DIFFERENTIAL EFFECTS OF PHOSPHORUS AND POTASSIUM FERTILITY ON NUTRIENT UPTAKE AND YIELD OF SOYBEAN VARIETIES (Glycine max L. Merrill)

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ROBERT CHARLES KALNBACH

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ABSTRACT

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(Glycine max L. Merrill)

By

Robert Charles Kalnbach

Effects of P and K fertilizer applications on seed yield, dry matter yield and on nutrient accumulation were studied under greenhouse and field conditions using ten soybean varieties grown in Michigan. Varietal differences in seed yield response, dry matter yield and nutrient accumulation were insignificant.

Increase in seed yield and dry matter accumulation were greater when P and K were in balanced combinations than when imbalanced combinations were applied. Seed yield increases were greater for applications of P than for K. Decreases in root dry weights were obtained from P applications under low levels of K. A balanced application of high P and K fertilizer resulted in higher seed yields and dry matter accumulation than balanced applications at the medium rate.

Incremental increases in P and K fertility inversely affected rates of soybean seed emergence when seeds were placed in contact with soil-fertilizer substrate. Increasing phosphorus levels was more responsible for reduced rates of seedling emergence than increasing potassium levels.

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Robert Charles Kalnbach

Fertilizer P and K applications affected P, K, Ca, Mg, Mn, Fe, Zn and B plant tissue concentrations. No correlation resulted between nutrient concentration in plant tissue and yield of dry matter for soybeans grown in the greenhouse.

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INTRODUCTION

The effect of fertilizers and soil fertility on soybean yields and plant composition has been the subject of considerable investigations for many years. The opinion of some agronomists is that some soybeans grown in rotation with crops which have been fertilized and limed according to soil test usually do not respond to additional fertilizers. Other investigators confirm yield increases from applied P and K only at low soil P and K concentrations.

Varietal responses to applied nutrients have been investigated in many plant species. Marked differences in yield responses to varying amounts of P and K have been observed among soybean varieties. Although varietal differences in sensitivity and tolerance of soybeans to phosphorus were observed several years ago, these yield increases have not been as pronounced as responses to potassium applications.

It is generally conceded that the soybean is native to Eastern Asia and has evolved from an ancient agriculture where soils were very low in available nutrients. Under these conditions of low fertility it seems reasonable that soybeans selected from wild strains may not have included the genetic ability to respond to higher fertility conditions. Preferential selection of genes to respond to higher fertility evnironments probably did not occur under constant low fertility conditions. Plants may also have been selected as to their efficiency in nutrient uptake on poor soils, thus the parentage for soybeans grown today may be from these lines.

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The variability for nutrient uptake and utilization within soybean lines must be determined if efficiency and increased production are to be obtained. The plants' ability to respond to mineral nutrition consists of its ability to absorb, translocate and utilize nutrients, thus providing a physiological basis for a genetic study.

In understanding differential responses it is of utmost importance to be cognizant of the magnitude of interrelationships between the micronutrient and macronutrient elements. Varietal differences in rooting patterns and growth may also cause differential responses from various methods of fertilizer applications.

Soil fertilizty patterns, coupled with applied fertilizer factors, play an important role in obtaining maximum yields, but choice of variety, weed control and row spacing are considered by superior soybean producers as being more important. Choice of variety, then, may be made by growers who select a variety which yields well under high fertility levels in experimental plots without regard to the fertility levels of their own fields. Although some general principles exist, to prescribe production factors for producing maximum yields in a specific location is difficult because of the diverse environmental conditions involved. Agronomists must be aware of varietal differences, optimum levels of nutrients for different varieties and the tolerance levels of these varieties when fertility is either above or below the optimum for individual varieties.

The objectives of this study were to examine the conclusions of other investigators in relation to soil fertility parameters on soybean varieties grown in Michigan. Questions to be answered concerning the mineral nutrition of soybeans were:

1. To determine if any relationships exist between levels of added phosphorus, potassium and seed yield on a soil low in phosphorus and potassium.
2. To determine if varietal differences in yield response of soybeans result from soil and/or different levels of applied P and K.
3. Do varieties differ in concentrating P, K and other elements in their plant tissue at varying levels of P and K in the nutrient medium?
4. Are there varietal differences in seedling emergence to increments of P and K fertility.

