To the Graduate Council:

I am submitting herewith a dissertation written by Nuri H. Al-Mohammadi entitled "Yield and Selected Chemical and Morphological Responses of Several Soybean Cultivars to Soil pH." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Plant and Soil Science.

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R. J. Lewis, Major Professor

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and recommend that it be accepted:

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YIELD AND SELECTED CHEMICAL AND MORPHOLOGICAL RESPONSES OF SEVERAL SOYBEAN CULTIVARS TO SOIL PH

A Dissertation

Presented for the

Doctor of Philosophy

Degree

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Nuri H. Al-Mohammadi

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ABSTRACT

Yield responses of soybeans to soil pH have been difficult to demonstrate on most soils in Tennessee. Yet, liming has consistently been recommended as a practice to maintain productive soils near neutral. A study was conducted with 21 soybean cultivars on a productive West Tennessee soil to evaluate several chemical and morphological characteristics of these cultivars and determine which of the characteristics had any impact on yield.

Twenty-one soybean cultivars belonging to three maturity groups (IV, V, and VI) were planted in three soil pH levels of 5.3, 5.9, and 6.8 in a split-plot arrangement of treatments in a randomized complete block design having four replications. The soil pH levels were the main plots and the cultivars were assigned to the split plots. The study was conducted on a Loring silt loam (Typic Fragiudalf) soil at Ames Plantation.

Results indicated that in 1981 as soil pH level increased from 5.3 to 6.8, single and double seeded pods on the main stem, triple seeded pods on the branches, branches per plant and leaf Ca increased. In 1982, yield, triple seeded pods on both main stem and branches, seed weight, leaf Ca, and N increased as soil pH increased. Leaf P decreased in 1982 while leaf Mn decreased as pH increased in both years of the study. Soybeans were treated with supplemental Mo in 1981 but not in 1982.

Stepwise regression suggested that leaf P-concentration or soil pH were the best single variable models, expressing 42 to 80 percent of the variation in yield for most of the cultivars in maturity group VI in 1981 and 1982, respectively.

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CHAPTER I

INTRODUCTION

Excessive soil acidity has long been recognized as a major detrimental factor in soil productivity under humid climates. Changes in soil pH affect a large number of soil characteristics which affect plant growth. Sensitivity of plant species and varieties to such changes differ widely. Altering soil acidity may also alter the populations and activities of the microorganisms responsible for transformations involving N, S, and P in the soil, indirectly affecting the availability of these elements to plants. Manganese and/or Al toxicities, Ca, Mg, Mo, and P deficiencies are usually associated with soil acidity.

In Tennessee, soybeans are the number one cash crop. Many soybean cultivars have been recommended for this state. One of the major problems which soybean production has been facing is the low level of soil pH. No intensive studies had been carried out for the response of these recommended cultivars to soil pH levels.

The objectives of this study were (1) to determine how yield, chemical composition and selected morphological characteristics of soybeans are affected by soil pH, (2) ascertain the effect of soil pH on the comparative performance of selected soybean cultivars and (3) determine which characteristics are responsible for yield changes as influenced by soil pH.

CHAPTER II

LITERATURE REVIEW

A. SOIL ACIDITY

Excessive acidity has long been recognized as one of the reasons soils become unproductive. Since the second century B.C., records have shown liming was practiced to correct soil acidity (Barber, 1967). Commonly, soil acidity is measured by soil pH and may be an indirect measure of the availability of most of the inorganic nutrients in the soil (Adams, 1978). If the soil pH falls below 5.0, most agronomic crops require some lime (Weeks et al, 1967).

On large portions of the earth's surface, rainfall exceeds evapotranspiration for much of the year with nutrient leaching occurring. Soluble salts and bases are gradually removed by such leaching. Initially, the leached surface soil becomes slightly to moderately acid, while the subsoil may remain neutral or alkaline. As weathering proceeds, the entire profile eventually becomes acidic and finally even acidic components are leached from the soil. Once this occurs, the surface soil pH and ultimately the pH of the entire profile once more approaches neutrality. Only highly weathering resistant minerals like iron and aluminum oxides, and some of the trace metal oxides remain from the original parent material (Bohn et al, 1979).

Soil acidity may also arise from exposure to the air of mine spoils containing iron pyrite, crop fertilization, and drainage of marine floodplains containing high sulfide sediments which may oxidize to H_2SO_4 upon exposure. In addition, acidity may be produced by plant residues or organic wastes decomposing into organic acids (Bohn et al, 1979).

Soil acidity has a pronounced effect on a number of soil constituents such as soil minerals, soil microorganisms and plant roots. High hydrogen ion concentrations favor the weathering of minerals resulting in release of various ions such as K^+, Mg^{+2}, Ca^{+2}, Mn^{+2}, and Al^{+3}. In lower pH ranges, the solubility of salts including carbonates, phosphates, and sulfates is higher. The release of Al by clay minerals in various forms is largely pH dependent. Clay minerals adsorb Al in the form of $Al(OH)^{+2}$ or $Al(OH)_2^+$ (Jenny, 1961). This adsorption becomes weaker as the pH decreases, thus more soluble Al[Al^{+3}, $Al(OH)^+2$, or $Al(OH)_2^{+1}$] comes into soil solution in acid soils (Lathwell and Peech, 1964). The concentration of soluble Al decreases dramatically at higher soil pH levels (6.5-7.0). Soluble Al can be toxic to plant growth, so the pH of all high clay containing soils should be maintained at 6.5 or a little higher (Mengel and Kirkby, 1979).

Valmis (1953) conducted an experiment to study two soil pH levels and Al concentration effects on barley dry matter yields, of barley grown in nutrient solution. He found that at pH 4.2 a relatively high yield was obtained as compared with the yield at pH 5.8, provided that the concentration of Al in the nutrient solution was low. There was a drastic reduction in dry matter yield when Al concentration was increased in the pH 4.2 treatment. It seemed that the concentration of Al rather than the low pH of the nutrient solution was the growth limiting factor in this case. Adams and Lund (1966) concluded that Al particularly affects root growth in experiments with cotton. These workers found considerable damage to roots when the soil solution contained Al^{+3} in concentrations in the order of 1.1×10^{-5} M. Martini et al, 1974, found that optimum soybean yields were obtained when liming adjusted Al from 0.1 to 0.5 meq/100 g (1-5% Al saturation), and soil pH from 5.2-5.7. Mengel and Kirkby (1979) concluded that most plant response is related to lowering the Al concentration rather than raising the pH.

Lime recommendations from agricultural experiment stations were historically designed to raise soil pH to 6.5 or higher. Recently, some recommendations aim for pH levels somewhat below 6.5 (Hall, 1978).

Soil pH is a principal criterion for determining when lime is needed. Crops respond to liming because one or more of the following conditions has been corrected: hydrogen-ion, aluminum and manganese toxicities, calcium, magnesium, and molybdenum deficiencies (Adams, 1978).

An agricultural liming material is defined as a material whose Ca and Mg compounds are capable of neutralizing soil acidity. There are different liming materials including quicklime, hydrated lime, limestone, shells, and some byproducts like slag (Barber, 1967).

Ground limestone is the most common liming material. In 1975, about 34.3 million tons of agricultural liming materials were sold in the United States (Suits et al, 1978).

B. SOIL PH-MN RELATIONSHIP

Manganese occurs in many primary minerals and rocks, particularly in ferromangnesian materials. Manganese released from these rocks by weathering may form some secondary minerals like pyrolusite (MnO_2) and manganite [MnO(OH)]. Soils may differ considerably in their Mn content. Soils usually contain 200-300 ppm. Divalent Mn ions and Mn oxides are the most important soil Mn forms. Clay minerals and organic matter adsorb Mn^{+2} which is the most important Mn form in the soil solution. The dominance of one Mn form over another depends on the oxidation-reduction condition in the soil. Divalent Mn and easily-reducible Mn are the most important forms in plant nutrition because Mn^{+2} is the form which plants can take up (Mengel and Kirkby, 1979). The combination of these two forms is called "active Mn." Since the divalent Mn level in the soil is governed by oxidation-reduction processes, all factors influencing these processes affect Mn availability. Soil pH, organic matter content, microbial activity, and soil moisture are the important factors in the oxidation-reduction processes. In paddy soils, for example, the dominant process is reduction, so levels of available Mn become high which may cause Mn toxicity (Mengel and Kirkby, 1979).

Soil pH is one of the most important factors which govern Mn availability. Manganese deficiency is usually associated with high pH values and/or high organic matter content. On the other hand, Mn toxicity is not uncommon in soils with low pH levels. This is due to the higher solubility of Mn compounds under low pH conditions. Lindsay

(1972) reported that soluble Mn decreased 100 fold for each pH unit increase. Manganese deficiency may occur under high soil pH conditions. Page (1962) concluded that increasing soil pH enhanced the production of Mn soil organic matter complexes which decreased Mn availability. Jones (1957) suggested that the microbial activity which influences Mn oxidation is pH dependent. This optimum activity was reached at pH around 7.

Martini et al (1974) attributed the highly significant response of soybeans to lime to high available Mn levels and low pH, as well as other factors, in their study of the response of soybeans to liming of acid soils in Brazil.

Most of the Mn in acid soils with a pH less than 5.5 is present in soluble and/or exchangeable form and soil exchangeable Mn is closely related to soil pH. Plants grown on these soils may suffer Mn toxicity and/or iron deficiency resulting from the competition of Mn with Fe for positions in the heme nucleus in the Fe containing enzymes in the plant. Manganese, in high concentrations, may interfere also with Fe transport from roots to shoots. Liming these soils results in the reduction of soluble Mn levels thus correcting Fe deficiency conditions (Hati et al, 1979).

Keyser and Munns (1979) concluded that high Mn and low Ca content of acid soils slowed the growth of Rhizobia bacteria. They also concluded that the high concentrations of Mn in the acid soils studied was toxic to legume plants.

C. MOLYBDENUM

Molybdenum was discovered as an element in 1782. Igneous rocks of the earth's crust contain about 1 x 10^{-2} ppm. Major Mo containing minerals are Molybdenite (MoS_2), Wulfenite ($PbMoO_4$), Molybdite ($FeO_3 \cdot 3MoO_3 + H_2O$), Provellite [$Ca(MoW)O_4$], and Ilsemannite ($Mo_2 \cdot 4MoO_3$) (Curtis, 1972).

Most agricultural soils have a total Mo content between 0.6-3.5 ppm, but the average available level is about 0.2 ppm. Molybdenum occurs largely in the soil as an oxycomplex (MoO_4^{-2}). The adsorption of molybdate, by soil minerals and colloids, is closely dependent on soil pH. At neutral pH, this adsorption is very low, but it increases as the pH falls. The availability of Mo to plants is therefore poor. As soil pH goes up, Mo availability increases by the exchange of adsorbed molybdate ions on the colloid for OH^- in the soil solution (Mengel and Kirkby, 1979). Molybdate may also be exchanged by other anions which have sufficient exchange energy. This may be of significance in the beneficial effect of phosphate application on Mo availability (Walker et al, 1955). The most effective ions in increasing the Mo level in soil solution and hence Mo uptake by plants are OH^- ions (Plant, 1956).

Molybdenum concentration in the soil solution may vary considerably. Workers have reported these concentrations to be between 2 x 10^{-8} and 8 x 10^{-8} M (Lavy and Barber, 1964). Soils differ widely in their fraction of total Mo in the soil solution. About 66% of the total Mo in some Californian soils, for example, is water soluble. On the other hand, in Mo deficient soils in Florida, the water soluble Mo made up less than 1% of the total Mo (Mengel and Kirkby, 1979). Water soluble and exchangeable Mo are not the only forms of soil Mo; the element also occurs in nonexchangeable form in a number of mineral structures.

Molybdate ions could also be adsorbed by Fe oxides (Jones, 1957; Lucas and Kenzek, 1972; and Karimian and Cox, 1978) and, to a lesser extent, by Al hydroxides and kaolinite (Reyes and Jurinak, 1967). Iron oxides containing the adsorbed molybdate may be transformed with time to the insoluble compound ferrimolybdite (Follett and Barber, 1967). Availability of soil Mo to plants increases as the displacement of molybdate from adsorbates and precipitates by OH^- occurs.

Little data is available on Mo requirement of plants as measured by tissue analysis. Molybdenum applications did not increase soybean yields when the Mo level was greater than 0.14 mg g^{-1} in trifoliolates (Mortvedt and Anderson, 1982). Increases in yields and concentrations of Mo and N in soybean plants occurred when Mo was applied to plants having a tissue level of <0.13 mg g^{-1} with highest yields and concentrations obtained in plants with leaf Mo ranging between 0.22 and 0.51 mg g^{-1} (Hagstrom and Berger, 1965; Boswell and Anderson, 1969). Plant response to applied Mo often was more closely related to N concentration in leaf tissue than to Mo concentration. Analyzing legumes for N rather than Mo may be preferable in determining crop response to Mo on acid soils (Mortvedt, 1981).

Some workers concluded that the response of soybeans to applied Mo probably related to seed size. Peterson and Purvis (1961) concluded that sufficient Mo contained by large seeds, like soybean seeds, could be the reason why soybeans did not respond to applied Mo. Harris et al (1965) reported that total Mo in seed of the same cultivar obtained from six states varied from 0.6 to 22.4 mg g^{-1} and seeds from five of these states contained <2.6 mg g^{-1} and all progeny produced from seeds with <2.6 mg g^{-1} responded to applied Mo. Long and Lewis (1966) obtained a response to applied Mo with seed containing 4.9 mg g^{-1} Mo.

Liming, fertilizer application, and seed treatment are used to correct Mo deficiencies of crops. Consistent relationships between liming to correct soil acidity and response to applied Mo are not always found. Soybean yields on some soils are not affected by lime applications when Mo is applied, while Mo applications do not increase yields on limed soils (Parker and Harris, 1962). On the other hand, Anthony (1967) reported that there is evidence of the need for Mo by soybeans even where high lime rates were applied to very acid soils. Hagstrom and Berger (1953) reported that soybean yields and N uptake were increased when about 400 g ha^{-1} of Mo were broadcast on an acid soil. Boswell and Anderson (1969) obtained almost equal yield increases from a Mo application of 217 g ha^{-1} on soybean seed or a foliar application of the same rate at the prebloom growth stage on three soil ranging in pH from 5.0 to 5.9.

Little information is available in the literature concerning soybean morphological characteristics as affected by soil chemical factors. There have been some studies conducted on changes in morphological characteristics as a result of moisture or population stresses or seed size. Johnson and Harris (1967) studied the influence of plant population on yield, plant height, lodging, and seed size of some soybean cultivars. Fontes and Ohlrogge (1972) studied the influence of seed size and plant population on yield, seed weight, and lodging of soybean. Other workers studied irrigation, moisture stress, row spacing effects on yields, vegetative and reproductive development, number of nodes, branches, pods on branches and main stem of some soybean cultivars (Shaw and Laing, 1966; Basnet et al, 1974; Ashley and Ethridge, 1978; Momen et al, 1979; Ramseur et al, 1984).

CHAPTER III

MATERIALS AND METHODS

A. FIELD EXPERIMENTATION

This field study was conducted at Ames Plantation, which is located in southwest Tennessee, in both 1981 and 1982 on a Loring silt loam classified as a Typic Fragiudalf (fine, silty, mixed, thermic).

The soil pH levels were maintained nearly constant for several years by the addition of lime. The three soil pH levels were 5.3, 5.9, and 6.8.

The experimental design of the field study was a randomized complete block design with a split-plot factorial arrangement of treatments and four replications. The main plots were the three pH levels, and the split-plots were the 21 soybean cultivars.

Twenty-one soybean [Glycine max (L.) Merr.], cultivars adapted to this geographical area, representing three maturity groups (IV, V, and VI) were utilized. Plot size was one row, 1 m x 6.7 m. The 21 cultivars used in this experiment were:

1. Group IV: Columbus, Delta, FFR 446, Franklin, Mitchell, Stevens, and Wilstar 430.
2. Group V: Asgrow 5474, Asgrow 5618, Bay, Bedford, Dare, Essex, Forrest, Nathan, and York.
3. Group VI: Centennial, Jeff, Lancer, Lee 74, and Pickett 71.

Ten most recently matured trifoliates were collected from each plot at the early pod forming stage of growth (R5). These samples were oven dried at 65°C for about 72 hrs and ground in a Wiley mill. The ground material was kept in sealed plastic bags for chemical analysis.

Soil samples were taken from the top 15 cm. Soil samples were air dried, passed through a 2 mm sieve, and stored in plastic bags for pH determination. Soil pH was determined potentiometrically with a 1:1 soil-water ratio.

Cultivars were harvested according to their maturity groups. At the time of harvesting, plant height was recorded for each experimental unit and two representative plants were randomly selected for morphological analysis.

For each plant the following characteristics were recorded: plant height (cm), number of nodes on the main stem, number of branches, number of single seeded, double seeded, and triple seeded pods on the main stem in every node, and number of single, double, and triple seeded pods on each branch. From each plot 100 seed weight and yields were taken and reported on a 13 percent moisture basis. All plants received foliar applied Mo when the plants reached 25 cm in 1981. No Mo was applied in 1982.

To save space several of the morphological characteristics have been abbreviated. These are listed in Table 1.

Table 1. Abbreviations of Selected Morphological Characteristics.

Symbol	Description
SPMS1	Single seeded pods on the main stem
SPMS2	Double seeded pods on the main stem
SPMS3	Triple seeded pods on the main stem
SP_1BR	Single seeded pods on the branches
SP_2BR	Double seeded pods on the branches
SP_3BR	Triple seeded pods on the branches
HT	Plant height (Cm)
Seed Wt.	Seed weight

B. PLANT TISSUE ANALYSIS

The ground trifoliate tissue samples were analyzed for the following nutrients: N, P, K, Ca, Mg, and Mn. Phosphorus, K, Ca, Mg, and Mn were analyzed as follows: 1.000 g samples were weighed and put into porcelain crucibles, ashed at 500°C for 16 hrs. After cooling the crucibles, 8 ml of 20% HCl were added, warmed, and the ashed material dissolved with the aid of a glass rod with policeman. The contents were quantitatively transferred to a funnel containing a number 41 Whatman filter paper. The filtrates were received in 100 ml volumetric flasks. The crucibles and the papers were rinsed several times with deionized water and the flasks brought to volume with deionized water. The concentrations of these nutrients were determined by Atomic Absorption Spectrophotometer with the exception of P. Phosphorus was determined colorimetrically by the ammonium vanadate method.

Nitrogen was determined in separate samples as follows: 0.200 g of the ground tissue was put in a 125 ml Erlenmeyer flask. Ten ml of concentrated H_2SO_4 was added and left overnight for pre-digestion. Flasks were placed on a hot plate at 215°C until the volume was reduced by nearly half, cooled, and 20 ml of 35% H_2O_2 added, replaced on the hot plate until the solution cleared. Another hydrogen peroxide treatment was occasionally required before the color cleared.

Heating continued until bubbling stopped to assure that all the hydrogen peroxide was evaporated. After the flasks were cooled, the contents were quantitatively transferred to 250 ml volumetric flasks with deionized water. Nitrogen was analyzed in these samples as NH_4-N by a Technicon Auto Analyzer (Thomas et al, 1967).

C. STATISTICAL ANALYSIS

Variables that required transformation to allow the data to fit a normal distribution are given in Table 2. Selected statistical procedures were employed to analyze the data by the Statistical Analysis System as outlined in SAS Users Guide, 1982. Regression analyses were performed on soil hydrogen ion activity, however the signs shown in the regression tables five through seven, and 14 through 16, were reversed to reflect soil pH influences.

Table 2. Selected Transformation Factors for Some Morphological and Chemical Characteristics of 21 Soybean Cultivars.

Variables	Original	Transformation Factor
Double seeded pods on main stem	Number	log 10 (X + 0.001)
Double seeded pods on branches	Number	log 10 (X x 10 + 1)
Seed weight	(g)	log 10 (X x 10)
Calcium	Percent	log 10 (X x 10)
Magnesium	Percent	log 10 (X x 10 + 1)
Manganese	Percent	log 10 (X x 10)

CHAPTER IV

RESULTS AND DISCUSSION

The discussion of the results obtained from this study for each characteristic beginning with the general trends of soil pH effects on yield, chemical and morphological characteristics of the cultivars is presented first followed by a discussion of cultivar influences on many of these same characteristics.

