient concentrations – Princeton, 2002.*

Plot Number	N Conc. (%)	P Conc. (%)	K Conc. (%)	Mg Conc. (%)	Zn Conc. (ppm)
1	6.82	0.43	1.77	0.228	64.7
2	7.15	0.59	1.89	0.234	59.4
3	7.05	0.42	1.72	0.219	60.4
4	7.08	0.48	1.70	0.216	63.2
5	6.85	0.35	1.70	0.215	65.0
6	6.75	0.36	1.63	0.211	65.3
7	7.26	0.44	1.74	0.216	58.7
8	6.92	0.51	1.87	0.227	54.2
9	6.88	0.62	2.05	0.232	55.3
10	7.29	0.51	1.77	0.211	60.4
11	7.24	0.43	1.70	0.205	59.9
12	7.41	0.42	1.64	0.195	61.2
13	7.12	0.50	1.80	0.214	62.9
14	7.14	0.41	1.77	0.207	62.5
15	7.17	0.59	1.88	0.229	58.8
16	6.63	0.41	1.89	0.236	67.6
17	7.19	0.41	1.69	0.209	66.7
18	7.05	0.51	1.83	0.218	63.0
19	6.91	0.40	1.69	0.209	64.9
20	7.15	0.58	1.70	0.213	57.3
21	7.04	0.42	1.65	0.210	64.9
22	6.88	0.43	1.74	0.212	64.6
23	7.38	0.60	1.92	0.224	61.1
24	7.00	0.54	1.86	0.220	62.7
25	6.84	0.46	1.74	0.216	63.8
26	7.19	0.56	1.75	0.214	59.3
27	7.20	0.40	1.71	0.201	59.2
28	7.16	0.46	1.72	0.206	61.9
29	7.15	0.60	1.87	0.219	57.3
30	6.95	0.50	1.80	0.213	62.6
31	7.03	0.56	1.83	0.213	61.9
32	7.01	0.44	1.80	0.219	62.7
33	6.94	0.49	1.76	0.216	63.6
34	7.26	0.51	1.76	0.205	61.4
35	7.40	0.63	1.82	0.216	60.5
36	7.18	0.57	1.80	0.215	57.8
37	7.09	0.44	1.80	0.212	65.0
38	7.44	0.57	1.81	0.212	56.4
39	6.95	0.49	1.76	0.214	60.5
40	no data	no data	no data	no data	no data
41	6.86	0.45	1.72	0.211	63.6
42	7.27	0.53	1.76	0.212	60.1
43	7.21	0.59	1.86	0.217	59.1
44	7.27	0.48	1.77	0.211	61.4
45	7.29	0.50	1.68	0.213	62.1
46	7.21	0.57	1.80	0.221	58.6
47	7.23	0.40	1.65	0.203	64.7
48	7.13	0.39	1.66	0.209	65.7
49	7.05	0.55	1.74	0.223	64.6
50	7.16	0.53	1.72	0.218	63.7
51	7.12	0.61	1.77	0.224	66.4
52	7.09	0.53	1.78	0.214	63.4
53	7.03	0.58	1.81	0.217	64.0
54	7.04	0.56	1.81	0.209	64.7
55	7.10	0.44	1.65	0.199	63.6
56	7.09	0.39	1.59	0.197	67.1
57	6.74	0.34	1.63	0.181	82.5
58	7.14	0.39	1.63	0.192	67.9
59	7.33	0.47	1.60	0.206	65.2
60	7.30	0.51	1.76	0.211	67.0
61	7.11	0.47	1.68	0.208	70.6
62	7.14	0.54	1.76	0.221	61.8
63	7.10	0.48	1.66	0.215	69.2
64	7.14	0.53	1.58	0.213	65.4

VITA

Máximo Uranga was born in Rosario, Province of Santa Fe, Argentina the 31st of October, 1974. He grew up on his family's farm located in southeastern Cordoba Province, where he attended elementary school education. When he started high school, all the family moved to live in the city of Rosario, where Máximo completed his high school education. He received the B.S. degree of "Ingeniero Agrónomo" from the Universidad Nacional de Rosario, located in Rosario, Argentina. After completing his degree, he worked for more than two years in the Extension Department of a fertilizer company in Argentina.