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LITERATURE REVIEW

Soybeans probably originated in Southeast Asia and evolved as plants considered to be adaptive to soils low in fertility, characteristic of that region. Dunphy et al. (18) noted that the soybean crop in the United States is based on a rather narrow genetic base. Only about 30 genotypes or less than 1 percent of those in the collection of the United States Regional Soybean Laboratory appear in the ancestry of present day commercial varieties. Lack of responsiveness to high soil fertility then may be genetic and only a selective breeding program will result in isolines capable of responding to higher fertility regimes.

In the United States the principle early use of soybeans was as a forage crop used mainly for hay, silage, soilage and pasture for hogs and sheep (57). It was not until after 1941 that the acreage of soybeans grown for forage was surpassed by that grown for grain. Allen (2) found varietal differences in soybean lines concerning maximum forage yields with high levels of N, P, K, Mg, and Ca.

Some attention should be directed toward differential approaches of soil fertility factors affecting forage production and those affecting seed production of soybeans. Forage production is increased more by fertilization than is seed production (2) (45). Welch et al. (62), reported that higher dry matter amounts in the forage did not reflect higher seed yields. However seed yield increases have been shown to be less responsive to high fertility treatments as reported by Hanway and Weber (28) and Walsh and Hoeft (60). Also Bureau et al.

(10) showed soybean yields were slightly depressed at each phosphorus level where fertilizer phosphorus was applied.

Before investigating plant responses to selected nutrients it is of interest to consider total nutrient absorbtion by plants throughout the growing season for a basic understanding of the general nutritional requirements of a crop. Kalra and Sopra (38) investigating phosphorus absorbtion of rape, oats, soybeans and flax showed that soybeans absorbed about 3X more phosphorus in the last 60 days of growth than the other three crops. Phosphorus uptake in soybeans for approximately the first 40 days of growth exhibited a lag period during which absorbtion was comparatively low. This could be due to the fact that soybeans absorb the bulk of phosphorus late in the season after the root system is fully expanded.

Hammond et al. (25) reported that Richland soybeans yielding 43 bu/acre absorbed 184, 17, 56, 105, and 66 lbs. of N, P, K, Ca, and Mg per acre respectively. Hanway and Weber (27) and Harper (30) observed that the rates of nutrient and dry matter accumulation of soybeans increased prior to full bloom and then decreased to zero after the greenbean stage. The greatest uptake occurred between full bloom and mid pod fill with later growth stages revealing a decreased uptake of N, P and K, probably resulting from translocation of these nutrients from vegetative tissue to the developing seed. Later growth stages also revealed that Ca and Mg uptake either remained high or actually increased, indicating the immobility and continued requirements for these elements in seed production.

Henderson and Kamprath (31) reported that accumulation of nitrogen and phosphorus was not as rapid as dry matter accumulation for the first 110 days. Calcium accumulation was very similar to dry matter accumulation throughout the growing season with potassium accumulation being greater in the early growth stage. Magnesium accumulation was less than dry matter accumulation until late in the growing season when Mg uptake became more rapid.

Using tissue analysis, Walsh and Hoeft (60) reported that P concentrations in plant leaves rose markedly when P was banded, but that yields did not increase significantly. Nelson et al. (50) found that increasing K contents of plant tissue resulted in increased yields. Similar results were observed by Miller et al. (48) where an increase in yield was more closely related to an increase in K content than to P content of plant parts. Yield responses from added P were obtained only when K was adequate.

Although considerable research has been focused on the effect of fertilizers and soil fertility on soybeans, inconsistencies are found in the literature concerning studies with phosphorus and potassium. Hanway and Weber (27) and Johnson and Harris (36) reported that soybean yield responses from P and K were usually small and that high applications of K alone actually decreased yields. In contrast, Miller et al. (48) reported yields increased with an increase in applied K with or without added P while yield reductions were obtained when moderate to high rates of P were applied with little or no K. Maples and Keogh (45) however reported that P and K combinations showed no interaction between the effects of P and K. Response to each element was largely independent. Beacher and Crally (4) found low levels of K (40 lbs K_2O/acre) applications gave greater increases alone than low levels of P (20 lbs P_2O_5/acre), but higher yields were obtained with high level

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levels of P (80 lbs P_2O_5/acre) than with high levels of K (80 lbs K_2O/acre).