Since several characteristics were not found to be significantly influenced by soil pH in either year of the study, they will not be discussed. They are single and double seeded pods on branches, plant height, nodes on the main stem, and leaf K and Mg-concentrations.

A. YIELD

Soil pH had no significant effect on yields across all soybean cultivars in 1981 but significant positive ($P < 0.05$) effects were noted in 1982 (Tables 3 and 4). There were significant differences in yield among the cultivars in both years. The interaction of cultivars x pH was significant in 1981, but not in 1982. Generally yield across all cultivars tended to increase as soil pH increased from 5.3 to 6.8 in both years (Figure 1).

As previously mentioned, soil pH had a significant effect on soybean yields only in 1982. However, since cultivars showed a highly significant effect in both years, a few general trends might be pointed out. Beginning with the maturity group IV cultivars in 1981, one can

Table 3. Mean Squares for Yield, Morphological, and Chemical Characteristics of 21 Soybean Cultivars at Three Soil pH Levels in 1981.

Characteristic	pH	Rep x pH	Cultivar	Cultivar x pH
	Source of Variation			
df	2	6	20	40
Yield	1119703.32	419514.18	2188137.93**	207039.67*
Seeds per pod on:				
Main stem				
one	19.48*	1.97	14.77**	3.07
two	0.271*	0.370	0.3166**	0.0261
three	0.0353	4.8439	18.8099**	4.8523
Branches				
one	6.8937	2.1520	10.9477**	3.2018
two	0.5704	0.1631	1.9125**	0.1607
three	328.4996*	59.7828	330.7828**	53.4977
Wt./100 seeds	0.0034	0.0031	0.0324**	0.0020
Height	21.9408	136.6353	2392.2520**	206.5585*
Nodes/Main Stem	11.1742	7.5564	80.7057**	2.0893
Branches/Plant	17.7670*	2.0321	20.4243**	2.9691
P	0.0071	0.0024	0.0014**	0.00026
K	0.2041	0.1395	0.1966**	0.0188
Ca	0.2078**	0.0116	0.0395**	0.0030
Mg	0.0590	0.0120	0.0129**	0.0025*
Mn	0.3864**	0.0104	0.0215**	0.0043*
N	0.0013	0.0105	0.0209**	0.0045

*,**Significant at 0.05 and 0.01 levels of probability, respectively.

Table 4. Mean Squares for Yield, Morphological, and Chemical Characteristics of 21 Soybean Cultivars at Three Soil pH Levels in 1982.

	Source of Variation			
	pH	Rep x pH	Cultivar	Cultivar x pH
Characteristic	df 2	6	20	40
Yield	7021121.956**	210430.9178	1280263.791**	130931.638
Seeds per pod on:				
Main stem				
one	0.1916	0.1667	21.7702**	3.9848
two	0.0272	0.0400	0.5928**	0.0299
three	412.6103*	20.3382	763.3739**	83.7987
Branches				
one	3.8575	13.3223	27.7967**	10.3411
two	0.4971	0.1598	1.0184**	0.2937
three	710.7159*	109.4813	30.2024**	122.3188
Wt./100 seeds	0.0206*	0.0030	0.0435**	0.0014
Height	282.2728	243.2412	166.7175**	83.3587
Nodes/Main Stem	3.8891	13.1735	56.4659**	8.3193*
Branches/Plant	8.1171	7.5735	10.6989**	3.6295
P	0.0089*	0.0015	0.0066*	0.0030
K	0.1214	0.1511	0.5408**	0.0176
Ca	0.0707**	0.0037	0.0443**	0.0028
Mg	0.0053	0.0013	0.0152**	0.0021*
Mn	0.1665*	0.0232	0.0209**	0.0048*
N	0.0598*	0.1667	0.0448*	0.0094**

*,**Significant at 0.05 and 0.01 levels of probability, respectively.

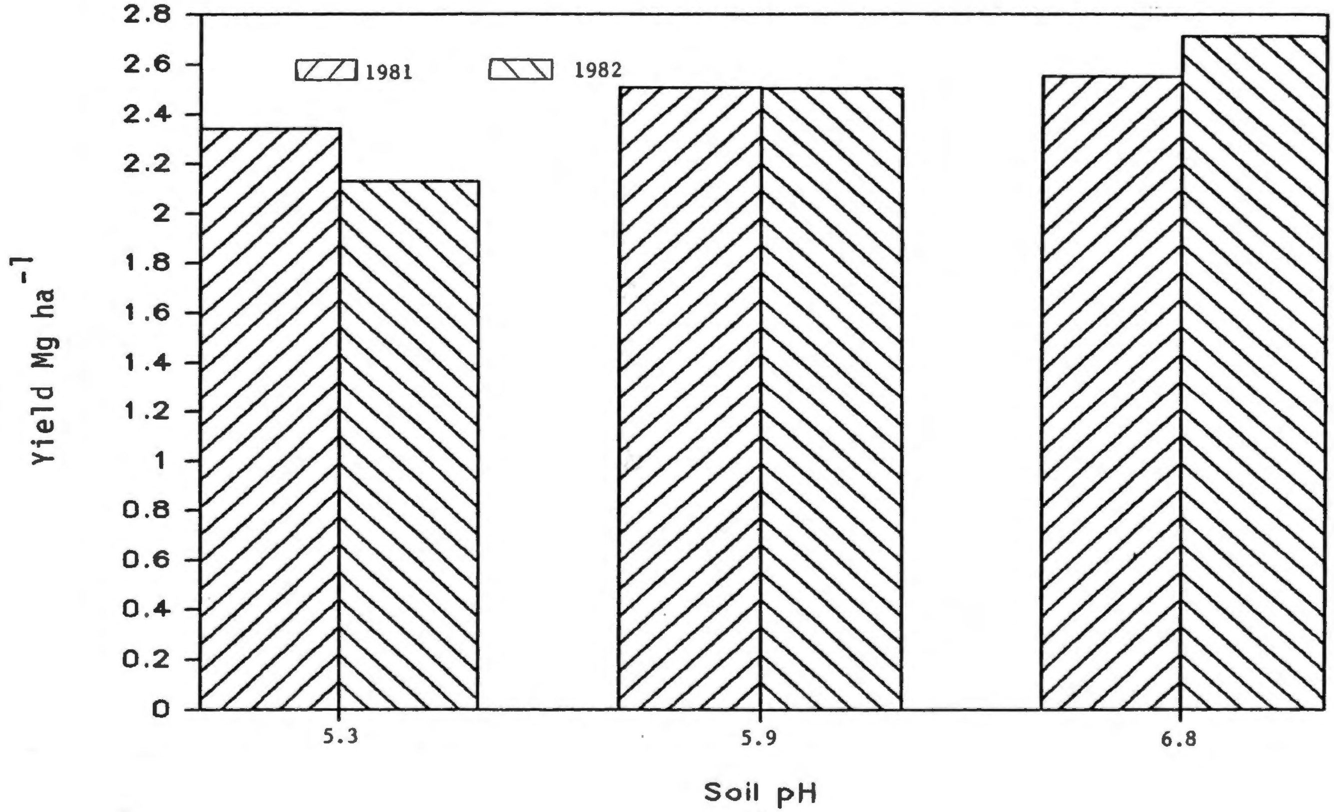

Figure 1. Mean Yields at Three Soil pH Levels, Averaged Across Twenty-one Cultivars in 1981 and 1982.

note that yields were higher at pH values 5.9 and 6.8 than at 5.3 with the exceptions of Columbus, Delta and Stevens (Figure 2, Appendix Table A-1). With Columbus and Delta this trend was reversed, both showing a decreasing yield trend with increasing pH. Stevens produced its lowest yield at pH 5.9 and almost equal yields at pH levels 5.3 and 6.8. A general trend was more difficult to identify with the group V cultivars (Figure 3). Here soil pH seemed to have little influence on yield with the exception of Forrest which exhibited a rather pronounced yield increase at pH 6.8 in 1981. In group VI, cultivars gave a greater yield at pH values of 5.9 and 6.8 than at 5.3, except Jeff (Figure 4). The greatest response was shown by Centennial, its yield being the highest at pH 6.8 of any cultivar in the study in 1981.

In 1982, the experiment was repeated. As can be seen from the response of the group IV cultivars, a more pronounced yield response to increasing soil pH was observed (Figure 5). Although some of the yield differences are small and not statistically significant ($P < 0.05$), most cultivars gave yield responses to each increase in soil pH. This pattern of yield responses was continued with group V and VI cultivars (Figures 6 and 7). In group V approximately one-half of the cultivars exhibited these consistent trends, but the general benefit of growing the plants at a soil pH of at least 5.9 is evident. Once again, as in 1981, Centennial produced the highest yield and it occurred at pH 6.8.

From the previous discussion, it appears that some cultivars' yield (e.g., Columbus and Delta) responded negatively to the increase in soil pH in 1981. Other cultivars reached their highest yield in

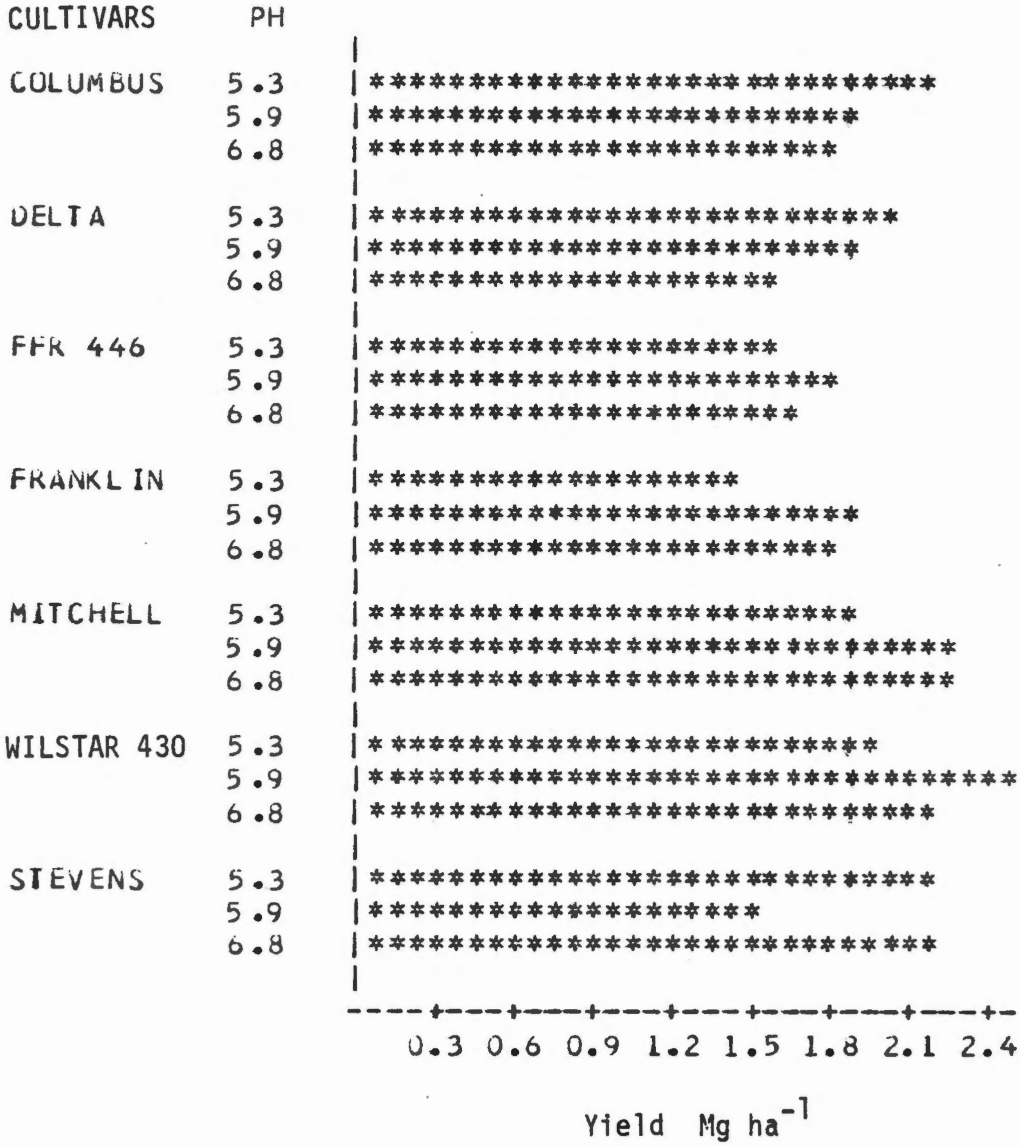

Figure 2. Mean Yields of Maturity Group IV Soybean Cultivars Grown at Three Soil pH Levels in 1981.

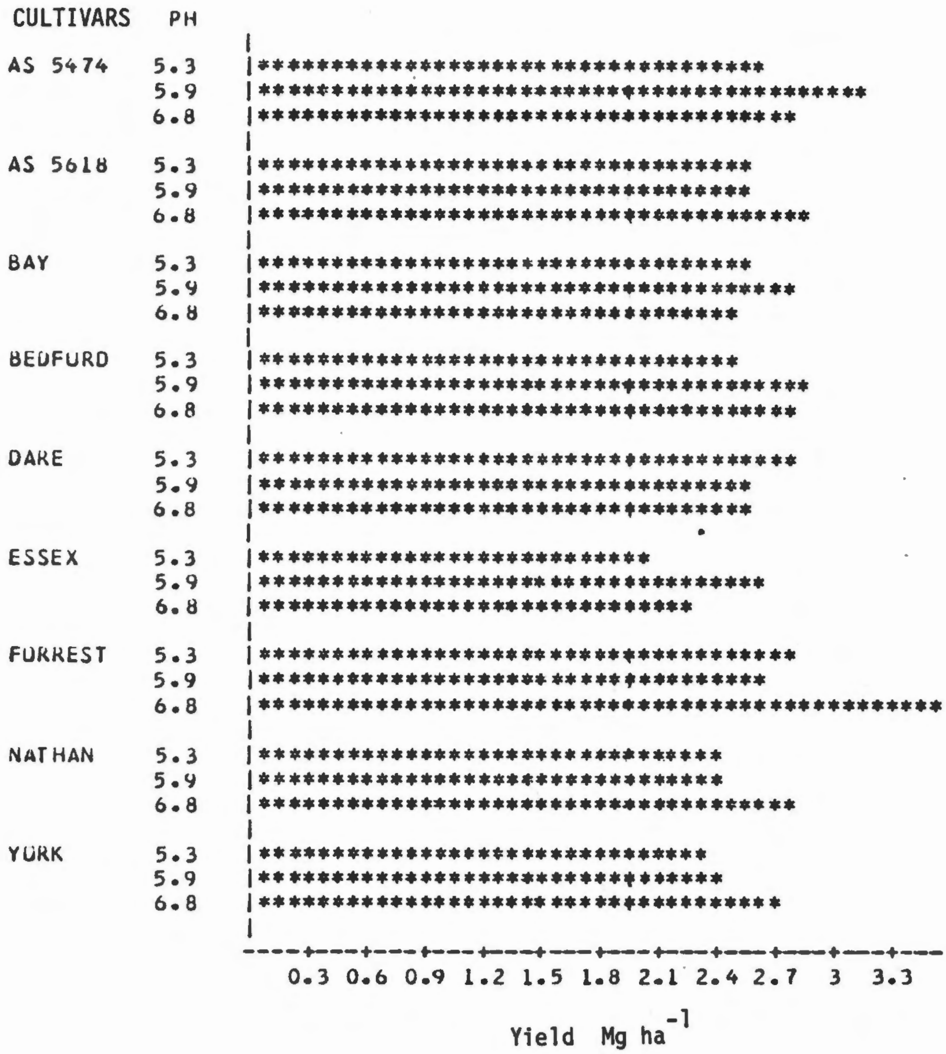

Figure 3. Mean Yields of Maturity Group V Soybean Cultivars Grown at Three Soil pH Levels in 1981.

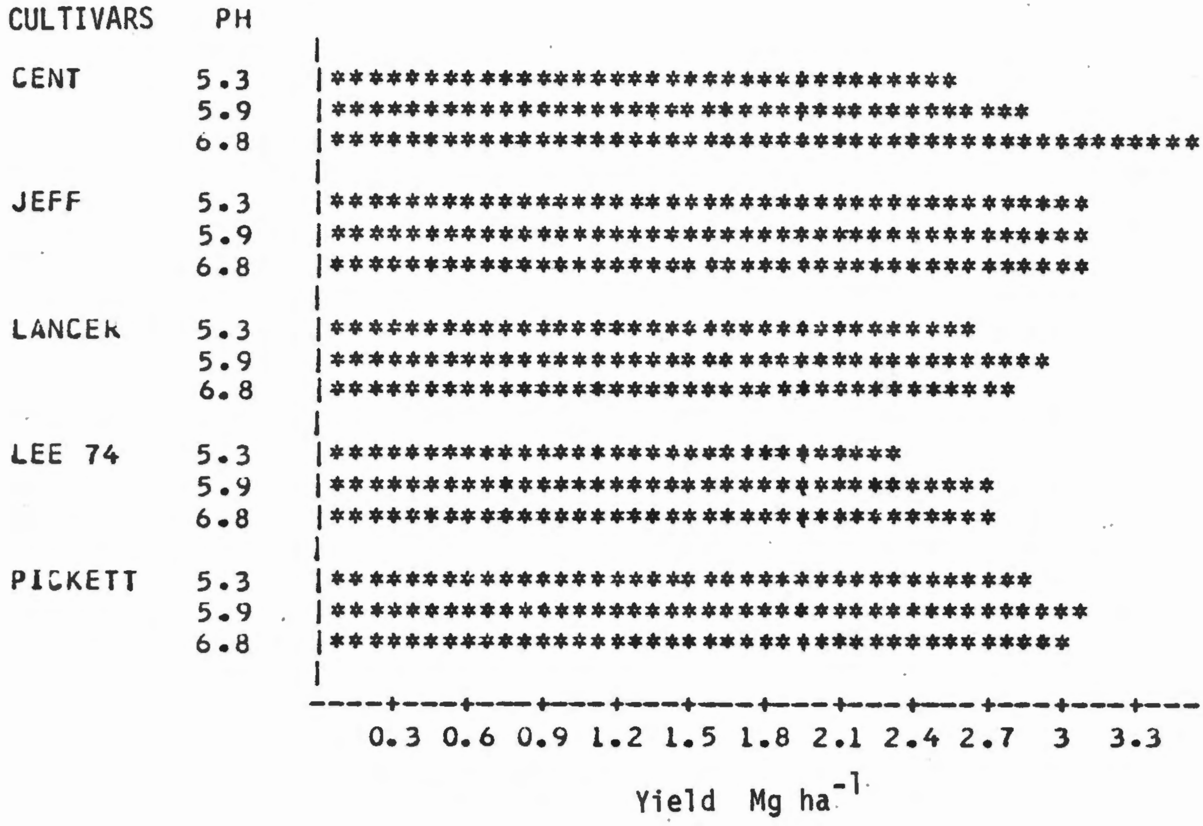

Figure 4. Mean Yields of Maturity Group VI Soybean Cultivars Grown at Three Soil pH Levels in 1981.