Several researchers have reported that increases in yield were greater for added K than P or other nutrients (40) (45) (60) (64). In rare instances such as reported by Anthony (3) and Boswell and Anderson (7), soybean yields did respond more to phosphorus than to potassium in Mississippi and Georgia. Such findings may be explained by the generally low levels of available K in soils of that area.

Generally yields are related more to soil P and K content than to fertilizer P and K (10) (11) (39) (59). Welch et al. (62) reported that when applications of 100 lbs P_2O_5/acre was banded, 28 percent of the phosphorus in the plant tissue came from the applied fertilizer on a soil low in available P while 19 percent of plant tissue P came from fertilizer P on a soil high in available P. This indicates that the available soil phosphorus is a very important source of phosphorus for soybeans. Bureau et al. (10) stated that the increase in the level of soil phosphorus coupled with applications of phosphatic fertilizers resulted in an apparent depressing effect on soybean yields. Walsh and Hoeft (60) however observed that banded K along with increasing soil test K improved yields significantly.

Different crops vary greatly in their ability to utilize added fertilizers. Kalra and Sopra (38) noted that soybeans were much more efficient in utilizing soil P than rape, oats or flax while the latter three were much more efficient in uptake of fertilizer P. Krantz et al. (42) also concluded that soybeans absorbed the least amount of fertilizer P compared to corn, cotton and potatoes with corn and soybeans absorbing the bulk of P late in the season. This might be expected since P_2O_5 in this study was placed in a band 7.5cm to the side of the seeds. Soybeans have a tap root system whereas corn has a secondary completely fibrous system. It appears more likely that corn roots would be more in contact with the banded P at the side than soybeans. Rouse (56) reported results from field experiments in which P build up and depletion with soybean grain was comparable to cotton and corn for grain, while potassium removal by soybean seeds was greater than either corn or cotton.

It is interesting to note that the available literature on nutrient utilization does not mention facts concerning the relationship between the concentration of roots in the fertilizer zone. Root concentrations and morphological structures in the fertilizer band may influence nutrient uptake. In a study of the mechanism of nutrient uptake by soybeans, Oliver and Barber (52) found that root interception was the main mechanism for the supply of Ca, Cu, Al and Sr; mass flow was most important for B and diffusion was the principle mechanism for K, Mn, Fe and Zn uptake.

The synergistic relationships and interactions between P, K and other plant nutrients have the focus of many investigations (1) (5) (19) (21) (24) (26) (29) (34) (35) (37) (41) (42) (47) (53) (61) (63). Hutchings (34) summed up the complexity of nutrient interactions by stating "The effects of P on growth, nodulation and composition of soybeans are significantly dependent on the effects of other and essential and commonly deficient nutrients."

Zinc deficiencies on soybeans at high P levels were observed by Paulsen and Rotimi (53). They suggested that the origin of the P effect on zinc uptake appeared to be in the roots. P apparently slows translocation of Zn from roots to plant tops. Miller et al. (47) reported the possible mechanism involved in Fe chlorosis may involve cytochrome oxidase, an Fe enzyme which is affected by bicarbonate acting on metabolism. Bicarbonate in nutrient solution cultures increases the soluble P in solution which in turn induces Fe chlorosis more than the bicarbonate concentrations.

Complementary relationships were observed under field conditions among K, Ca and Mg at the pod filling stage for soybeans (41). Mg and Ca content increased when Ca was absent while Ca and K increased when Mg was not present. Generally the effect of nutrient deficiencies appeared directly as decreased changes in weight and numbers of seeds but the effect on chemical composition was negligible. Hanway and Weber (29) observed that P and K fertilizer treatments on nodulating soybean isolines had little effect on N concentration in plant parts while N applications generally decreased P levels in plant parts. K additions had little or no effect on P accumulation or K increases in the seeds. deMooy and Pesek (15) observed that when K or Ca was applied with P, phosphorus toxicity symptoms were less severe and when all three elements were applied, leaf symptoms did not develop. Ca is relatively immobile in plants and therefore necessitates a constant supply in the external environment to reduce P toxicity symptoms throughout the life of the plant.