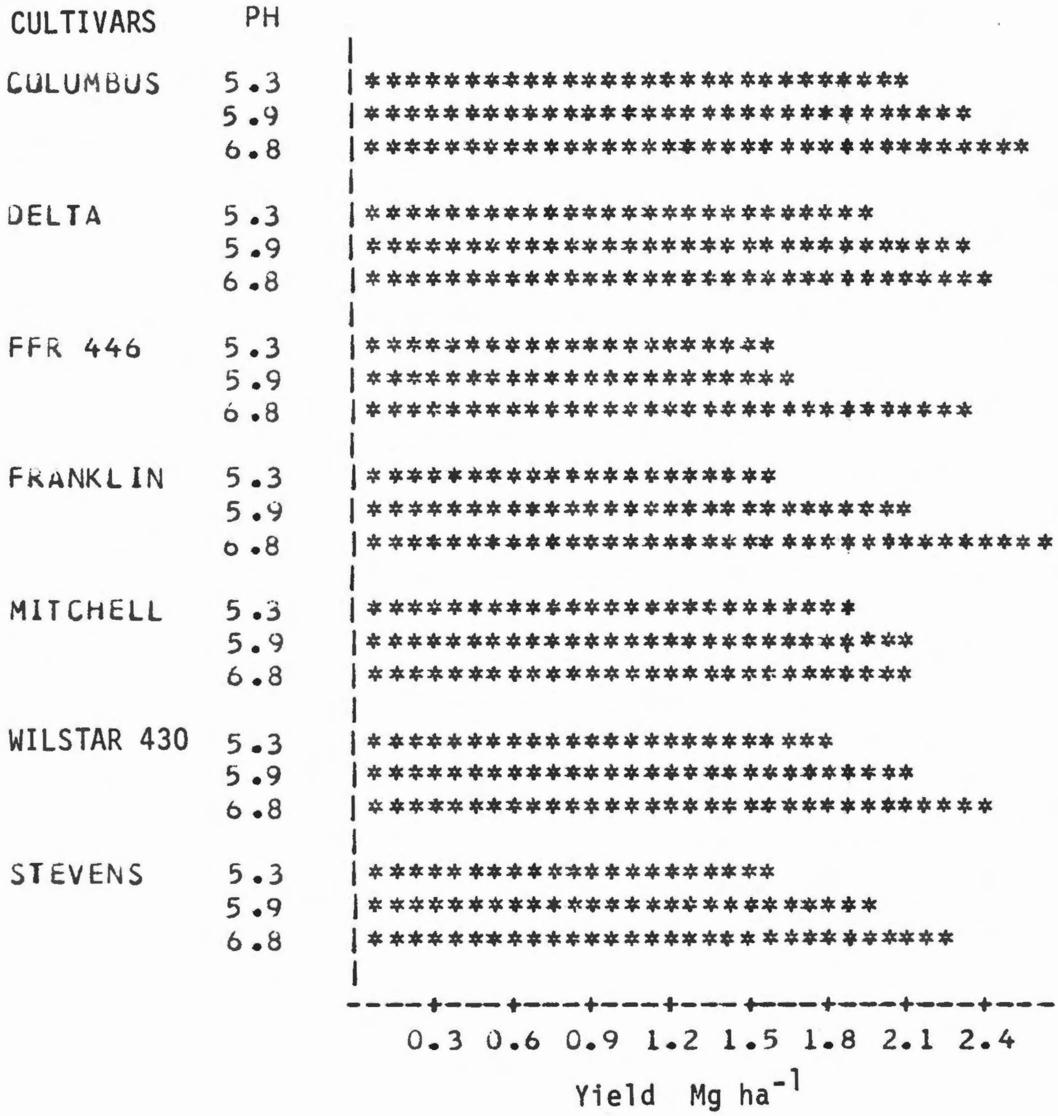

Figure 5. Mean Yields of Maturity Group IV Soybean Cultivars Grown at Three Soil pH Levels in 1982.

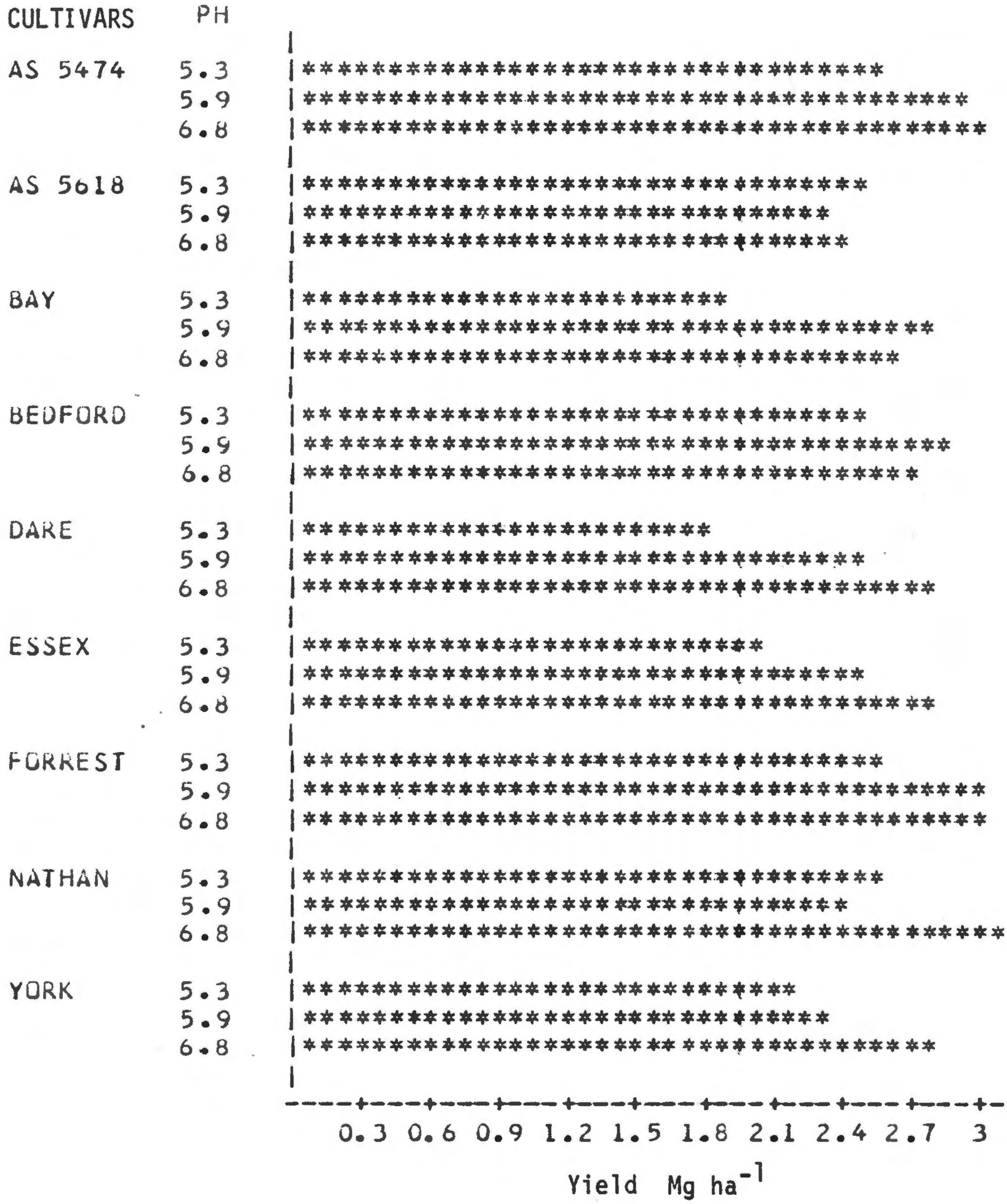

Figure 6. Mean Yields of Maturity Group V Soybean Cultivars Grown at Three Soil pH Levels in 1982.

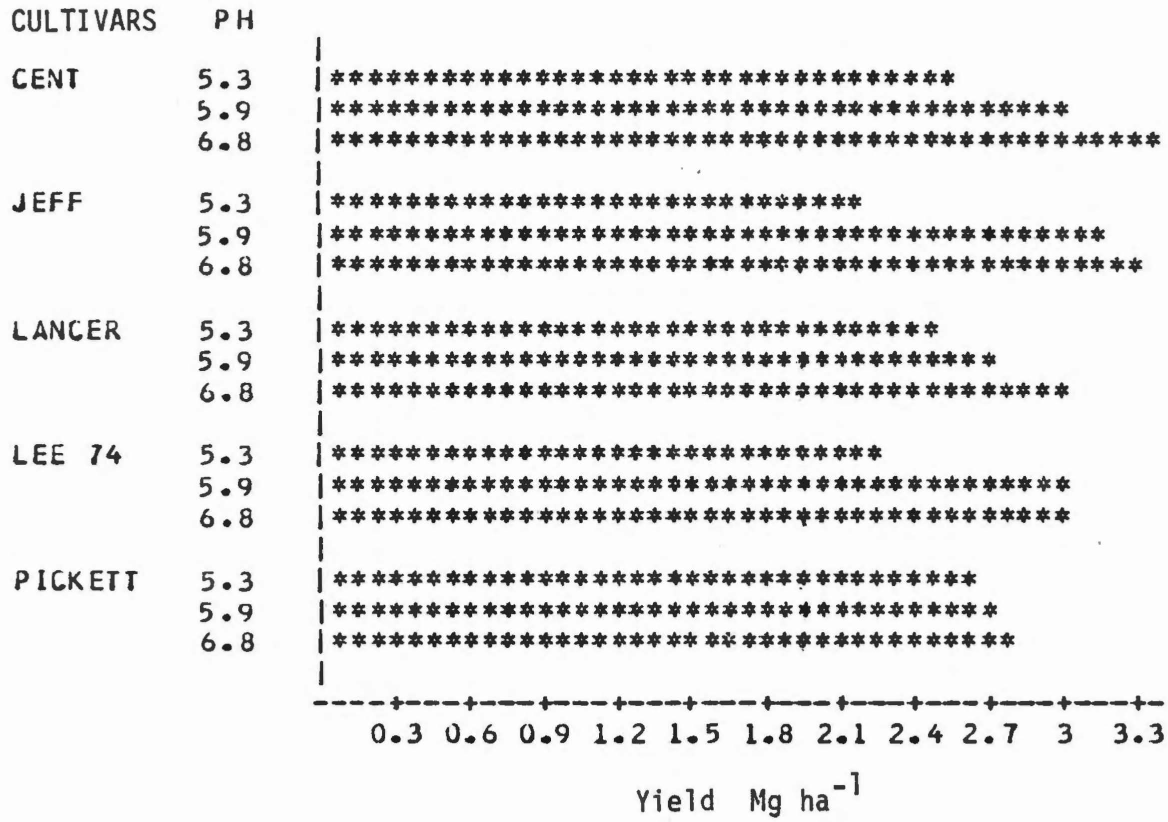

Figure 7. Mean Yields of Maturity Group VI Soybean Cultivars Grown at Three Soil pH Levels in 1982.

1981 at pH 5.9 (e.g., FFR 446, Franklin, Wilstar 430, Asgrow 5474, Bay, Bedford, Essex, and Lancer). Some had no yield differences between pH 5.9 and 6.8 (e.g., Mitchell in both years; Dare and Lee 74 in 1981; Forrest and Lee 74 in 1982). The others responded positively to the increase in soil pH (e.g., Centennial in 1981; Columbus, Delta, and Franklin in 1982).

B. PODS ON THE MAIN STEM

There were significant differences ($P < 0.05$) in the average number of single and double seeded pods on the main stem due to soil pH in 1981 (Table 3, p. 18). In 1982 there were no differences in the average number of those pods, but there were significant differences in triple seeded pods due to soil pH (Table 4, p. 19). There were significant differences among cultivars in the numbers of all pods in both years. Cultivars produced many more double than single or triple seeded pods on the main stem in 1981 (Figure 8). In 1982, cultivars produced more triple seeded pods than in 1981, but the average of single and double seeded pods remained almost the same (Figure 9). The number of single and double seeded pods increased as soil pH increased in 1981 while in 1982 the number of triple seeded pods increased as soil pH increased.

Although the number of single seeded pods on the main stem was significantly affected by soil pH in 1981 (Table 3, p. 18), not all cultivars were affected by the change in soil pH (Steven, Asgrow 5474, Asgrow 5618, Dare, Essex, and Centennial, Appendix Table A-2). In some cultivars, single seeded pods increased as pH increased from 5.3 to

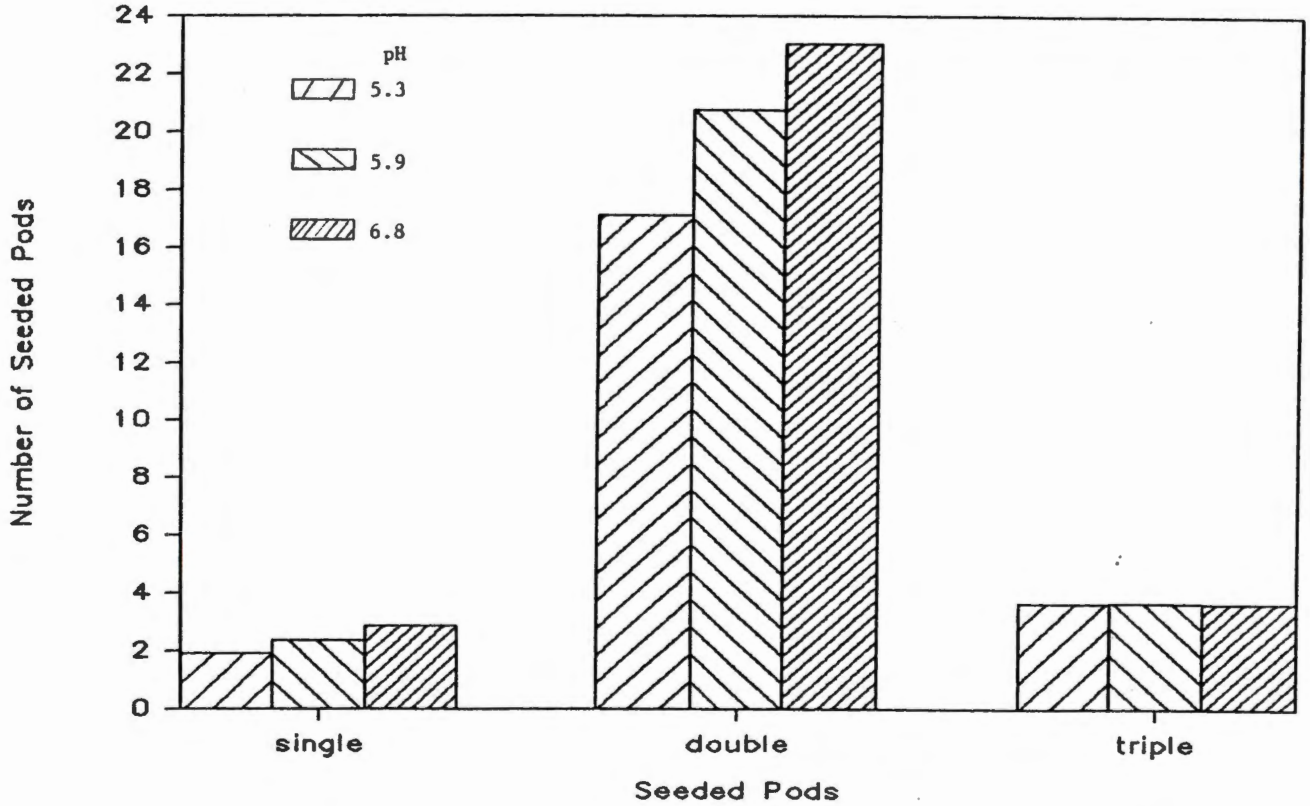

Figure 8. Average Number of Seeded Pods on Main Stem at Three Soil pH Levels Averaged Across Twenty-one Cultivars in 1981.

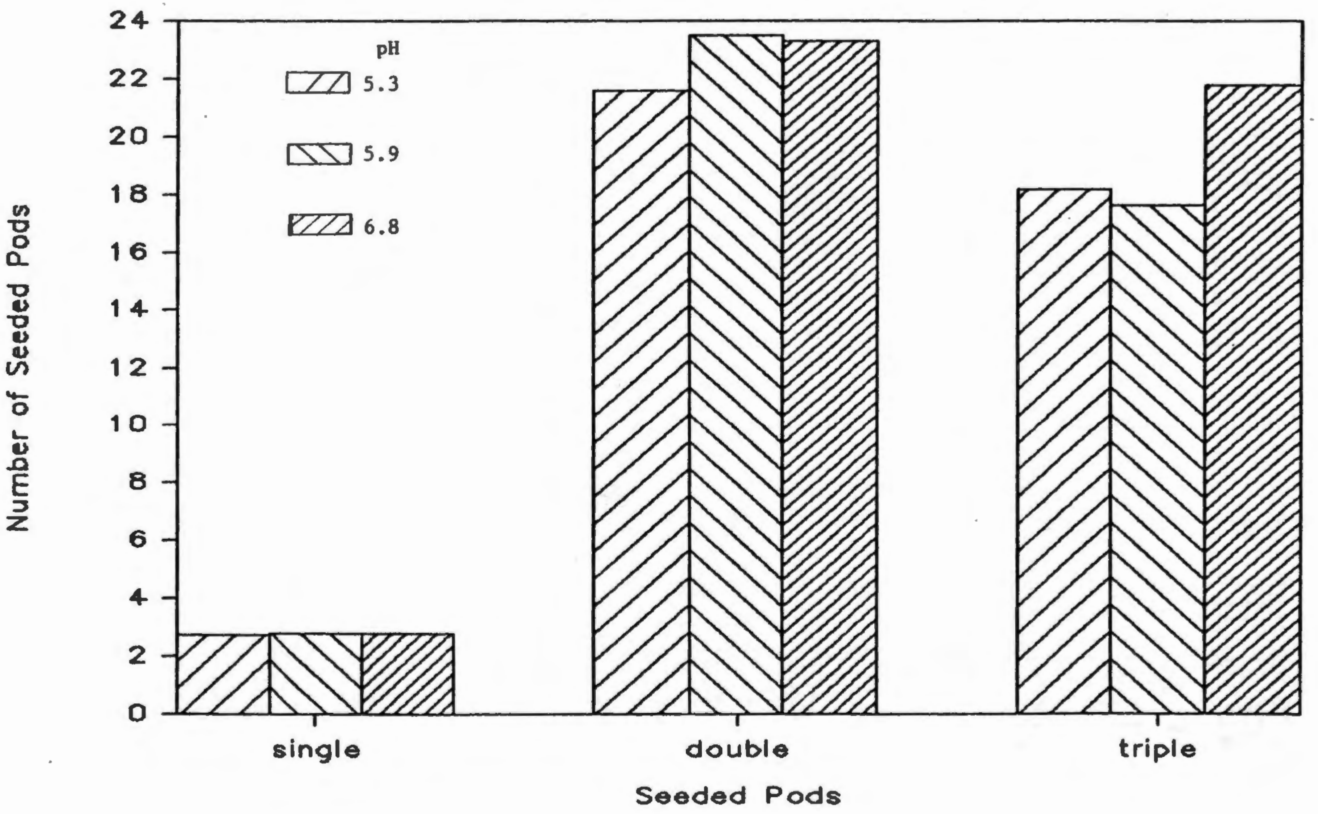

Figure 9. Average Number of Seeded Pods on Main Stem at Three Soil pH Levels Averaged Across Twenty-one Cultivars in 1982.

5.9, but decreased when pH increased to 6.8 (Delta, FFR 446, and Mitchell). Others exhibited consistent increases with soil pH such as Wilstar 430 and Forrest. In some other cultivars, single seeded pods increased as soil pH increased from 5.3 to 5.9, then did not change at pH 6.8 (Columbus, Franklin, and Nathan).

Numbers of double seeded pods on the main stem were significantly affected by soil pH in 1981 (Table 3, p. 18), but some cultivars were not affected (FFR 446, Mitchell, Wilstar 430, and Bay, Appendix Table A-2). In some, the numbers increased as pH increased from 5.3 to 5.9, decreasing again as pH increased to 6.8 (Delta, Franklin, and Pickett 71). In Bedford, York, Jeff, Lancer, and Lee 74, the double seeded pods increased with each pH increase.

In 1982, the numbers of triple seeded pods on the main stem were significantly affected by soil pH, but this trend was not found with all cultivars. They were not affected in Franklin, Asgrow 5474, Asgrow 5618, and Dare (Appendix Table A-2). In some, triple seeded pods increased as pH increased from 5.3 to 5.9, decreasing when pH went to 6.8 (Columbus, Delta, Bay, Centennial, and Jeff). The numbers of triple seeded pods did not change as pH increased from 5.3 to 5.9 with Stevens, Nathan, and Pickett 71, but increased at pH 6.8 while in other cultivars, they decreased as pH increased from 5.3 to 5.9, but then increased when pH went to 6.8 (Mitchell, Wilstar 430, Bedford, Essex, and Lee 74).

Soybean cultivars used in this study were significantly different from each other for all characteristics studied in both years (Tables 3 and 4, pp. 18 and 19). This suggests a high diversity in the germplasm.

Cultivars were grouped according to their maturity in each year and there were some common features for most members of each maturity group which might be different from other maturity groups. In 1981, double seeded pods dominated the main stems of all cultivars in the three maturity groups across the three soil pH levels (Figure 8). Maturity groups V and VI produced more double seeded pods on the main stem than the early maturity group IV (Figures 10, 11, and 12). Regression analysis of the number of seeded pods on the main stems on soil pH in 1981 showed that Columbus (group IV), Nathan and York (group V) were the only cultivars which had a significant positive ($P < 0.10$) relationship of double seeded pods with soil pH (Tables 5 and 6). Asgrow 5618 (group V) and Lancer (group VI) showed a significant positive ($P < 0.10$) relationship of triple seeded pods on the main stem with soil pH (Tables 6 and 7). Bedford and Forrest showed a significant ($P < 0.10$) negative relationship of triple seeded pods with pH.