Soybeans have been shown to exhibit toxicity symptoms at low levels of boron. Oertli and Roth (51) reported B toxicity symptoms appeared in soybeans with concentrations in solution of 2 ppm. Potassium seemed to be the element most responsible for reducing the B content of the soybean plant. Woodruff et al. (63) found that applications of 2 lb. of B per acre would prevent high rates of K_2O (in excess of 280 lb/acre) from depressing Ca and Mg uptake. It appeared that the adverse effects upon plant growth and the uptake of Ca and Mg when large amounts of K were added was associated with the absense of suitable amounts of B in the plant system. The opposite has been observed for high rates of P by Weber and Caldwell (61). Chlorotic plants growing in the presense of levels of P contained considerably more B than the control plants. Also, Ca content was higher and Mg, P and Fe concentrations were twice that of the control plants.

Fellers (20) reported a 150 percent increase in soybean nodulation from liming and phosphorus applications. Boswell and Anderson (7), Hutchings (34) and Martini et al. (46) found that Ca significantly contributes to the efficiency of P in the early growth of the plant. P responses were obtained only after the Ca requirements were fulfilled. Fletcher and Kurtz (23) also reported a significant increase in nodulation from P applications. It appears that the application of Ca has a synergistic effect resulting in the growth of nodule forming bacteria on soybean roots and the release of soil P which in turn aids in nodule formation.

Varietal Differences

Differential abilities to uptake nutrients have frequently been noted within different varieties of common crop species. Early work by Lyness (44) in 1936 revealed varietal differences within twenty-one imbred lines and hybrids of corn to N, P, K, and Ca. Also noted were close correlations between yield response to phosphorus and the number and characteristics of secondary roots. Morphological dif

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differences involving increased root:top ratios in the high phosphorus absorbing capacity varieties may have been genetic in nature and responsible for different uptake capacities.

Differential responses to fertility have been studied extensively in soybeans. In 1943, Allen (2) reported varietal differences in forage yields of Morse and Virginia soybeans to N, P, K, Mg and Ca levels of fertility. Howell (32) was one of the first investigators to report varietal differences in response to P over a wide range of phosphorus treatments. The cultivar 'Chief' classifed as P-tolerant increased in yield with up to 112 ppm P in nutrient solution while the 'Lincoln' cultivar classified as P-sensitive decreased in yield at greater than 50 ppm P in solution. Howell and Bernard (33), classified 44 soybean varieties to P sensitivity and found 23 lines tolerant, 8 slightly sensitive, 5 intermediate, 4 sensitive and 4 very sensitive.

Differential responses to P fertility were also confirmed by other investigators (6) (22) (23). Fletcher and Kurtz (23), also noted that the number of nodules on the P-sensitive 'Lincoln' cultivar were reduced more than on P-tolerant 'Chief.' Percent P and K in plant tissue also increased more in 'Lincoln' than in 'Chief' as P additions increased. Outdoor pot experiments by deMooy and Pesek (14), also revealed significant varietal differences in nodule fresh weight due to phosphorus fertilization of 400-500 pp2m P and 600-800 pp2m K. Foote and Howell (22), reported that varietal differences in response to P are determined by the roots. When 'Lincoln' shoots were grafted onto 'Chief' roots and vice-versa the sensitivity response was determined by the root. The ability to respond then must be controlled genetically in the soybean roots ability to absorb and utilize nutrients.

Bernard and Howell (6), confirmed the existence of a major gene pair NPnp responsible for significant differences in reaction to phosphorus. Dunphy et al. (18), field tested 75 cultivars of soybeans using either no P and K or high rates of P and K granular fertilizer. Larger responses to fertility occurred more often among the higher yielding genotypes than the lower yielding genotypes. Exceptions to these findings have also been reported in the literature. Caviness and Hardy (12), reported inconsistencies in genetic line X fertilizer interaction for six cultivars of soybeans over a six year period. Similar results were reported by Miller et al. (49) with 'Harosoy,' 'Chippewa' and 'Hawkeye' cultivars showing inconsistencies to P and K fertilizer. 'Harosoy' showed a reduction in yield with high P but responded very positively to high K. Nelson et al. (50), however observed no significant varietal differences with respect to K, but observed highly significant differences between varieties in response to applications of Mg.