In 1982, there was a general increase in the number of triple seeded pods on the main stem in all maturity groups (Figure 9 and Appendix Table A-2). Triple seeded pods were dominating the main stems of group IV cultivars (Figure 13). Double seeded pods were dominating the main stems of maturity group V with the exception of Asgrow 5474 and Bay and three of the five cultivars of group VI (Figures 14, 15, and Appendix Table A-2). Group V cultivars had more single seeded pods than most cultivars of maturity groups IV and VI. Regression analysis of seeded pods on the main stem on soil pH for the three maturity groups in 1982 showed that Columbus and Mitchell of maturity group IV had a

```
CULTIVARS      SEEDS/POD

COLUMBUS           1      |**
                   2      |******************
                   3      |****
                          |
DELTA              1      |**
                   2      |**************
                   3      |***
                          |
FFR 446            1      |*
                   2      |**************
                   3      |***
                          |
FRANKLIN           1      |*
                   2      |***********
                   3      |***
                          |
MITCHELL           1      |**
                   2      |**************
                   3      |***
                          |
STEVENS            1      |*
                   2      |*************
                   3      |***
                          |
WILSTAR 430        1      |*
                   2      |***********
                   3      |***
                          |
                          -----+----+----+----+----+----+----+-
                               5   10   15   20   25   30   35

                                          Pods
```

Figure 10. Means of Seeded Pods on the Main Stem of Maturity Group IV Soybean Cultivars Across Three Soil pH Levels in 1981.

```
CULTIVARS      SEEDS/POD

AS 5474            1     |*
                   2     |**************
                   3     |**
                         |
AS 5618            1     |**
                   2     |**********************
                   3     |****
                         |
BAY                1     |*
                   2     |*************
                   3     |***
                         |
BEDFORD            1     |**
                   2     |*******************
                   3     |****
                         |
DARE               1     |**
                   2     |***********************
                   3     |******
                         |
ESSEX              1     |****
                   2     |********************
                   3     |*****
                         |
FORREST            1     |***
                   2     |**********************
                   3     |**
                         |
NATHAN             1     |*****
                   2     |*********************************
                   3     |*****
                         |
YORK               1     |**
                   2     |***********************
                   3     |****
                         |
                         -----+----+----+----+----+----+----+-
                              5   10   15   20   25   30   35

                                         Pods
```

Figure 11. Means of Seeded Pods on the Main Stem of Maturity Group V Soybean Cultivars Across Three Soil pH Levels in 1981.

```
CULTIVARS      SEEDS/POD

CENT               1      |****
                   2      |************************************
                   3      |*****
                          |
JEFF               1      |***
                   2      |***********************************
                   3      |******
                          |
LANCER             1      |***
                   2      |**********************************
                   3      |*****
                          |
LEE 74             1      |**
                   2      |*****************
                   3      |**
                          |
PICKETT            1      |***
                   2      |*******************
                   3      |***
                          |
                          -----+----+----+----+----+----+----+-
                               5   10   15   20   25   30   35

                                           Pods
```

Figure 12. Means of Seeded Pods on the Main Stem of Maturity Group VI Soybean Cultivars Across Three Soil pH Levels in 1981.

Table 5. Regression of the Morphological Characteristics on Soil Hydrogen Ion Activity for Maturity Group IV Soybean Cultivars in 1981 and 1982.

		Seeded Pods									
		Main stem			Branches						
Cultivars	Yield	Single	Double	Triple	Single	Double	Triple	Plant Height	Seed Wt. per 100 Seeds	No. of Nodes	No. of Branches
1981											
Columbus			††								
Delta						*			††	††	**
FFR 446											
Franklin									*		
Mitchell											
Stevens										**	
Wilstar 430											
1982											
Columbus	*	††									
Delta	*										
FFR 446	††						††		**		
Franklin	**					*	††		*	††	
Mitchell		††						- *	**		
Stevens	**										
Wilstar	††					*					

††,*,**Significant at 0.10, 0.05, and 0.01 levels of probability, respectively.

Table 6. Regression of the Morphological Characteristics on Soil Hydrogen Ion Activity for Maturity Group V Soybean Cultivars in 1981 and 1982.

Cultivars	Yield	Seeded Pods						Plant Height	Seed Wt. per 100 Seeds	No. of Nodes	No. of Branches
		Main stem			Branches						
		Single	Double	Triple	Single	Double	Triple				
1981											
Asgrow 5474											
Asgrow 5618				††							
Bay											
Bedford				-††	*		-††				
Dare									*		
Essex											
Forrest				-††							
Nathan			††							††	
York			††								
1982											
Asgrow 5474									††		
Asgrow 5618											
Bay	**										
Bedford									††		
Dare	*								*	-††	
Essex	**										
Forrest	††	††	††								
Nathan									††		
York	††				*				**	*	

††,*,** Significant at 0.10, 0.05, and 0.01 levels of probability, respectively.

Table 7. Regression of the Morphological Characteristics on Soil Hydrogen Ion Activity for Maturity Group VI Soybean Cultivars in 1981 and 1982.

		Seeded Pods									
		Main stem			Branches						
Cultivars	Yield	Single	Double	Triple	Single	Double	Triple	Plant Height	Seed Wt. per 100 Seeds	No. of Nodes	No. of Branches
1981											
Centennial	*					††	††				
Jeff											
Lancer				††	*			-††			
Lee 74	††										
Pickett 71											
1982											
Centennial	*										
Jeff	**									*	
Lancer							-*		††		-*
Lee 74	**								*		
Pickett 71								††	**		

††,*,** Significant at 0.10, 0.05, and 0.01 levels of probability, respectively.

```
CULTIVARS     SEEDS/POD

COLUMBUS          1     |*
                  2     |****************
                  3     |************************************
                        |
DELTA             1     |**
                  2     |***********
                  3     |**************************
                        |
FFR 446           1     |**
                  2     |*************
                  3     |**************************
                        |
FRANKLIN          1     |**
                  2     |**********
                  3     |**************************
                        |
MITCHELL          1     |*
                  2     |**********
                  3     |**********************
                        |
STEVENS           1     |*
                  2     |*********
                  3     |****************************
                        |
WILSTAR 430       1     |**
                  2     |************
                  3     |***************************
                        |
                        -----+----+----+----+----+----+----+----+-
                             5   10   15   20   25   30   35   40

                                          Pods
```

Figure 13. Means of Seeded Pods on the Main Stem of Maturity Group IV Soybean Cultivars Across Three Soil pH Levels in 1982.

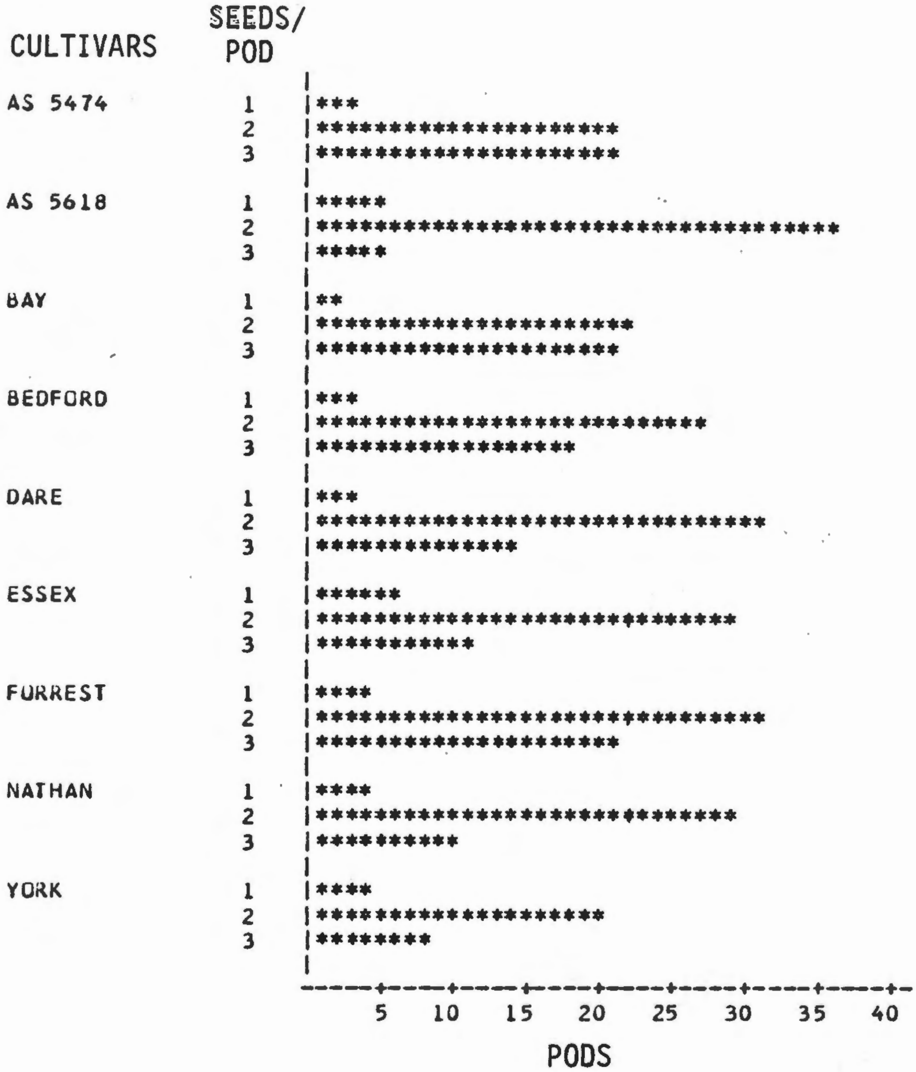

Figure 14. Means of Seeded Pods on the Main Stem of Maturity Group V Soybean Cultivars Across Three Soil pH Levels in 1982.

```
CULTIVARS    SEEDS/POD

CENT             1     |****
                 2     |******************************************
                 3     |**************
                       |
JEFF             1     |***
                 2     |*************************************
                 3     |************
                       |
LANCER           1     |**
                 2     |****************************************
                       |
                 3     |***********
                       |
LEE 74           1     |**
                 2     |*****************
                 3     |*************************
                       |
PICKETT          1     |**
                 2     |*********************
                 3     |************************
                       |
                       -----+----+----+----+----+----+----+----+-
                            5   10   15   20   25   30   35   40

                                          Pods
```

Figure 15. Means of Seeded Pods on the Main Stem of Maturity Group VI Soybean Cultivars Across Three Soil pH Levels in 1982.

positive significant relationship between single seeded pods and soil pH (Table 5). Forrest of maturity group V had a positive significant relationship of single and double seeded pods with pH (Table 6).

C. PODS ON THE BRANCHES

More double seeded pods were found on the branches than either single or triple seeded pods in both years (Figures 16, 17, and Appendix Table A-3). Low numbers of single seeded pods were found at all three pH levels. The only significant difference noted in podding on the branches was an increase in the number of triple seeded pods in both years (Tables 3 and 4, pp. 18 and 19; Figures 16 and 17).

The number of triple seeded pods on the branches was significantly increased as soil pH level increased in both years (Tables 3 and 4, Figures 16 and 17). In 1981, some cultivars, such as Stevens, Wilstar 430, and Lee 74, did not follow this trend (Appendix Table A-3). Others such as Delta, Franklin, Mitchell, York, Centennial, Jeff, and Lancer had an increase in triple seeded pods as soil pH increased from 5.3 to 5.9, but decreased at pH 6.8. Some tended to increase as soil pH increased, for example, Columbus, FFR 446, Bay, and Essex.

In 1982, triple seeded pods on the branches of some cultivars decreased as pH increased from 5.3 to 5.9, but increased at pH 6.8 (Stevens, Asgrow 5474, Essex, Nathan, York, and Jeff). Others increased as pH increased, for example Columbus, Delta, and Lee 74.

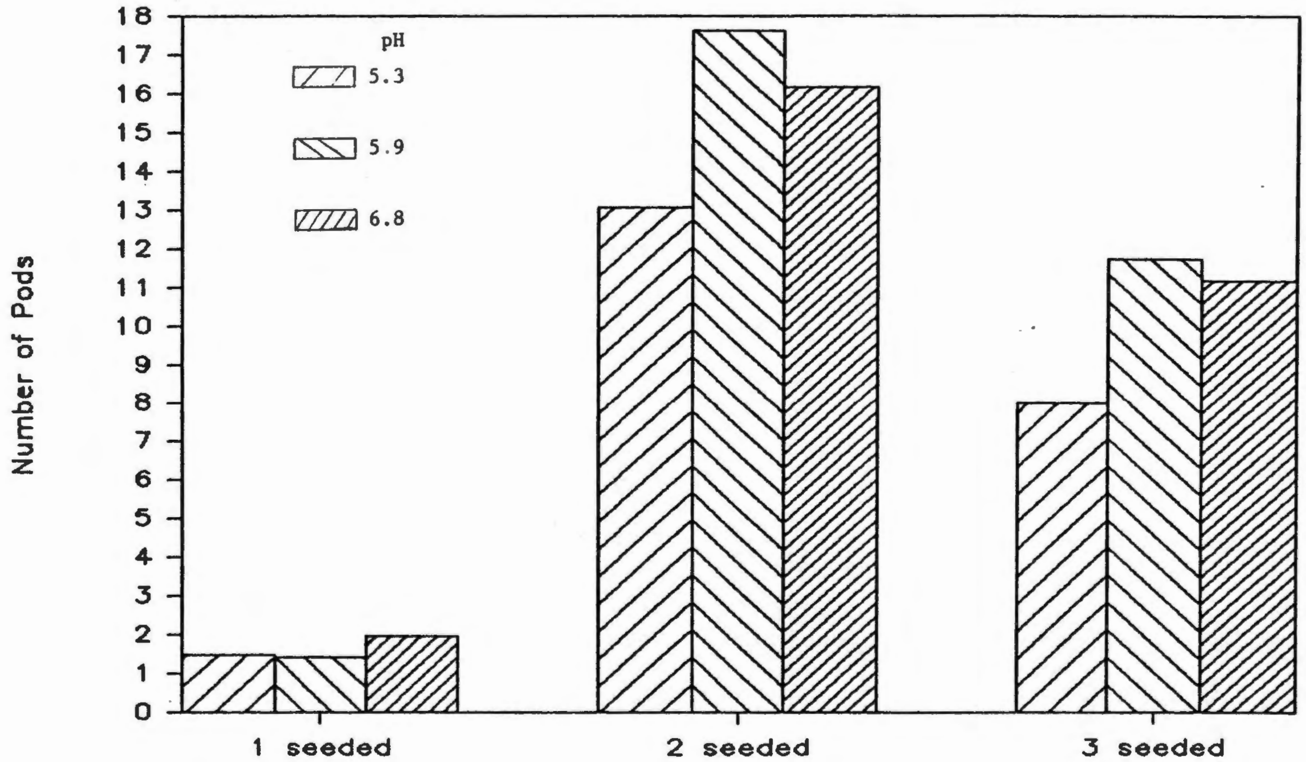

Figure 16. Average Number of Seeded Pods on Branches Across Twenty-one Soybean Cultivars at Three Soil pH Levels in 1981.

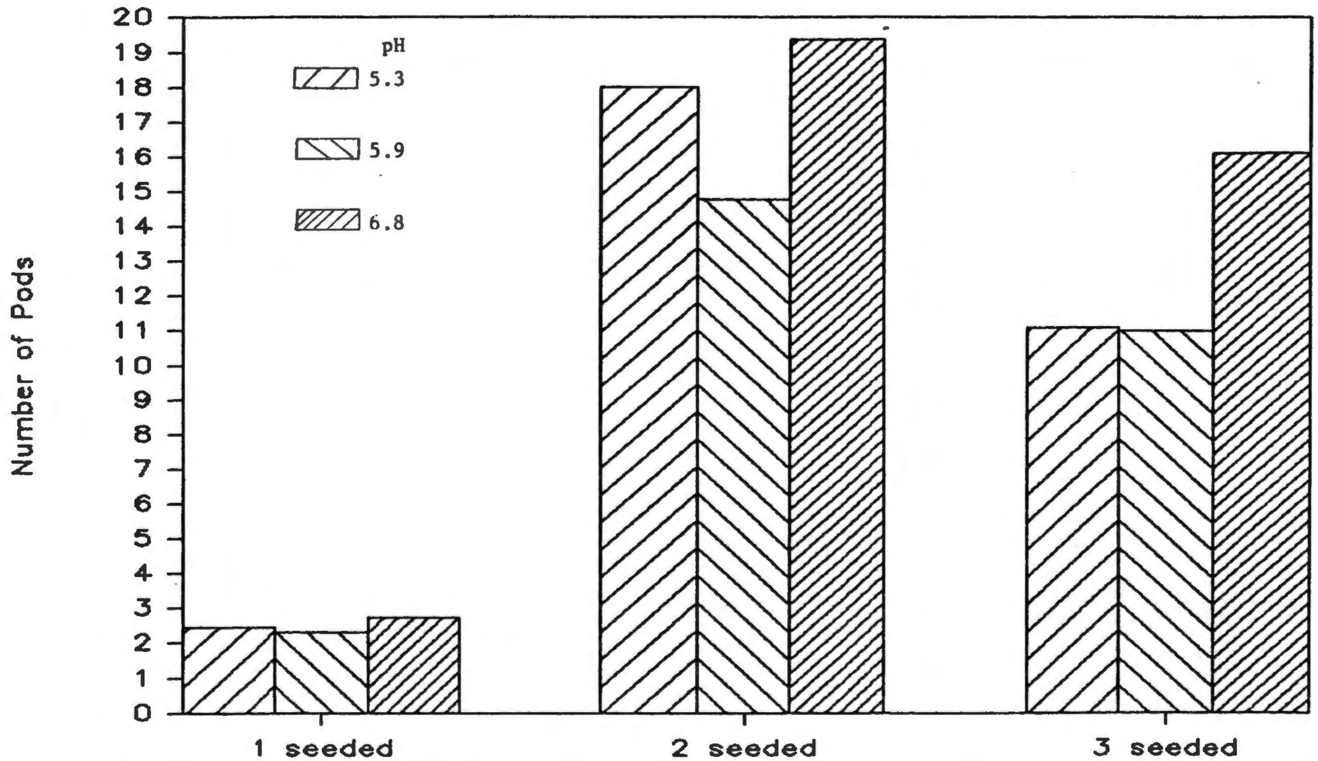

Figure 17. Average Number of Seeded Pods on Branches Across Twenty-one Soybean Cultivars at Three Soil pH Levels in 1982.

Some cultivars were not affected as pH increased from 5.3 to 5.9, but tended to increase at pH 6.8 (FFR 446, Wilstar 430, and Dare).

Triple seeded pods dominated the branches of maturity group IV soybean cultivars in both years (Figures 18 and 19); whereas, in most cases double seeded pods dominated the branches of maturity group V members in both years (Figures 20 and 21) and group VI cultivars were a mix of the two trends (Figures 22 and 23). Bedford (group V) gave a significant positive relationship ($P < 0.05$) between single seeded pods and soil pH in 1981 (Table 6, p. 37). In 1982, York showed the same relationship. Centennial, Jeff, and Lancer (group VI) had mostly double seeded pods on their branches in 1981. Lee 74 and Pickett 71 had about the same number of double and triple seeded pods in 1981, but mostly triple seeded pods in 1982. Centennial (group VI) showed a significant positive relationship between double and triple seeded pods and pH in 1981. In 1982, Lancer showed a significant negative relationship ($P < 0.05$) between triple seeded pods and soil pH (Table 7, p. 38).

Stepwise regression for all characteristics on yield was performed for all cultivars in each maturity group in 1981 and 1982. R-square values for the best 1, 2, and 3 variables model for all cultivars in each maturity group are presented in Tables 8 through 13.

Seed weight accounted for 23 to 71 percent of the variation in yields of 9 cultivars in 1981 and 1982. Soil pH accounted for 50 to 83 percent of the variation in yields of 7 cultivars in the three maturity groups in 1982 (Tables 9, 11, and 13).

```
CULTIVARS     SEEDS/POD |
COLUMBUS          1     |*
                  2     |*******
                  3     |*************
                        |
DELTA             1     |****
                  2     |***************************
                  3     |*************************************
                        |
FFR 446           1     |**
                  2     |*****************
                  3     |**********************
                        |
FRANKLIN          1     |
                  2     |********
                  3     |***************
                        |
MITCHELL          1     |*
                  2     |***************
                  3     |******************************
                        |
WILSTAR 430       1     |
                  2     |***********
                  3     |************************
                        |
STEVENS           1     |*
                  2     |*****
                  3     |************
                        |
                        ----+---+---+---+---+---+---+---+---+-
                            2   4   6   8  10  12  14  16  18

                                          Pods
```

Figure 18. Means of Seeded Pods on the Branches of Maturity Group IV Soybean Cultivars Across Three Soil pH Levels in 1981.

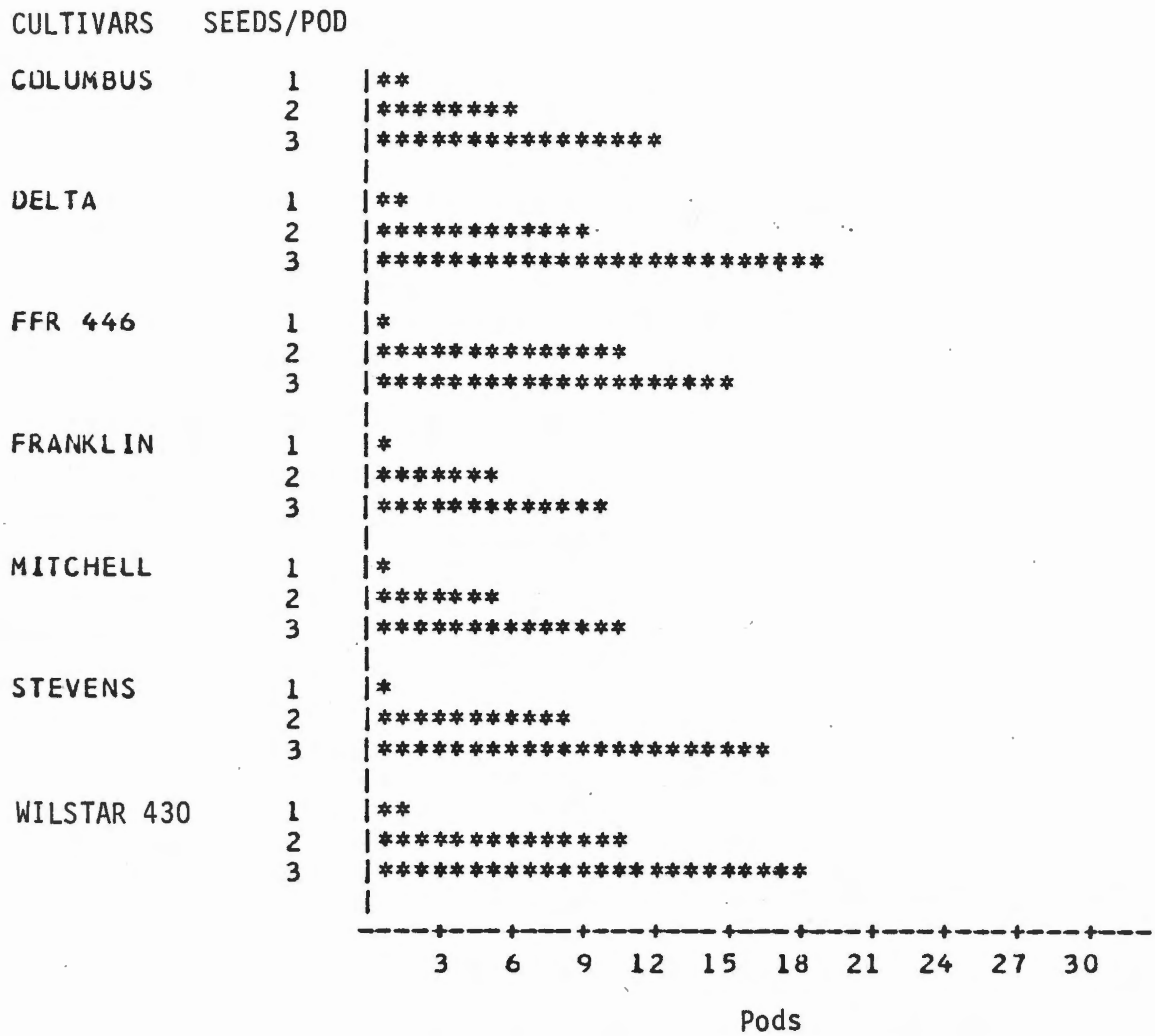

Figure 19. Means of Seeded Pods on Branches of Maturity Group IV Soybean Cultivars Across Three Soil pH Levels in 1982.

```
CULTIVARS   SEEDS/POD
                       |
AS 5474         1      |*
                2      |***********
                3      |************
                       |
AS 5618         1      |***
                2      |*******************************
                3      |*****
                       |
BAY             1      |**
                2      |*****************
                3      |****************
                       |
BEDFORD         1      |**
                2      |************************************
                3      |**********************
                       |
DARE            1      |**
                2      |******************************
                3      |***********
                       |
ESSEX           1      |**
                2      |******************
                3      |*******
                       |
FORREST         1      |***
                2      |*************************
                3      |**************
                       |
NATHAN          1      |****
                2      |**********************************
                3      |**********
                       |
YORK            1      |*****
                2      |***************************************
                3      |********************
                       |
                       ----+---+---+---+---+---+---+---+---+---
                           3   6   9  12  15  18  21  24  27

                                      Pods
```

Figure 20. Means of Seeded Pods on the Branches of Maturity Group V Soybean Cultivars Across Three Soil pH Levels in 1981.

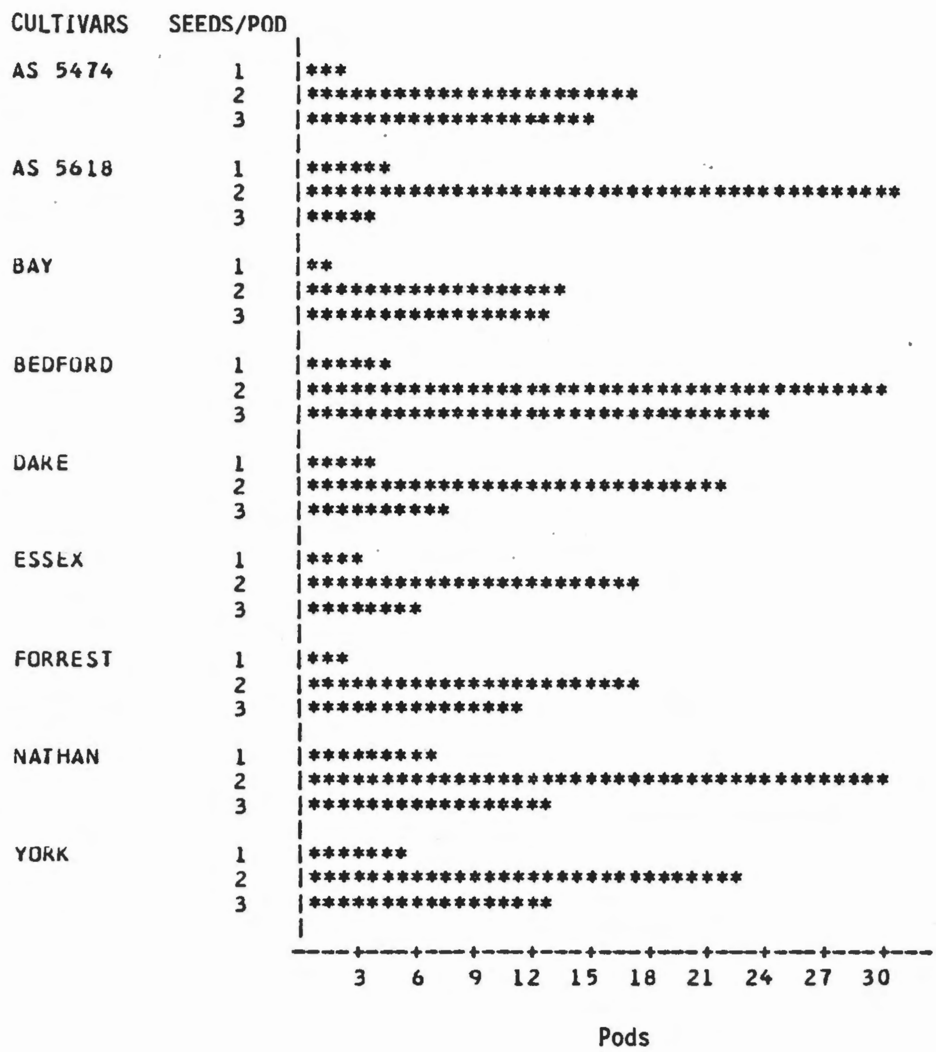

Figure 21. Means of Seeded Pods on Branches of Maturity Group V Soybean Cultivars Across Three Soil pH Levels in 1982.

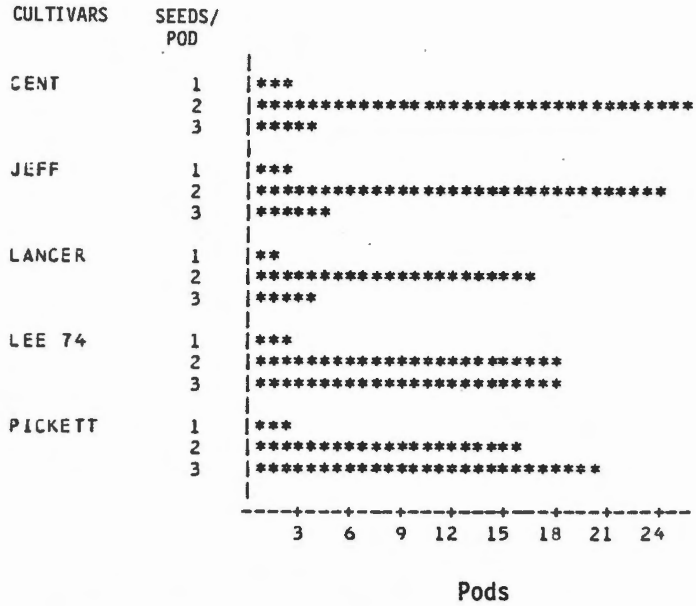

Figure 22. Means of Seeded Pods on Branches of Maturity Group VI Soybean Cultivars Across Three Soil pH Levels in 1981.

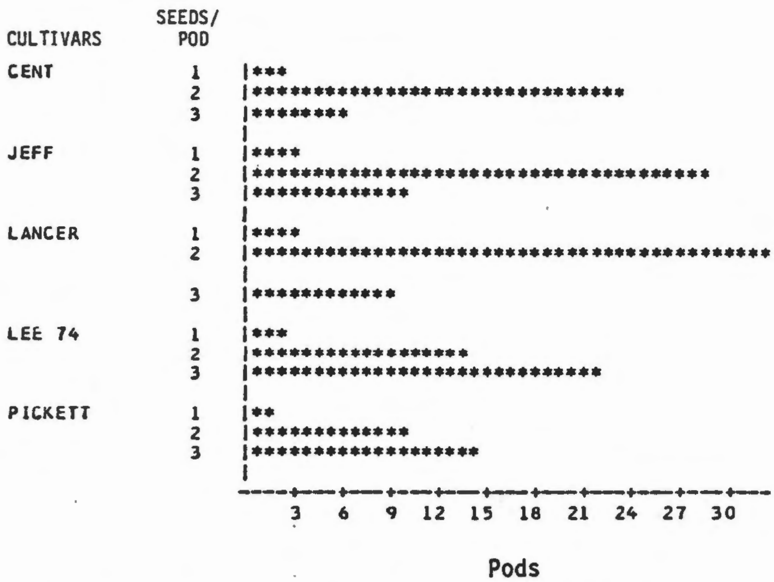

Figure 23. Means of Seeded Pods on Branches of Maturity Group VI Soybean Cultivars Across Three Soil pH Levels in 1982.

Table 8. R^2 Values for the Best 1, 2, and 3 Variables Model to Explain the Variation in Yield for Maturity Group IV Soybean Cultivars in 1981.

	Variables		
Cultivar	1	2	3
Columbus	SPMS1 (0.39)	No. of nodes SPMS1 (0.69)*	HT, SP_1BR, SP_3BR (0.88)**
Delta	Mg (0.33)	Mg, Mn (0.53)	$SPMS_1$, Mg, Mn (0.80)*
FFR 446	P (0.39)	No. of nodes, P (0.63)	P, Mn, pH (0.82)*
Franklin	Seed Wt. (0.70)**	HT, Seed Wt. (0.86)**	Seed Wt., SPMS2, SP_2BR (0.94)**
Mitchell	Mn (0.30)	SPMS1, Mn (0.41)	HT, P, Mn (0.52)
Wilstar 430	Seed Wt. (0.71)**	Seed Wt., N (0.98)**	Seed Wt., N, P (0.99)**
Stevens	SPMS3 (0.36)*	SPMS3, P (0.61)*	HT, Seed Wt., SPMS3 (0.83)**

*,**Significant at 0.05 and 0.01 levels of probability, respectively.

Table 9. R^2 Values for the Best 1, 2, and 3 Variables Model to Explain the Variation in Yield for Maturity Group IV Soybean Cultivars in 1982.

Cultivars	Variables 1	Variables 2	Variables 3
Columbus	Seed Wt. (0.45)*	Seed Wt., SP_3BR (0.58)*	SP_2BR, Ca, pH (0.85)**
Delta	Mn (0.47)*	Seed Wt., Mn (0.63)*	Seed Wt., SP_2BR, Mg (0.72)*
FFR 446	SP_3BR (0.78)**	SP_3BR, Mn (0.94)**	SP_1BR, SP_3BR, Mg (0.94)**
Franklin	pH (0.74)**	HT, pH (0.79)**	HT, Ca, pH (0.83)**
Mitchell	No. of nodes (0.13)	SPMS2 No. of nodes (0.34)	No. of nodes, SPMS2, K (0.62)
Wilstar 430	P (0.34)*	P, Mn (0.74)**	SP_3BR, P, Mn (0.82)**
Stevens	pH (0.50)**	P, pH (0.77)**	P, K, pH (0.88)**

*,**Significant at 0.05 and 0.01 levels of probability, respectively.

Table 10. R^2 Values for the Best 1, 2, and 3 Variables Model to Explain the Variation in Yield for Maturity Group V Soybean Cultivars in 1981.

Cultivars	Variables 1	Variables 2	Variables 3
Asgrow 5474	Seed Wt. (0.23)	Seed Wt., SP_2BR (0.42)	Seed Wt., SP_2BR, Mn (0.57)
Asgrow 5618	SPMS3 (0.50)*	No. of nodes, SPMS3 (0.67)*	HT, No. of nodes, SPMS3 (0.82)**
Bay	Seed Wt. (0.36)*	Seed Wt., SPMS3 (0.47)*	No. of Branches, SPMS3, SP_1BR (0.64)*
Bedford	No. of Branches (0.13)	No. of Branches, Mg (0.26)	No. of Branches, SPMS1, Mg (0.54)
Dare	HT (0.71)**	HT, P (0.81)**	HT, Seed Wt., N (0.89)**
Essex	SPMS3 (0.68)**	HT, SPMS3 (0.84)**	HT, SPMS3, Mg (0.90)**
Forrest	SP_2BR (69)**	No. of nodes, SP_2BR (84)**	No. of Branches, No. of Nodes, SP_2BR (0.89)**
Nathan	Ca (0.47)*	SP_3BR, Ca (0.76)**	SPMS2, SP_2BR, Ca (0.85)**
York	SPMS3 (0.42)*	SPMS3, Mn (0.60)*	Seed Wt., SPMS3, SP_2BR (0.73)*

*,** Significant at 0.05 and 0.01 levels of probability, respectively.

Table 11. R^2 Values for the Best 1, 2, and 3 Variables Model to Explain the Variation in Yield for Maturity Group V Soybean Cultivars in 1982.

Cultivars	Variables 1	Variables 2	Variables 3
Asgrow 5474	SPMS1 (0.66)**	Seed wt., SPMS1 (0.78)**	Seed Wt., SPMS1, Ca (0.87)**
Asgrow 5618	No. of Nodes (0.24)	HT, SPMS1 (0.41)	HT, SPMS1, $SPMS_3$ (0.78)**
Bay	pH (0.68)**	N, pH (0.87)**	SP_1BR, N, pH (0.96)**
Bedford	Seed Wt. (0.52)*	Seed Wt., No. of Nodes (0.62)*	Seed Wt., No. of Nodes, SP_3BR (0.68)*
Dare	Seed Wt. (0.63)**	Seed Wt., P (0.89)**	Seed Wt., P, Ca (0.93)**
Forrest	pH (0.28)	SPMS1, pH (0.57)*	SPMS1, SP_2BR, pH (0.69)*
Nathan	SP_3BR (0.48)*	SP_3BR, P (0.60)*	No. of Branches, $SPMS_3$, P (0.76)*
York	Seed Wt. (0.58)**	Seed Wt., P (0.76)**	Seed Wt., SP_3BR, P (0.84)**

*,**Significant at 0.05 and 0.01 levels of probability, respectively.

Table 12. R^2 Values for the Best 1, 2, and 3 Variables Model to Explain the Variation in Yield for Maturity Group VI Soybean Cultivars in 1981.

	Variables		
Cultivars	1	2	3
Centennial	Ca (0.49)	SPMS2, P (0.79)*	SPMS1, SPMS2, P (0.93)*
Jeff	P (0.44)*	No. of Branches, P (0.68)*	Seed Wt., No. of Branches, N (0.92)**
Lancer	P (0.46)*	SP_2BR, P (0.66)**	HT, SP_2BR, P (0.75)**
Lee 74	SPMS1 (0.29)	Mg, pH (0.53)	No. of Branches, Mg, pH (0.68)
Pickett 71	P (0.42)*	Seed Wt., K (0.63)*	Seed Wt., SP_3BR, K (0.73)*

*,**Significant at 0.05 and 0.01 levels of probability, respectively.

Table 13. R^2 Values for the Best 1, 2, and 3 Variables Model to Explain the Variation in Yield in Maturity Group VI Soybean Cultivars in 1982.

Cultivars	Variables		
	1	2	3
Centennial	pH (0.62)**	No. of Nodes, pH (0.82)**	No. of Nodes, N, pH (0.88)**
Jeff	pH (0.83)**	K, pH (0.91)**	Seed Wt., K, pH (0.93)**
Lancer	Seed Wt. (0.45)*	Seed Wt., Mg (0.86)**	Seed Wt., SP$_3$BR, Mg (0.91)**
Lee 74	pH (0.63)**	Ca, pH (0.89)**	No. of Nodes, Ca, pH (0.93)**
Pickett 71	P (0.51)*	P, Mg (0.77)**	HT, SPMS1, P (0.96)**

*,**Significant at 0.05 and 0.01 levels of probability, respectively.

Phosphorus was the best single variable model for most cultivars in maturity group VI in 1981 (Table 12). Phosphorus concentration accounted for 44, 46, and 42 percent of the variation in yield of cultivars Jeff, Lancer, and Pickett 71, respectively. Calcium and the number of single seeded pods on the main stem accounted for 49 and 29 percent of the variation in yield of Centennial and Lee 74, respectively. In 1982, soil pH became the predominate single variable of the cultivars in the same maturity group (Table 13). Soil pH accounted for 62, 83, and 63 percent of variation in yields of Centennial, Jeff, and Lee 74, respectively. Seed weight and P accounted for 45 and 51 percent of variation in yields of Lancer and Pickett 74, respectively.