Hanway and Weber (27) observed that dry matter yields and the N, P and K percentages in plant tissue of 8 varieties of soybeans were consistently similar. Studies by deMooy and Pesek (17), involving four cultivars of soybeans grown at two field locations revealed that 'Chippewa' differed significantly from the other varieties in response to K levels, and varied significantly from 'Harosoy' with respect to P levels and that 'Harosoy' yielded higher than the other varieties at all fertility combinations. In a pot experiment grown in the open, deMooy and Pesek (16), observed varietal differences in seed yield from P and P X Ca with the strongest differential response in P uptake occurring at the end of flowering.

Genotypic variability of soybean roots in their reductive capacity of nutrient elements has been investigated by several workers. Paulsen and Rotimi (53) reported that detrimental effects of P were overcome by zinc additions in P-tolerant 'Chief' but not in P-sensitive 'Lincoln.' P apparently slows translocation of Zn in the root to plant parts. Walker and Schillinger (58), studied genotypic response to K and suggested that differential yield responses may be related to the potential of the roots to absorb potassium.

METHODS AND MATERIALS

Greenhouse and field experiments were conducted to study the effects of soil phosphorus and potassium levels on dry matter yield, seed yield and concentration of these and other nutrients in plant tissues.

Greenhouse Experiment 1976

A completely randomized design was employed with four replications including factorial components of ten varieties and three levels each of P and K fertility. Soil was obtained from the top 20 cm of an Alcona sandy loam. Before potting, soil was ground but not fumigated since soybeans were not grown on the soil five years prior to the experiment and incidence of soybean disease organisms was considered negligible. Six composite soil samples were taken after grinding and soil analysis was performed by the Michigan State University Soil Testing Laboratory. The soil used in the experiment tested 17 pp2m P and 80 pp2m K with a pH of 7.2 and was used as the low treatment level (check). Phosphorus was applied as monocalcium phosphate $Ca(H_2PO_4)$. H_2O, and potassium was applied as potassium chloride KCl. The following P and K treatments were employed:

a. Medium P applied at 21.5 pp2m

b. High P applied at 43.0 pp2m

c. Medium K applied at 80.0 pp2m

d. High K applied at 160.0 pp2m

P and K were applied separately to determine the individual effects and in combination to determine interaction between the two elements. Nutrients for each treatment were dissolved in 150 ml of water which was then thoroughly mixed with 0.9076 Kg of soil in each pot. Eight seeds each of ten soybean varieties, representative of Maturity Groups 0, I and II grown in Michigan were placed in separate pots on top of the soil-nutrient mixture and 4 cm of soil was placed over the seed. Seeds were inoculated using the slurry method. Ten days after planting, plants were thinned to four plants per pot to reduce interplant competition. A favorable soil moisture level was maintained with deionized water and the temperature was maintained at 22°C. Since soybeans are highly responsive to short days the photoperiod was kept at 16 hours per day to assure vegetative growth only.

Plants were harvested six weeks from planting just prior to the time in which flowering would occur. Plant tops were removed at the soil level from the roots which were then carefully removed from the soil by washing with water. Tops and roots were dried at 70°C for 48 hours and weighed and recorded separately. Composite samples of dried tops were ground in a laboratory mill using a 50-mesh screen. Samples were then sent to International Minerals and Chemical Corporation, Libertyville, Illinois for plant tissue analysis. Dry weights of tops and roots were statistically analyzed using the analysis of unweighted means and means were compared using the LSD method.

Field Experiment 1976

A split plot design was employed with factorial components consisting of ten varieties, three levels of P and K and three replications.

Fertility levels were main plots with varieties representing the subplots. Field studies were conducted in Eaton County, Michigan on a well drained Celina loam soil. The previous crop was wheat with a volunteer crop of red clover and a dense growth of quackgrass. One week prior to plowing, the field was sprayed with 1.9 liters of Roundup herbicide to control quackgrass. Plowing to a depth of 23 cm was followed by one discing. The seed bed was in excellent physical condition with adequate soil moisture content. Six composite soil samples were taken from the experimental area for analysis. The soil had a pH of 6.5 and tested 13 pp2m P and 80 pp2m K.