D. SEED WEIGHT

There were significant differences in seed weight as a result of soil pH differences only in 1982 (Table 4, p. 18). Cultivars differed from each other in both years. No interaction effect of cultivar by pH was detected in either year. In 1982, seed weight means across all cultivars at the three soil pH levels showed that seed weight increased as soil pH increased from 5.3 to 5.9 (Figure 24). Cultivar response to pH increase can be grouped into three main categories. Seed weight increased at every pH level in some cultivars such as Columbus, Delta, FFR 446, and Bedford (Appendix Table A-1). It increased only when pH increased from 5.3 to 5.9 in cultivars such as Stevens, Nathan, and Pickett 71. In some other cultivars, seed weight increased as pH increased from 5.3 to 5.9, but decreased as pH increased to 6.8 (Asgrow 5618, Lancer, and Wilstar 430). Regression analysis of seed weight on

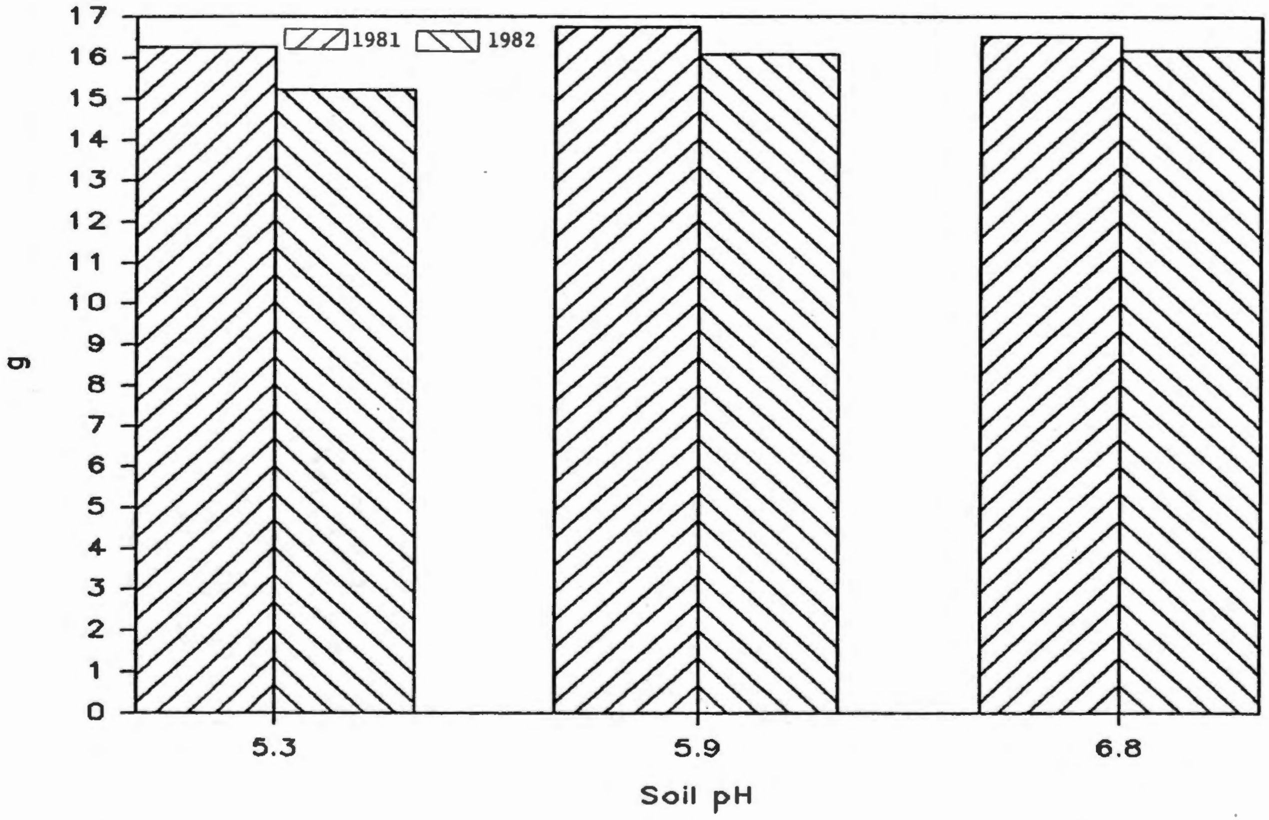

Figure 24. Mean Seed Weight Averaged Across Twenty-one Cultivars Grown at Three Soil pH Levels in 1981 and 1982.

soil pH showed that, in general, seed weights of some cultivars were related to soil pH in 1982 more than in 1981 (Tables 5, 6, and 7, pp. 36, 37, and 38). This agrees with analysis of variance (Tables 3 and 4, pp. 18 and 19). In 1982, seed weight had a positive significant relationship with soil pH in cultivars FFR 446, Franklin, and Mitchell of maturity group IV, Asgrow 5474, Bedford, Dare, and York of group V, Lancer, Lee 74, and Pickett 71 of group VI.

E. BRANCHES

Branches per plant showed significant differences as soil pH increased only in 1981 (Table 3, p. 18). Branches per plant across all cultivars increased as soil pH increased from 5.3 to 5.9 in 1981 (Figure 25). No significant interaction of cultivars x pH was found in either year (Tables 3 and 4, pp. 18 and 19). In 1981, cultivars differed from each other in the number of branches per plant (Appendix Table A-4). In some of the cultivars, the average number of branches per plant increased as pH increased from 5.3 to 5.9, but decreased as pH increased to 6.8 (Franklin, Mitchell, Bedford, and Lee 74). In some cultivars, the number of branches increased as pH increased from 5.3 to 5.9 and 6.8, for example, Delta and FFR 446 in 1981 (Appendix Table A-4). In Stevens and Jeff, it decreased as pH increased from 5.3 to 5.9 and 6.8. Regression analyses in 1982 showed that only Lancer had a significant negative relationship between number of branches and soil pH (Table 7, p. 38).

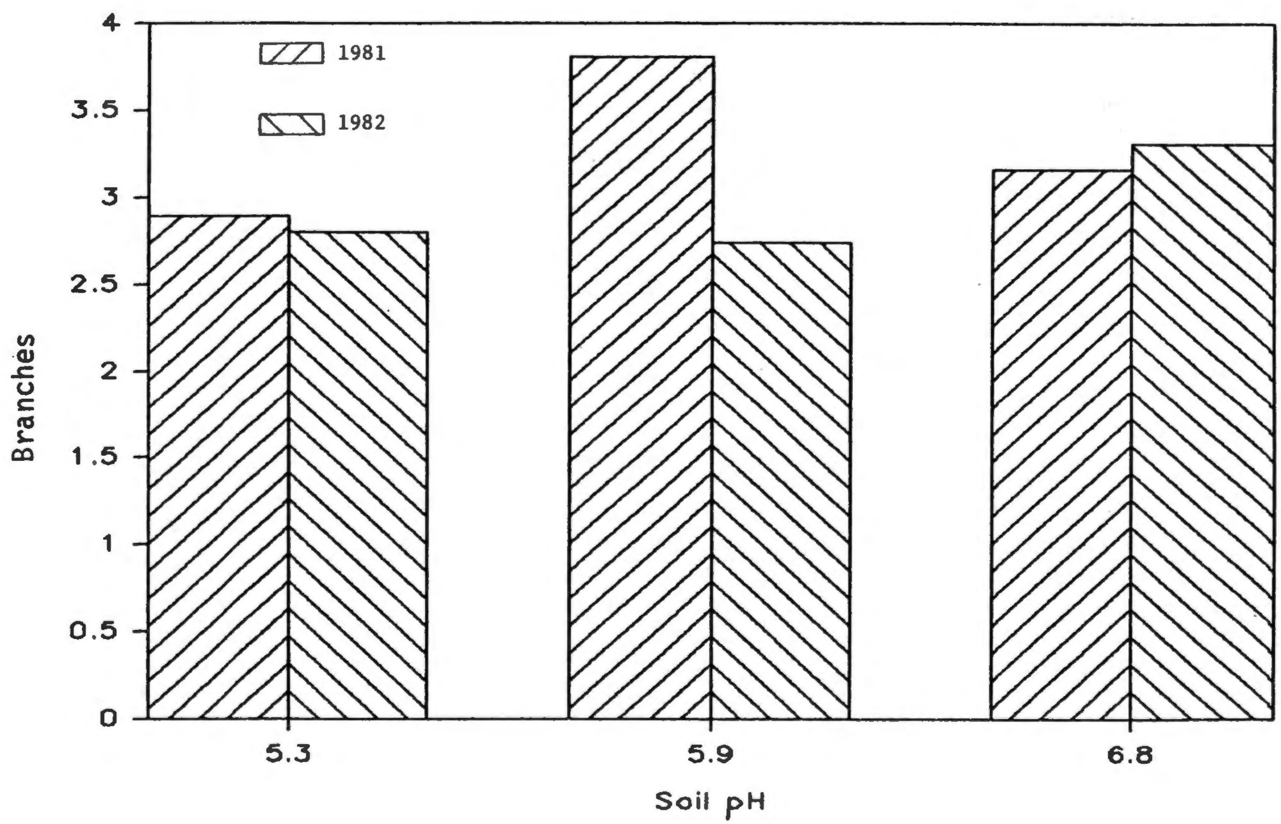

Figure 25. Mean Number of Branches Averaged Across Twenty-one Soybean Cultivars Grown at Three Soil pH Levels in 1981 and 1982.

F. NITROGEN CONCENTRATION

Leaf N-concentrations showed significant differences due to pH in 1982 (Table 4, p. 19). One might recall that Mo was not added in 1982. There were also significant differences in N-concentrations among the cultivars themselves. The cultivar by pH interaction was also found to be significant suggesting that soil pH had different effects on soybean cultivars in leaf N-concentration. Nitrogen concentration across all cultivars at the three soil pH levels indicated that N concentration increased as soil pH increased from 5.3 to 5.9 to 6.8 in 1982 (Figure 26).

In some cultivars, N increased as pH increased from 5.3 to 5.9 and 6.8 (Dare and York; Appendix Table A-5). In others, it increased as soil pH increased from 5.3 to 5.9, but decreased at pH 6.8 (Delta, Asgrow 5474, and Forrest). In some cultivars, it increased as pH increased only from 5.3 to 5.9, for example, Columbus, Bedford, and Lancer.

Again in 1982, Columbus of maturity group IV showed a significant positive relationship ($P < 0.10$) between N-concentration and soil pH (Table 14). Most members of maturity group V showed the same relationship (Table 15); however, none of maturity group VI showed such relationship (Table 16).

G. PHOSPHORUS CONCENTRATIONS

Leaf P-concentrations were significantly affected by soil pH levels only in 1982 (Table 4, p. 19). Mean P-concentrations across all

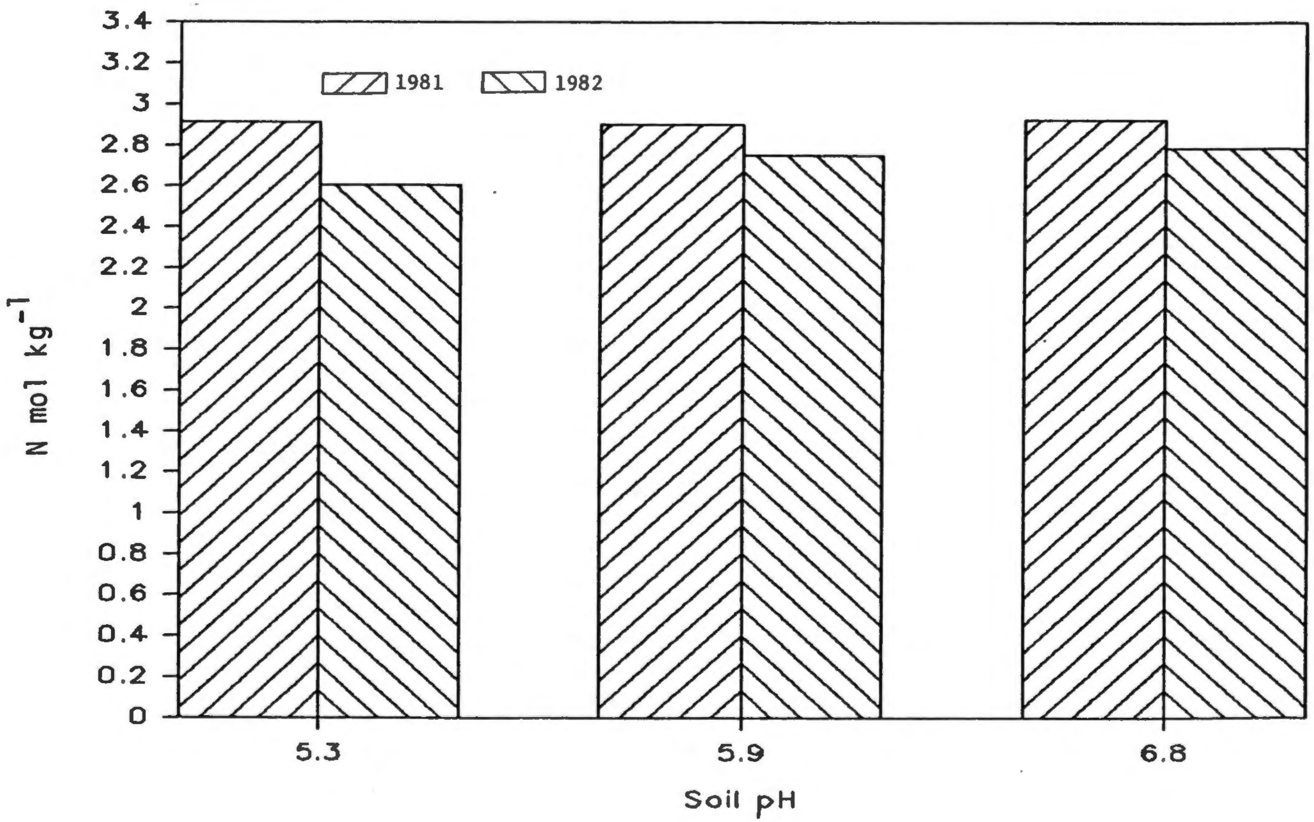

Figure 26. Mean Nitrogen Concentration in Soybean Leaves Across Twenty-one Cultivars Grown at Three Soil pH Levels in 1981 and 1982.

Table 14. Regression of the Soybean Leaf Chemical Composition on Soil Hydrogen Ion Activity for Maturity Group IV Soybean Cultivars in 1981 and 1982.

Cultivars	N	P	K	Ca	Mg	Mn
1981						
Columbus				*		-**
Delta			-††		*	-**
FFR 446				*		-**
Franklin				*	††	-**
Mitchell	††		-††	**	*	-*
Stevens			-††	*	*	-**
Wilstar 430	**					-**
1982						
Columbus	††					
Delta						-*
FFR 446				††		
Franklin						-*
Mitchell						
Stevens						-*
Wilstar 430						-††

††,*,** Significant at 0.10, 0.05, and 0.01 levels of probability, respectively.

Table 15. Regression of the Soybean Leaf Chemical Composition on Soil Hydrogen Ion Activity for Maturity Group V Soybean Cultivars in 1981 and 1982.

Cultivars	N	P	K	Ca	Mg	Mn
---------- 1981 ----------						
Asgrow 5474				**	*	-**
Asgrow 5618	††			††		-*
Bay				**	††	-**
Bedford		-††			**	
Dare				**		
Essex			*	*		-**
Forrest				††		-††
Nathan			*	**	*	-*
York			*	**	*	-**
---------- 1982 ----------						
Asgrow 5474	††			††		
Asgrow 5618	††			*		
Bay			††			-††
Bedford	*			*		
Dare	††				††	
Essex	††				-*	
Forrest						
Nathan						
York	*			*	**	

††,*,**Significant at 0.10, 0.05, and 0.01 levels of probability, respectively.

Table 16. Regression of the Soybean Leaf Chemical Composition on Soil Hydrogen Ion Activity for Maturity Group VI Soybean Cultivars in 1981 and 1982.

Cultivars	N	P	K	Ca	Mg	Mn
1981						
Centennial				**		
Jeff						-††
Lancer		††		**		-††
Lee 74				**	*	-**
Pickett 71				*		-*
1982						
Centennial						
Jeff						
Lancer				*		-*
Lee 74				*		-††
Pickett 71						

††,*,** Significant at 0.10, 0.05, and 0.01 levels of probability, respectively.

cultivars decreased noticeably as pH increased from 5.3 to 6.8 (Figure 27). Cultivars significantly differed from each other in P concentrations in 1982. In some cultivars, P concentration decreased consistently as pH increased from 5.3 to 5.9 and 6.8 (Mitchell, Bay, Bedford, and Pickett 71). In some others, it decreased as pH increased from 5.3 to 5.9, but increased as pH increased to 6.8 (Wilstar 430, and Lee 74). Regression analyses showed that only Bedford of maturity group V and Lancer of group VI had a significant relationship ($P < 0.05$ and 0.10) between P concentration and soil pH in 1981 (Tables 15 and 16).

H. CALCIUM CONCENTRATIONS

Leaf Ca-concentrations were significantly affected by soil pH in both years (Tables 3 and 4, pp. 18 and 19). As might be expected, Ca concentration for all cultivars increased as pH increased from 5.3 to 5.9 to 6.8 in both years (Figure 28). Significant differences existed in Ca concentrations among cultivars in both years. In 1981, Ca concentration in Delta and York increased as pH increased from 5.3 to 5.9, but decreased as pH increased to 6.8 (Appendix Table A-6). With FFR 446, Asgrow 5618, and Dare, Ca increased as pH increased from 5.3 to 5.9. Regression analyses showed that in most cultivars in the three maturity groups Ca concentrations had a positive significant relationship with soil pH.

In 1982, Columbus and Mitchell exhibited little change in Ca concentration. Delta, Franklin, and Nathan increased only when pH increased from 5.3 to 6.8 (Appendix Table A-6). On the other hand in 1982, only

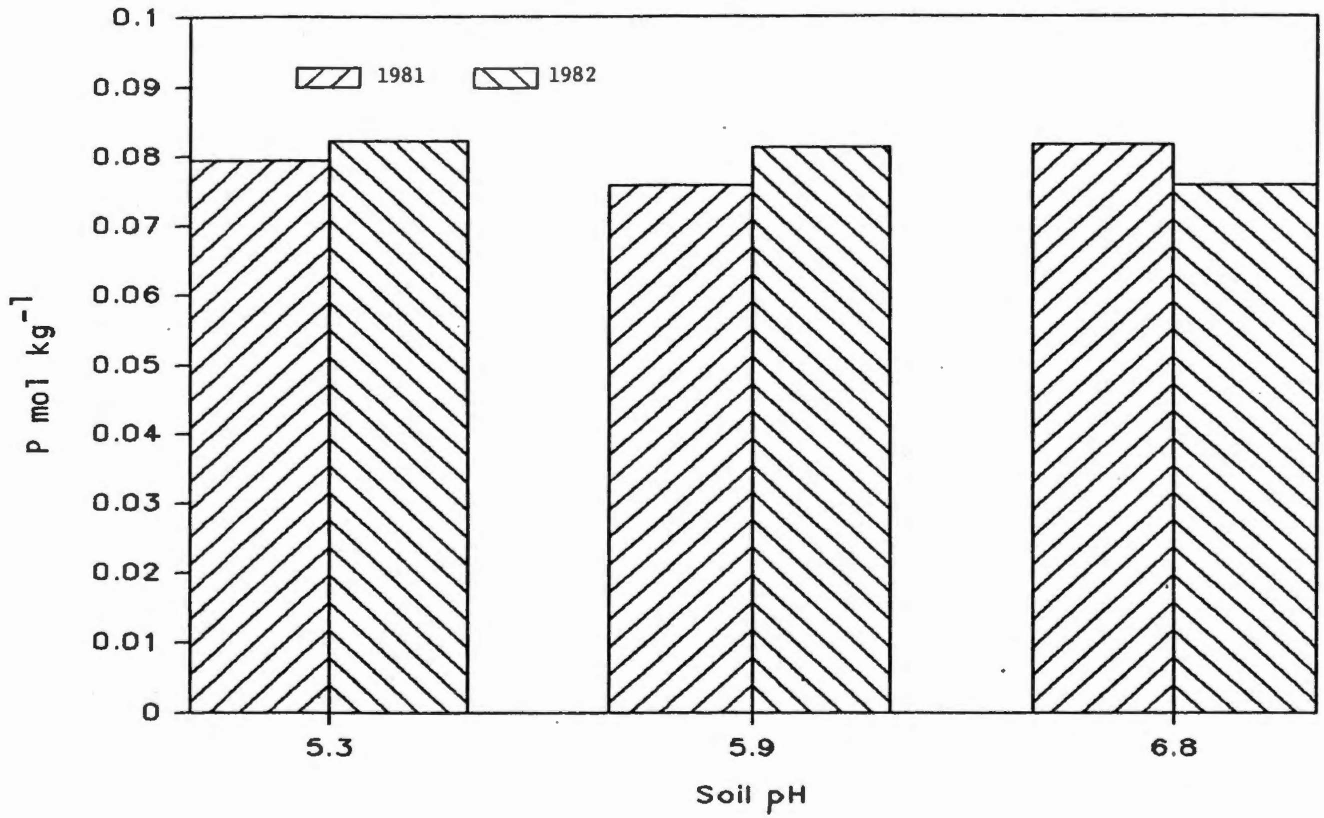

Figure 27. Mean Phosphorus Concentration in Soybean Leaves Across Twenty-one Cultivars Grown at Three pH Levels in 1981 and 1982.

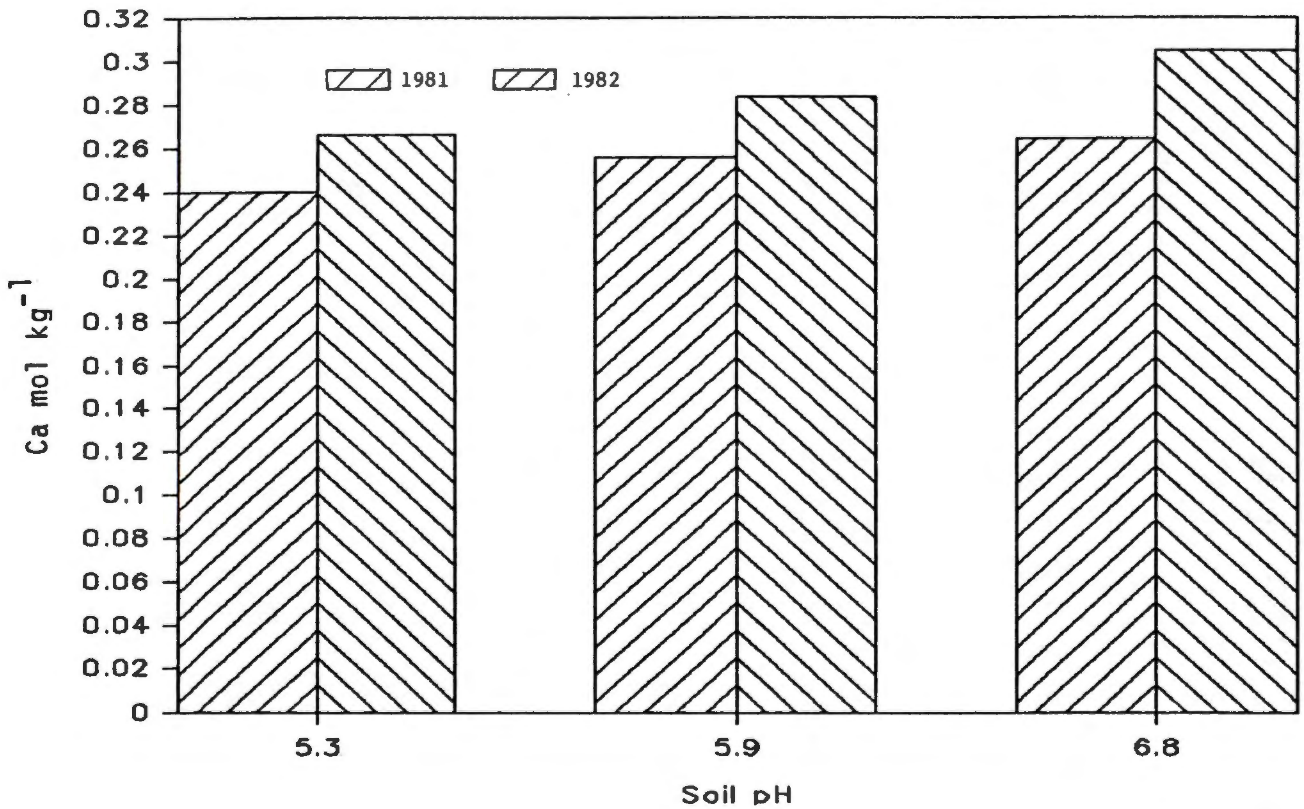

Figure 28. Mean Calcium Concentration of Soybean Leaves Across Twenty-one Cultivars Grown at Three Soil pH Levels in 1981 and 1982.

FFR 446 in maturity group IV , Asgrow 5474, Asgrow 5618, Bedford, and York in maturity group V, and Lancer and Lee 74 in maturity group VI showed a positive relationship between Ca-concentration and soil pH (Tables 14, 15, and 16).

I. MANGANESE CONCENTRATIONS

Leaf Mn concentration was significantly affected by soil pH in both years (Tables 3 and 4, pp. 18 and 19). Expectedly, leaf Mn-concentrations across all cultivars decreased as pH increased from 5.3 to 5.9 and 6.8 (Figure 29). Cultivar x pH interactions were present in both years leading to the conclusion that soil pH did not affect all cultivars in the same way or to the same extent. Cultivars showed significant differences in Mn concentrations in both years. In 1981, Mn concentrations in some cultivars decreased mainly as soil pH increased from 5.3 to 5.9 (Delta, Mitchell, Stevens, and Wilstar 430). In some others, Mn concentration decreased only when soil pH went to 6.8 (Dare and Jeff) (Appendix Table A-6).

In 1982, FFR 446, Mitchell, and Forrest showed a decrease in Mn concentration only at pH 6.8 (Appendix Table A-6). Bedford, Dare, and York showed no or very little response of Mn concentration to soil pH.

Regression analyses showed that most cultivars in the three maturity groups showed significant negative relationships ($P < 0.10$, 0.05, and 0.01) between Mn concentrations and soil pH in 1981 (Tables 14, 15, and 16, pp. 63, 64, and 65). The negative relationship was not as pronounced among cultivars in 1982 as it was in 1981.

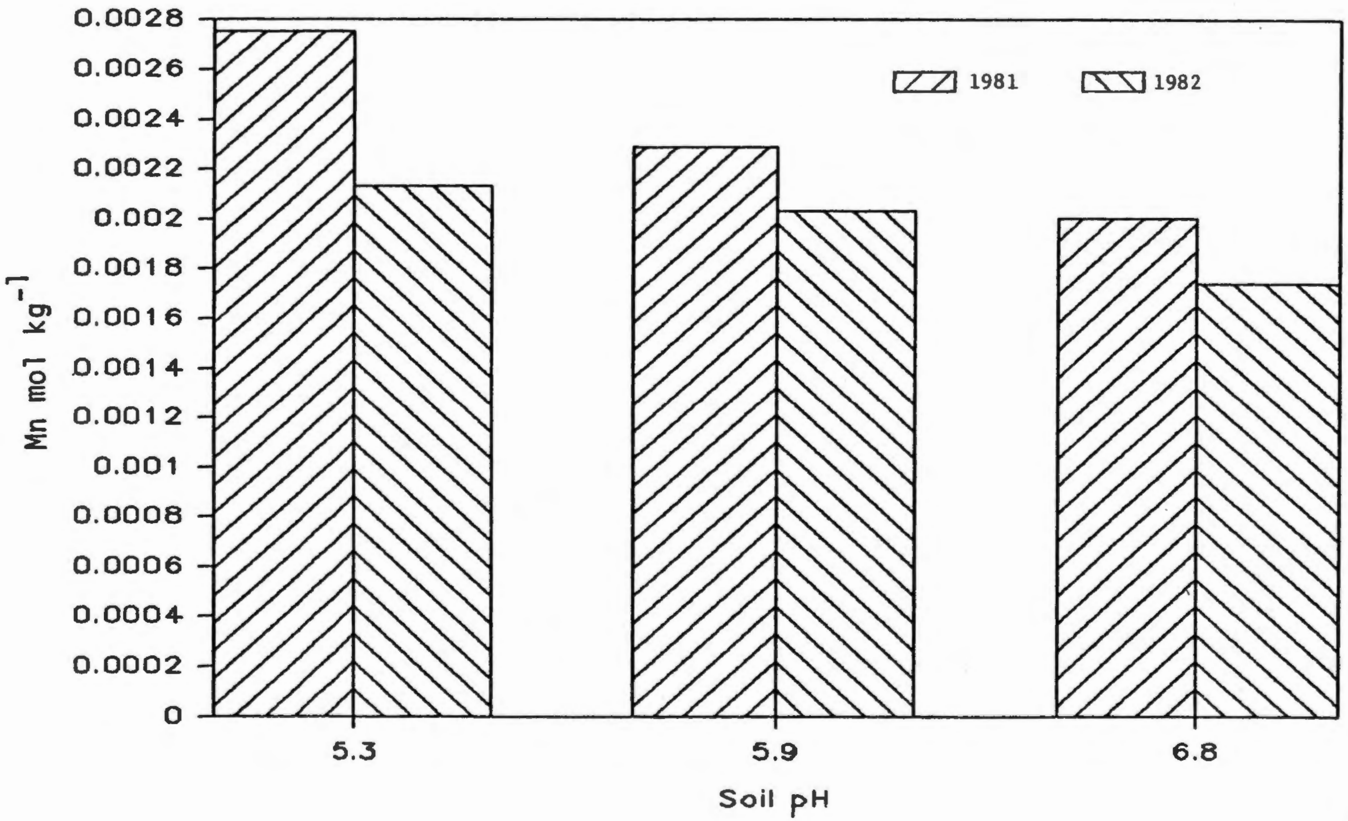

Figure 29. Mean Manganese Concentration of Soybean Leaves Across Twenty-one Cultivars Grown at Three Soil pH Levels in 1981 and 1982.

During this rather complete study of the many characteristics of the cultivars, it soon became apparent that it would be difficult to single out one or two properties that would have a major effect on yield. Obviously, many, if not most, of these properties interact, the emergence of one tending to be compensated by variations in others. However, it seemed to this researcher that efforts should be concentrated on determining numbers of pods and any changes in the weight of seed. It is these factors which were found to have a meaningful effect on yield.

Also, another situation which should be addressed is the presence or absence of a Mo treatment. As was previously mentioned, the 1981 crop received supplemental Mo while the 1982 crop did not. More yield responses were noted in 1982 as soil pH increased thus perhaps confounding this study to some degree. However, availability of most essential nutrients is altered substantially by changes in soil pH, therefore, it may be unfair to be overly concerned about this situation. Instead one may tend to evaluate the relative need for lime and/or Mo with this diversity of genetic material.

CHAPTER V

SUMMARY AND CONCLUSIONS

A field experiment was conducted in West Tennessee at Ames Plantation on a Loring silt loam (Typic Fragiudalf) soil. Twenty-one selected cultivars of soybeans were planted at three soil pH levels, 5.3, 5.9, and 6.8. The purpose of this study was to measure selected chemical and morphological characteristics and to ascertain which of these characteristics were affected by soil pH. It was also determined if the various cultivars differed in their response to soil pH.

The characteristics measured in this study were: yield, leaf N, P, K, Ca, Mg and Mn, number of nodes, plant height, seed weight (100 seed), number of single, double and triple seeded pods on the main stem, number of single, double and triple seeded pods on branches and the number of branches.

Soybean yield averaged across the 21 cultivars increased as soil pH increased from 5.3 to 6.8 only in 1982. Seed weight per 100 seed increased as soil pH increased in 1982. There were no differences in plant height found in this study as a result of soil pH differences. Average number of branches per plant increased with the increase in soil pH in 1981, but the number of nodes on main stem did not. Average numbers of single, double, and triple seeded pods on both main stem and branches increased with soil pH in both years. Soybean leaf N-concentrations were not affected by soil pH in 1981, but increased in

1982. Leaf P-concentrations increased with soil pH only in 1982. Leaf Ca-concentrations increased as soil pH increased while leaf Mn-concentrations decreased as soil pH increased.

Soybean yields show a positive response to increasing soil pH in both years, but that response was more defined in 1982 when the plants were not sprayed with Mo. Generally, it is recommended that plants or seeds should be treated with Mo, especially when soil pH is relatively low. Soil pH itself seemed to have no direct clear effect on soybean yields when the nutrient supply is adequate, under the conditions of this study. Soybean yield response to soil pH with and without Mo treatment deserves more detailed study and for longer periods of time on different soil conditions.

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APPENDIX

Table A-1. Mean Yields and 100 Seed Weight for Twenty-one Soybean Cultivars at Three Soil pH Levels in 1981 and 1982.

	Yield (Mg ha^{-1})						100 Seed Weight (g)					
Cultivar	pH 5.3		5.9		6.8		5.3		5.9		6.8	
	Yr 81	82	81	82	81	82	81	82	81	82	81	82
Columbus	2.138	2.111	1.884	2.352	1.781	2.580	18.7	16.6	18.9	17.7	19.6	18.0
Delta	2.042	1.924	1.865	2.321	1.570	2.393	15.1	15.4	16.4	15.9	17.6	16.2
FFR 446	1.545	1.568	1.775	1.679	1.655	2.325	12.9	13.8	14.5	15.3	14.1	16.2
Franklin	1.452	1.574	1.882	2.087	1.773	2.595	12.8	16.9	18.8	18.1	15.7	18.5
Mitchell	1.857	1.870	2.257	2.105	2.251	2.129	17.2	18.2	18.3	20.6	17.1	21.3
Stevens	2.176	1.543	1.519	1.925	2.158	2.279	16.0	16.3	14.9	17.5	16.7	17.5
Wilstar 430	1.957	1.810	2.500	2.091	1.296	2.367	25.2	20.3	21.2	21.6	21.3	19.9
Asgrow 5474	2.660	2.545	3.120	2.890	2.760	3.027	16.4	14.4	17.5	14.9	16.5	15.4
Asgrow 5618	2.513	2.459	2.518	2.306	2.842	2.414	17.8	16.7	18.7	17.2	18.6	16.3
Bay	2.526	1.898	2.764	2.740	2.454	2.650	19.4	19.8	19.8	16.7	18.7	16.3
Bedford	2.441	2.441	2.883	2.881	2.775	2.688	15.1	12.0	15.3	13.1	14.9	15.5
Dare	2.797	1.836	2.527	2.445	2.523	2.743	16.6	13.2	15.4	13.8	15.0	14.4
Essex	2.040	1.988	2.634	2.475	2.246	2.782	15.1	-	14.8	-	14.2	-
Forrest	2.811	2.555	2.654	3.014	3.501	3.003	16.5	12.5	14.6	12.7	15.5	12.5
Nathan	2.384	2.585	2.373	2.414	2.774	3.045	15.2	12.7	14.9	13.3	14.2	13.3
York	2.339	2.180	2.427	2.300	2.675	2.745	20.9	17.6	20.5	18.6	20.6	18.8
Centennial	2.552	2.543	2.862	2.993	3.509	3.346	13.8	12.6	15.0	15.8	13.5	13.7
Jeff	3.076	2.186	3.097	3.176	3.104	3.285	17.5	13.6	16.2	13.9	16.7	14.8
Lancer	2.627	2.466	2.895	2.667	2.793	2.981	16.4	15.2	17.8	16.3	16.6	16.1
Lee 74	2.348	2.230	2.683	2.996	2.690	3.011	15.1	13.2	15.3	14.4	15.4	14.8
Pickett 71	2.851	2.607	3.054	2.667	2.999	2.773	13.2	12.5	13.7	14.0	13.3	13.9
Bon LSD 0.05	0.588	0.546	0.588	0.546	0.588	0.546	2.4	2.5	2.4	2.5	2.4	2.5

Table A-2. Means of Single, Double, and Triple Seeded Pods on Main Stem of Twenty-one Soybean Cultivars at Three Soil pH Levels in 1981 and 1982.

Cultivars	Single seeded pods on main stem						Double seeded pods on main stem						Triple seeded pods on main stem					
pH	5.3		5.9		6.8		5.3		5.9		6.8		5.3		5.9		6.8	
Year	81	82	81	82	81	82	81	82	81	82	81	82	81	82	81	82	81	82
			No						No						No			
Columbus	1.7	2.5	3.0	1.2	2.6	0.3	13.1	15.5	20.3	17.8	20.4	12.83	4.0	32.0	4.2	41.8	3.1	34.3
Delta	0.8	1.0	3.3	1.8	2.4	1.6	11.1	11.1	17.8	10.6	12.6	10.6	2.6	20.3	2.9	42.1	2.6	34.6
FFR 446	0.4	1.3	1.8	2.1	1.0	1.8	14.8	12.6	13.8	11.8	13.0	14.6	2.4	20.8	2.6	20.0	2.7	36.8
Franklin	0.5	1.2	1.1	2.2	1.2	1.8	9.0	8.8	12.6	10.0	10.7	10.6	2.6	26.6	3.1	25.7	3.3	24.3
Mitchell	1.3	2.1	2.0	1.2	1.5	0.5	13.0	13.1	15.7	7.1	12.0	10.8	2.5	28.0	3.6	17.8	2.8	21.1
Stevens	1.0	0.6	0.9	0.4	0.8	2.1	10.3	7.7	14.3	6.1	14.1	13.1	3.1	25.3	2.9	23.5	2.9	33.6
Wilstar 430	0.5	1.5	1.3	2.2	2.1	1.3	9.8	12.7	10.5	11.6	11.1	11.2	2.7	27.1	3.4	21.6	2.6	32.3
Asgrow 5474	1.2	3.2	0.8	1.5	1.6	2.7	13.5	21.5	10.1	17.5	19.5	23.7	2.3	21.8	1.5	21.1	2.1	21.3
Asgrow 5618	2.5	5.3	2.1	4.2	2.8	3.8	16.5	35.6	28.4	33.2	20.4	39.7	2.0	4.0	4.0	4.5	5.4	5.2
Bay	1.0	1.7	0.6	1.7	1.9	1.6	12.6	20.6	12.4	25.8	15.4	18.7	2.7	19.7	3.3	23.0	3.5	20.5
Bedford	1.1	2.8	1.9	3.6	3.3	3.0	15.6	26.7	17.8	28.2	24.0	26.3	6.6	17.0	3.6	12.5	1.8	24.0
Dare	2.3	2.7	1.7	3.7	2.0	2.7	19.5	31.1	20.3	33.7	28.5	28.2	5.3	15.0	4.0	14.8	7.2	13.1
Essex	3.8	4.8	4.0	7.8	4.3	7.3	16.3	26.3	23.8	25.1	21.8	37.6	6.8	17.8	4.2	4.3	4.8	24.0
Forrest	1.3	1.7	1.6	3.7	6.9	5.5	16.3	22.8	16.0	36.1	35.3	32.5	3.8	21.6	1.5	18.7	1.4	21.3
Nathan	3.1	4.1	5.8	3.0	4.9	5.1	20.5	26.0	39.3	25.6	40.0	30.3	4.6	8.2	5.3	7.6	4.7	13.5
York	2.1	4.6	1.6	3.6	3.6	5.1	15.7	16.3	23.3	22.7	31.3	20.1	3.6	9.8	3.0	6.7	4.3	7.5
Centennial	4.1	5.6	4.5	2.5	4.1	3.6	33.6	44.3	32.5	44.3	24.5	36.1	5.5	10.5	4.3	17.16	6.0	11.7
Jeff	3.2	3.1	2.1	3.8	4.8	3.2	31.8	26.5	35.5	41.8	37.8	36.2	5.8	6.6	7.7	16.7	4.6	10.3
Lancer	3.5	1.7	2.9	3.5	3.7	1.7	31.5	35.7	33.1	40.5	37.3	39.6	3.3	14.1	7.1	9.7	5.7	9.3
Lee 74	1.8	4.3	1.6	1.0	2.2	1.7	16.1	18.8	17.7	15.2	18.0	18.3	1.8	24.6	2.3	16.8	1.7	34.5
Pickett 71	2.6	0.9	2.8	3.6	2.6	1.5	18.8	14.3	20.7	28.6	17.8	18.8	2.3	21.6	2.4	22.3	3.0	27.1
Bon.LSD0.05	3.0	3.8	3.0	3.8	3.0	3.8	14.2	12.8	14.2	12.8	14.2	12.8	3.1	12.8	3.1	12.8	3.1	12.8

Table A-3. Means of Single, Double, and Triple Seeded Pods on Branches of Twenty-one Soybean Cultivars at Three Soil pH Levels in 1981 and 1982.