The varieties used were the same as in the greenhouse so that the field data could be compared with the greenhouse data. The three phosphorus levels were 0, 25, and 50 lbs/acre (0, 28 and 56 kg/ha). Potassium levels were 0, 88 and 176 lbs/acre (0, 109 and 218 kg/ha). Each field plot consisted of four 76 cm rows, 6 meters long with 1.2 meter alley ways between tiers of plots. All plots were planted June 3rd. Soybean seeds were planted at a depth of 3.8 cm with 180 seeds per 6 meter row. Seeds were inoculated just prior to planting. Fertilizer applications were applied 10 cm to the side of the row and 5 cm below the seeding depth. Weed control consisted of a preemergence application of Lasso and Lorox herbicides with one cultivation and hand weeding during the growing season.

Before harvest the two middle rows were hand trimmed to 4.8 meters to assure uniform plot length. The outside rows were used as borders to eliminate possible effects of fertility and plant heights of adjacent plots. Mature plants from a random 30 cm section of each plot of one replication were harvested to collect data on number of pods, seed set and seed size (expressed as weight per 100 seeds). The two center rows were machine harvested September 29th. Harvested seed samples were oven dried to 5 percent moisture, weights in grams per plot were recorded and yields in kg/ha were recorded at 13 percent moisture. Seed yields were statistically analyzed using standard analysis of variance techniques and means compared using the LSD method. Statistical analysis for number of pods, seed set and seed weights were not performed as the data was taken from one sample.

RESULTS AND DISCUSSION

Greenhouse Study

Emergence

The influence of P and K fertility on the emergence of soybeans when placed in direct contact with the soil fertilizer mixture is shown in Table 1. Data of emergence was made on combined replicates. The data in Table 1 reveal a reduction in rate of emergence of soybean seedlings when placed in contact with the soil-fertilizer mixture and that the rate of emergence was generally proportional to the rate of fertilizer used. Potassium fertilizer did not inhibit emergence as much as phosphorus fertilizer as the average high phosphorus treatments reduced emergence 35 percent more than the average high potassium treatments. Cumulative effects on emergence and rate of emergence were observed when P and K were combined especially at the high levels. Probst (54) also observed similar results of delayed emergence due to P and K fertility combinations. However, potassium alone delayed emergence more than phosphorus applied alone on soybean emergence trials in his experiment in 1944. The varieties used in this early experiment may have been from different soybean lines whereas most of the present studies involve lines that are more sensitive to P than K (6) (10) (12) (13) (15) (18) (22) (23) (27) (33).

Although emergence was generally slower at the high fertility rates eight days after planting, the V3-V5 leaf stage showed plants were accelerated more due to fertility as compared to the check.

Table 1. Percent emergence of nine soybean varieties at various growth stages as affected by soil fertility in greenhouse pots

Growth stages	P and K levels								
	LL*	LM	LH	ML	MM	MH	HL	HM	HH
8 days	77	66	58	47	33	16	22	11	16
VI leaf stage	80	83	58	58	38	16	22	11	16
V2 leaf stage	100	83	77	77	50	52	41	33	27
V3-V5 leaf stage	100	100	94	91	86	77	86	77	58
$\overline{X}$	89	86	72	68	52	40	43	33	27

$\overline{X}$ Low-P	$\overline{X}$ Med-P	$\overline{X}$ High-P	$\overline{X}$ Low-K	$\overline{X}$ Med-K	$\overline{X}$ High-K
82	53	34	67	57	46

*Fertility symbols for this and all following tables.

First letter denotes phosphorus (P).

Second letter denotes potassium (K).

'L' denotes low fertility (check).

'M' denotes medium fertility.

'H' denotes high fertility.

Table 1 shows that the increase in the percent emergence from the 8 day stage to the V3-V5 leaf stage of growth was 23 percentage points for the LL (check) treatment compared to 64 percentage points for the HL treatment. It appears that the reduced rate of emergence from added fertilizer P and K was overcome after emergence by a faster rate of growth as compared to the no fertility treatments.

Apparent differences between soybean varieties could not be distinguished. However, the variety Hark revealed poor germination at all treatment levels and was discarded. The Hark seed was obtained from one year old stock as new seed was not available. Other investigators and growers have since confirmed the poor germination trait of Hark seed that is kept longer than 8 months from harvest. The variety Corsoy seemed to be affected the least by high applications of P and K fertility. Rates of emergence were comparatively equal for all treatment levels. Corsoy consistently yields very high in Michigan and may be better adapted to high levels of fertility and thus be more efficient in nutrient utilization. The other varieties in this study demonstrated less tolerance to high nutrient levels, resulting in slower rates of emergence, and therefore may be less efficient in nutrient utilization.