Cultivars	Single seeded pods on branches						Double seeded pods on branches						Triple seeded pods on branches					
pH	5.3		5.9		6.8		5.3		5.9		6.8		5.3		5.9		6.8	
Year	81	82	81	82	81	82	81	82	81	82	81	82	81	82	81	82	81	82
	No						No						No					
Columbus	0.8	1.6	0.0	1.7	1.1	0.7	2.8	7.6	3.5	3.7	4.0	7.0	2.9	9.6	7.0	11.3	9.6	16.3
Delta	0.0	1.8	1.5	1.6	2.1	1.1	2.8	7.5	21.1	5.8	17.7	13.8	6.3	12.5	30.0	14.3	21.8	29.7
FFR 446	1.0	1.3	1.5	0.7	1.1	0.9	7.3	9.5	6.5	8.1	11.0	13.5	7.1	10.3	9.8	10.0	16.5	22.7
Franklin	0.1	0.1	0.0	0.8	0.0	1.3	2.1	1.4	6.1	6.3	3.7	8.6	3.3	5.6	11.6	12.6	7.8	11.1
Mitchell	0.3	1.3	1.3	0.5	0.5	0.4	6.2	7.3	11.5	4.7	4.6	3.6	10.2	14.6	22.6	12.3	12.1	5.1
Stevens	0.7	2.1	0.4	0.3	0.3	0.5	1.5	8.5	2.8	5.3	3.3	10.5	4.5	14.4	6.5	12.7	6.1	22.1
Wilstar 430	0.2	1.3	0.3	3.2	0.3	0.6	7.1	4.8	5.1	10.1	5.3	16.8	13.6	12.2	9.6	12.2	13.6	28.8
Asgrow 5474	0.6	1.8	0.5	0.3	1.5	5.6	10.3	19.0	8.3	7.7	5.6	24.3	7.6	18.7	10.8	7.0	9.3	19.1
Asgrow 5618	1.7	5.2	1.6	5.1	2.5	2.1	22.3	35.1	28.0	22.5	19.0	35.0	4.2	3.7	2.4	2.6	4.9	4.5
Bay	0.8	2.1	0.8	0.8	2.5	0.9	10.9	11.0	11.5	16.0	16.8	14.5	9.8	11.8	12.4	14.6	14.6	11.7
Bedford	1.0	3.5	2.0	5.3	2.3	4.1	33.9	22.0	25.5	20.5	21.5	47.6	21.1	9.6	16.5	29.7	11.3	31.6
Dare	1.6	2.7	1.0	3.3	1.8	4.1	17.2	19.3	23.7	20.7	27.3	25.6	5.2	6.5	6.6	6.5	13.5	10.1
Essex	1.3	2.3	1.5	3.2	2.6	3.6	6.2	20.3	15.7	12.6	18.1	20.3	2.7	6.3	4.5	3.1	8.5	10.0
Forrest	1.0	2.5	1.6	1.5	3.8	3.0	15.3	20.3	17.1	15.6	24.7	15.0	9.1	12.8	10.1	10.8	11.9	9.8
Nathan	3.5	7.3	1.6	1.7	4.6	10.1	20.6	40.5	25.6	20.5	29.5	28.6	5.6	11.6	9.4	6.3	8.3	20.8
York	3.2	1.6	3.4	4.8	5.0	8.5	21.6	17.3	33.5	19.7	33.3	31.2	10.5	9.2	19.1	6.1	15.8	23.0
Centennial	1.4	3.0	2.0	2.5	3.4	1.1	16.9	32.1	35.6	19.0	23.8	17.2	1.1	6.1	6.8	4.8	4.0	7.6
Jeff	3.5	2.1	1.7	3.1	2.1	4.5	18.0	30.1	27.6	27.7	25.2	28.7	3.5	9.6	8.3	5.8	2.2	14.3
Lancer	2.6	3.8	0.4	2.3	0.5	1.6	13.1	42.5	21.8	30.0	15.0	24.3	2.2	16.7	5.4	6.3	3.1	3.5
Lee 74	3.1	1.8	2.3	3.3	1.6	1.2	18.6	10.3	21.6	16.3	14.3	14.0	20.3	16.6	17.5	20.2	17.0	26.3
Pickett 71	2.6	1.2	1.3	1.5	1.4	0.6	16.3	9.6	15.0	15.8	15.9	4.3	16.1	15.5	22.8	18.8	22.8	7.3
Bon LSD 0.05	2.9	4.2	2.9	4.2	2.9	4.2	14.9	19.8	14.9	19.8	14.9	19.8	12.8	18.5	12.8	18.5	12.8	18.5

Table A-4. Means of Branches per Plant, Nodes per Main Stem, and Plant Height for Twenty-one Soybean Cultivars at Three Soil pH Levels in 1981 and 1982.

Cultivars	Branches Per Plant						Nodes Per Main Stem						Plant Height					
	5.3		5.9		6.8		5.3		5.9		6.8		5.3		5.9		6.8	
	Yr. 81	82	81	82	81	82	81	82	81	82	81	82	81	82	81	82	81	82
Columbus	0.9	1.7	0.8	1.5	1.4	1.6	20.1	20.5	19.3	19.7	19.8	20.5	92.5	88.0	92.3	86.5	91.1	91.3
Delta	1.1	3.0	5.0	2.8	5.6	3.7	17.1	16.3	18.1	16.8	20.2	18.6	94.7	74.5	75.2	73.0	74.7	78.5
FFR 446	1.8	2.5	2.0	1.5	2.6	4.7	18.0	17.6	18.6	11.6	18.7	18.3	97.8	82.0	100.3	79.3	88.7	86.7
Franklin	0.9	1.3	1.6	2.3	1.0	2.1	16.3	13.1	17.3	16.7	17.3	16.6	82.6	69.0	82.8	74.2	82.5	77.7
Mitchell	2.1	3.1	2.8	2.1	1.8	3.0	17.2	19.6	18.6	16.7	17.0	18.0	75.8	83.3	84.6	76.7	71.7	74.0
Stevens	1.5	3.2	0.8	2.5	1.3	2.3	16.8	16.1	17.1	16.7	18.3	17.6	88.0	70.7	95.9	73.0	90.6	79.0
Wilstar 430	2.3	2.3	1.6	2.7	2.0	3.5	16.5	19.0	19.3	19.8	19.8	19.1	86.1	82.5	92.9	77.7	89.3	74.5
Asgrow 5474	3.0	2.1	3.1	1.8	2.9	3.5	12.4	15.5	12.1	14.5	12.4	15.7	54.2	82.5	64.5	83.5	91.0	80.5
Asgrow 5618	5.3	3.6	5.6	2.6	5.6	3.7	13.8	15.8	15.1	14.1	14.0	16.0	68.3	78.5	72.5	80.5	63.1	77.5
Bay	3.0	3.1	4.8	3.0	3.9	2.5	12.7	13.3	12.8	15.3	13.3	14.5	67.0	66.5	61.8	74.5	66.9	75.5
Bedford	4.1	3.5	4.8	4.0	3.5	6.1	15.5	18.0	16.1	16.2	14.5	18.7	84.0	93.7	90.1	92.5	76.4	94.0
Dare	3.6	2.3	5.0	2.2	5.0	2.6	12.6	17.3	13.3	15.6	12.9	13.5	71.6	72.0	64.6	82.0	59.6	71.5
Essex	1.5	2.6	3.0	2.1	2.7	2.3	9.7	12.1	11.3	13.0	10.5	11.6	40.1	51.7	48.7	57.2	42.6	52.3
Forrest	3.5	2.0	3.0	1.7	3.6	1.7	12.3	12.8	12.0	15.2	14.0	15.0	72.0	75.7	56.8	79.7	75.5	79.7
Nathan	3.7	5.7	3.4	2.2	3.5	5.7	14.5	18.6	15.5	15.5	16.9	17.3	85.3	99.0	86.6	95.7	94.9	87.0
York	4.6	2.8	7.3	7.3	4.4	6.0	12.1	13.0	13.0	14.8	12.9	15.3	51.1	62.5	42.6	66.7	60.6	70.5
Centennial	2.0	2.5	4.3	2.3	2.3	2.2	16.5	16.3	16.3	16.5	16.6	14.8	95.6	88.5	84.5	91.0	91.6	85.0
Jeff	5.5	3.1	4.8	3.1	3.0	5.3	16.1	12.8	16.3	16.0	16.2	16.5	94.1	70.6	93.7	89.0	98.2	89.7
Lancer	2.7	3.5	4.6	2.5	2.4	2.0	16.6	15.2	16.3	18.3	16.8	15.2	90.5	69.5	86.6	89.2	84.1	76.5
Lee 74	4.8	2.1	6.1	2.8	3.7	2.3	12.6	12.1	13.0	10.8	12.7	10.8	67.1	59.6	73.8	65.2	76.0	65.7
Pickett 71	2.6	2.3	4.0	3.3	4.1	1.3	12.8	11.0	13.1	14.3	11.5	11.6	73.8	55.7	70.8	74.0	64.8	71.2
Bon LSD .05	2.6	3.3	2.6	3.3	2.6	3.3	2.7	3.6	2.7	3.6	2.7	3.6	17.6	13.5	17.6	13.5	17.6	13.5

Table A-5. Means of N, P, and K Concentrations in the Leaf Tissue of Twenty-one Soybean Cultivars at Three Soil pH Levels in 1981 and 1982.

Cultivars	Nitrogen (Mol. Kg^{-1})						Phosphorus (Mol. Kg^{-1})						Potassium (Mol. Kg^{-1})					
	pH 5.3		5.9		6.8		5.3		5.9		6.8		5.3		5.9		6.8	
	Yr. 81	82	81	82	81	82	81	82	81	82	81	82	81	82	81	82	81	82
Columbus	2.825	2.446	3.023	3.023	3.021	3.013	0.0822	0.0959	0.0758	0.0967	0.0879	0.0887	0.366	0.468	0.364	0.527	0.370	0.499
Delta	2.766	2.780	2.786	3.104	2.689	2.973	0.0766	0.0879	0.0750	0.0862	0.0782	0.0782	0.376	0.407	0.347	0.416	0.305	0.428
FFR 446	2.736	2.735	2.780	2.867	2.857	2.741	0.0862	0.0919	0.0741	0.0919	0.0862	0.0862	0.338	0.475	0.356	0.521	0.317	0.446
Franklin	2.535	2.984	2.732	2.825	2.627	2.923	0.0758	0.0846	0.0758	0.0830	0.0790	0.0806	0.361	0.377	0.338	0.398	0.302	0.426
Mitchell	2.838	2.832	3.068	2.829	3.055	2.963	0.0862	0.0911	0.0790	0.0887	0.0887	0.0846	0.414	0.424	0.393	0.434	0.365	0.442
Stevens	2.852	3.118	2.789	3.004	2.777	2.827	0.0798	0.0895	0.0750	0.0879	0.0798	0.0854	0.371	0.400	0.357	0.414	0.299	0.449
Wilstar 430	2.770	2.943	2.948	2.879	3.091	3.055	0.0806	0.0919	0.0774	0.0879	0.0863	0.0919	0.370	0.465	0.368	0.476	0.350	0.471
Asgrow 5474	2.907	2.688	2.868	2.964	2.881	2.886	0.0774	0.0774	0.0693	0.0790	0.0766	0.0741	0.318	0.399	0.317	0.405	0.294	0.415
Asgrow 5618	2.871	2.543	3.014	2.961	3.014	2.920	0.0774	0.0750	0.0682	0.0774	0.0798	0.0774	0.311	0.328	0.299	0.353	0.286	0.347
Bay	2.967	2.623	2.891	2.349	2.930	2.721	0.0758	0.0750	0.0685	0.0709	0.0766	0.0669	0.351	0.352	0.353	0.367	0.317	0.403
Bedford	3.082	1.957	2.912	2.568	2.859	2.595	0.0887	0.0782	0.0814	0.0725	0.0822	0.0669	0.379	0.385	0.382	0.385	0.373	0.389
Dare	2.963	2.439	3.023	2.766	2.857	2.820	0.0774	0.0806	0.0750	0.0774	0.0774	0.0725	0.345	0.382	0.329	0.394	0.322	0.379
Essex	3.080	2.857	3.088	3.279	3.070	3.104	0.0822	0.0846	0.0572	0.0870	0.0822	0.0774	0.296	0.297	0.198	0.319	0.256	0.298
Forrest	2.900	2.566	2.816	2.914	2.880	2.475	0.0717	0.0725	0.0717	0.0774	0.0782	0.0588	0.299	0.330	0.301	0.342	0.306	0.332
Nathan	3.002	2.538	2.880	2.217	2.941	2.755	0.0814	0.0750	0.0758	0.0717	0.0822	0.0653	0.358	0.331	0.320	0.306	0.298	0.334
York	2.702	2.221	2.791	2.682	2.761	2.768	0.0741	0.0733	0.0677	0.0733	0.0741	0.0637	0.320	0.319	0.277	0.302	0.278	0.347
Centennial	2.957	2.381	2.743	2.632	2.970	2.588	0.0838	0.0817	0.0572	0.0814	0.0870	0.0817	0.373	0.439	0.293	0.464	0.387	0.455
Jeff	2.941	2.355	2.782	2.305	2.995	2.368	0.0774	0.0814	0.0806	0.0798	0.0854	0.0766	0.343	0.415	0.381	0.394	0.338	0.428
Lancer	3.193	2.529	3.059	2.791	3.170	2.721	0.0758	0.0846	0.0790	0.0846	0.0830	0.0798	0.357	0.437	0.389	0.468	0.394	0.482
Lee 74	3.236	2.566	3.013	2.232	2.955	2.811	0.0782	0.0774	0.0790	0.0758	0.0790	0.0766	0.332	0.393	0.314	0.414	0.313	0.368
Pickett 71	3.045	2.582	2.923	2.561	2.945	2.500	0.0774	0.0750	0.0782	0.0733	0.0838	0.0612	0.317	0.381	0.338	0.412	0.330	0.413
Bon LSD0.05	0.243	0.430	0.243	0.430	0.243	0.430	0.0126	0.0112	0.0126	0.0112	0.0126	0.0112	0.063	0.051	0.063	0.051	0.063	0.051

Table A-6. Means of Ca, Mg, and Mn Concentrations in the Leaf Tissue of Twenty-one Soybean Cultivars at Three Soil pH Levels in 1981 and 1982.

Cultivars	Calcium (Mol. Kg^{-1})						Magnesium (Mol. Kg^{-1})						Manganese (Mol. Kg^{-1})					
	pH 5.3		5.9		6.8		5.3		5.9		6.8		5.3		5.9		6.8	
	Yr. 81	82	81	82	81	82	81	82	81	82	81	82	81	82	81	82	81	82
Columbus	0.1920	0.2312	0.2618	0.2300	0.2899	0.2269	0.0997	0.1481	0.1090	0.1471	0.1183	0.1430	0.0023	0.0017	0.0018	0.0016	0.0017	0.0014
Delta	0.2356	0.2356	0.2524	0.2369	0.2437	0.2724	0.0792	0.1306	0.1162	0.1306	0.1131	0.1306	0.0027	0.0020	0.0019	0.0017	0.0017	0.0013
FFR 446	0.1913	0.2076	0.2387	0.2144	0.2300	0.2375	0.0905	0.1368	0.0853	0.1460	0.1131	0.1532	0.0024	0.0018	0.0019	0.0019	0.0018	0.0014
Franklin	0.2593	0.2624	0.2980	0.2662	0.3341	0.2905	0.0895	0.1471	0.1069	0.1419	0.1080	0.1419	0.0029	0.0022	0.0022	0.0017	0.0020	0.0016
Mitchell	0.1970	0.2319	0.2256	0.2450	0.2518	0.2418	0.0730	0.1296	0.0833	0.1275	0.0987	0.1286	0.0025	0.0019	0.0019	0.0019	0.0019	0.0017
Stevens	0.2456	0.2761	0.2655	0.2493	0.3054	0.2593	0.0792	0.1450	0.0874	0.1347	0.1069	0.1409	0.0028	0.0024	0.0019	0.0021	0.0019	0.0014
Wilstar 430	0.2394	0.2637	0.2468	0.2487	0.2817	0.2743	0.0987	0.1347	0.1028	0.1316	0.1111	0.1522	0.0025	0.0020	0.0018	0.0019	0.0019	0.0014
Asgrow 5474	0.2531	0.2655	0.3017	0.4053	0.3254	0.3042	0.0864	0.1224	0.0915	0.1296	0.1090	0.1306	0.0030	0.0022	0.0023	0.0023	0.0022	0.0020
Asgrow 5618	0.2512	0.2699	0.3173	0.3036	0.3179	0.3647	0.1141	0.1759	0.1358	0.1769	0.1337	0.1913	0.0028	0.0028	0.0024	0.0020	0.0020	0.0018
Bay	0.2618	0.3173	0.2892	0.3609	0.3254	0.3372	0.1008	0.1399	0.1080	0.1522	0.1275	0.1491	0.0032	0.0024	0.0025	0.0022	0.0021	0.0018
Bedford	0.2312	0.2225	0.2425	0.2375	0.2493	0.2718	0.0925	0.1162	0.1358	0.1275	0.1316	0.1224	0.0022	0.0017	0.0021	0.0018	0.0017	0.0017
Dare	0.2225	0.3036	0.2961	0.3173	0.2955	0.3441	0.1039	0.1481	0.1121	0.1563	0.1141	0.1563	0.0025	0.0020	0.0025	0.0020	0.0022	0.0020
Essex	0.2998	0.3534	0.3632	0.3765	0.3877	0.4102	0.1141	0.1810	0.1275	0.1673	0.1296	0.1615	0.0035	0.0025	0.0028	0.0023	0.0021	0.0020
Forrest	0.2506	0.2980	0.2827	0.3216	0.3036	0.3366	0.1121	0.1522	0.1141	0.1574	0.1141	0.1615	0.0029	0.0020	0.0027	0.0020	0.0022	0.0016
Nathan	0.1963	0.2562	0.2381	0.2556	0.3048	0.3004	0.0864	0.1265	0.0987	0.1286	0.1121	0.1337	0.0026	0.0018	0.0024	0.0019	0.0020	0.0016
York	0.2711	0.2861	0.3684	0.3946	0.3397	0.3615	0.0905	0.1244	0.1244	0.1656	0.1090	0.1522	0.0028	0.0020	0.0021	0.0021	0.0018	0.0019
Centennial	0.1820	0.2452	0.2011	0.2655	0.2294	0.2849	0.1111	0.1522	0.1220	0.1604	0.1162	0.1635	0.0022	0.0021	0.0023	0.0019	0.0018	0.0020
Jeff	0.2394	0.2649	0.2306	0.2836	0.2599	0.3042	0.1193	0.1327	0.1039	0.1388	0.1141	0.1388	0.0024	0.0018	0.0024	0.0021	0.0019	0.0016
Lancer	0.1982	0.2512	0.2188	0.2948	0.2418	0.3061	0.1162	0.1594	0.1213	0.1759	0.1152	0.1656	0.0025	0.0024	0.0023	0.0020	0.0020	0.0017
Lee 74	0.2231	0.2643	0.2512	0.2936	0.2930	0.3734	0.1121	0.1584	0.1296	0.1563	0.1286	0.1748	0.0030	0.0025	0.0025	0.0024	0.0018	0.0018
Pickett 71	0.2356	0.2836	0.2612	0.3017	0.3142	0.3042	0.1018	0.1337	0.1049	0.1358	0.1141	0.1368	0.0029	0.0021	0.0025	0.0018	0.0022	0.0018
Bon LSD 0.05	0.0518	0.0464	0.0518	0.0464	0.0518	0.0464	0.0213	0.0171	0.0213	0.0171	0.0231	0.0171	$4.5x10^{-4}$	$4.1x10^{-4}$	$4.5x10^{-4}$	$4.1x10^{-4}$	$4.5x10^{-4}$	$4.1x10^{-4}$

VITA

Nuri H. Al-Mohammadi was born in Fallujah, Iraq, on July 1, 1950. He was educated in the elementary and secondary schools of that city and was graduated from Al-Fallujah High School in June 1967. The following September he entered the College of Agriculture in The University of Baghdad, receiving a B.S. in Agriculture with a major in Soil Science in June 1971. The following October he was employed as a lab assistant and a graduate student in the Department of Soil Science of the same college. In September 1975, he was granted an M.S. degree in Soil Science and worked as an assistant instructor in the same department until December 1979 when he was awarded a study leave to pursue the Ph.D. degree in Soil Science.

In December 1984, he was granted a Ph.D. degree with a major in Plant and Soil Science from The University of Tennessee, Knoxville. He is a member of the American Society of Agronomy.

He was married to Suad M. Humadi on June 3, 1975. He is the father of three children, two sons, Anas and Feras and one daughter, Hiba.