Soybean leaf chlorosis from fertilization could not be revealed for any of the varieties as reported by other investigators (16) (22) (32). Symptoms of leaf chlorosis were observed by deMooy and Pesek (15), from rates of P at 600 pp2m and from P and K combinations at 600 pp2m and 800 pp2m, respectively. When either P or K was greater than 400 pp2m, leaf chlorosis could not be found. In this study, the high rates of P and K were 43 pp2m and 160 pp2m respectively, which may explain why no visual symptoms were found.

Dry Weight Yields

The analysis of variance for the greenhouse study is shown in Tables 2-4 for top, root and total plant dry weights. Dry weights of tops and roots were recorded separately to determine fertility treatment effects of P and K on top:root ratios. The variety and phosphorus x potassium interaction effects for dry weight of tops, roots and total, plant were all significant at the 1 percent probability level. The phosphorus treatment effect on root dry weights was significant at the 5 percent probability level. Although the differences between varieties were highly significant, total dry matter weight cannot be used as an indicator of seed yields according to many investigators. Welch et al. (62), observed that higher dry matter accumulations by soybeans did not reflect higher seed yields. Therefore, the major focus of discussion will be on the responses of soybeans to incremental changes in applied P and K fertility.

The variety differences in dry weights and percent top of total plant are presented in Table 5. It is of interest to note that the varieties Hodgson and Corsoy which have consistently yielded well in Michigan State University yield trials have a smaller top:root ratio, 1.59:1 and 1.47:1 respectively, as compared to an average of 1.75:1 for the remaining varieties. This may be a genetically controlled factor, producing a morphological difference between varieties, allowing the larger root system of Corsoy and Hodgson to be more effective in nutrient and water uptake.

Table 2. Analysis of variance for top dry weight obtained in the Greenhouse, Michigan State University, 1976

Source	df	Mean square	F
Variety	8	.037701	13.04**
P	2	.001803	0.602
Variety x P	16	.003987	1.37
K	2	.002653	0.916
Variety x K	16	.001862	0.643
P x K	4	.013419	4.63**
Variety x P x K	32	.002666	0.920
Error	80	.002895	

**Denotes significance at the 1 percent probability level.

Table 3. Analysis of variance for root dry weight obtained in the Greenhouse, Michigan State University, 1976

Source	df	Mean square	F
Variety	8	.013952	6.66**
P	2	.007451	3.56*
Variety x P	16	.003441	1.64
K	2	.001639	0.782
Variety x K	16	.001322	0.631
P x K	4	.014347	6.85**
Variety x P x K	32	.001882	0.890
Error	80	.002093	

*Denotes significance at the 1 percent probability level.

**Denotes significance at the 5 percent probability level.

Table 4. Analysis of variance for total plant dry weight obtained in the Greenhouse, Michigan State University, 1976

Source	df	Mean square	F
Variety	8	.092121	10.77**
P	2	.016273	1.90
Variety x P	16	.012795	1.49
K	2	.008383	0.98
Variety x K	16	.005478	0.64
P x K	4	.054903	6.42**
Variety x P x K	32	.007710	0.90
Error	80	.008546	

**Denotes significance at the 1 percent probability level

Table 5. Dry weight of tops, roots and total (gms/plant) for soybean varieties averaged over all P and K fertility

Variety	Plant parts				
	Top	Root	Total	Percent top of total	Top:Root
Swift	.524	.311	.836	63	1.68:1
Evans	.524	.300	.825	64	1.75:1
Steele	.541	.302	.844	64	1.79:1
SRF 150	.462	.284	.747	62	1.63:1
Hodgson	.614	.386	1.001	61	1.59:1
Amsoy 71	.532	.314	.847	63	1.69:1
Beeson	.662	.385	1.047	63	1.72:1
Corsoy	.487	.332	.820	59	1.47:1
SRF 200	.476	.281	.758	63	1.69:1

The data presented in Table 6 reveal that total dry matter accumulation was slightly reduced; 5.5 percent for medium phosphorus applications and 2.5 percent for high phosphorus applications, for all varieties averaged over all treatment levels as compared to the check. The effect of fertilizer P applications at the medium rate may have inhibited the soil P from being absorbed while the high P rate resulted in enough fertilizer P to overcome the soil P inhibition. Perhaps the residual soil P in the check treatment was more readily available for uptake, and plant metabolism may have been affected by higher concentrations in the root zone. The medium and high rates of P applications also increased the top:root ratio to 1.68:1 as compared to 1.60:1 for the check treatment. The smaller root ratios seemed to result in a general reduction in the total plant dry weight. Bureau et al. (10), observed similar effects on reduction of dry matter yields of soybeans from phosphatic fertilizer applications.

Potassium applications affecting dry matter yields were found to be statistically insignificant as shown in Tables 2-4. The medium K application was comparable to the check while a 4 percent increase in total plant dry weight yield resulted from the high K application as compared to the check as seen in Table 7. The medium and high K applications both resulted in top:root ratios of 1.65:1 as compared to 1.68:1 for the check. The resultant increase in root ratio contributed to a general increase in the total plant dry weight.

The phosphorus x potassium data on plant dry weights as shown in Table 8 reveal that an interaction is present. There was a tendency for the higher K treatments to increase dry weights when P applications were at the high level. With P held at the high rate increasing K from

Table 6. Effects of phosphorus level on dry weight accumulation of soybean plants averaged over all varieties and potassium levels

Treatment (P)	Top	Root	Total	Percent top of total plant
	(Average per plant dry weight in gms)			
Low	.542	.339	.882	61
Medium	.527	.305	.833	63
High	.536	.321	.860	63

Table 7. Effects of potassium level on dry weight accumulation of soybean plants averaged over all varieties and phosphorus levels

Treatment (K)	Top	Root	Total	Percent top of total plant
	(Average per plant dry weight in gms)			
Low	.531	.317	.848	63
Medium	.529	.318	.848	62
High	.547	.331	.879	62

Table 8. Effects of phosphorus x potassium on plant dry weight and percent top to total plant averaged over all varieties

Plant part	P and K levels								
	LL	LM	LH	ML	MM	MH	HL	HM	HH
	gms								
Top	.540	.528	.560	.550	.539	.492	.503	.523	.590
Root	.340	.333	.342	.332	.310	.274	.279	.310	.377
Total	.881	.861	.903	.882	.849	.767	.782	.833	.966
Percent top	61	61	62	62	63	64	64	63	61

$LSD_{.05}$ Top - .050

$LSD_{.05}$ Root - .042

$LSD_{.05}$ Total - .086

low to medium resulted in an increase of 6.5 percent in total dry weight (from 0.782 to 0.833 gm/plant) and increasing K from medium to high resulted in an increase of 16 percent in total dry weight (from 0.833 to 0.966 gm/plant). Miller, et al. (48), observed similar results in that yield response at high P applications were obtained only when K was adequate. Table 8 also shows that increasing K levels resulted in decreases in both roots and tops when P was held at the medium level. Decreases in plant dry weights from P applications were observed by deMooy and Pesek (15) with P x K treatments when less than 400 lb K/acre was applied. Table 8 also shows that high K applied at low P levels resulted in dry weight yields 13 percent larger than when high P was applied alone at low K. High K fertilization appeared to be most effective at either low or high levels of P.

The variety x phosphorus and variety x potassium interactions revealed inconsistencies in the total plant dry weights as shown in Table 9 and 10. Although P treatments did not consistently increase or decrease dry weights, all varieties except Corsoy had reductions in total plant dry weights at the medium P application as compared to the check. Amsoy 71 and SRF 200 also showed further dry weight decreases at the high P rate as compared to the medium rate while the other varieties increased dry weights more at high P than medium P.

The variety x potassium interaction shown in Table 10 reveals general increases in dry weight from high K applications for Swift, Evans, SRF 150, Hodgson and Beeson when compared to the check. Small decreases in dry weights from high K applications were noted for Steele, Corsoy and SRF 200 when compared to the check. When decreases in dry weights were noted for P or K when applied alone, the magnitude

Table 9. Effects of P on total plant dry weight and percent top of total plant averaged over all K treatments

Variety	Phosphorus treatments					
	Low P		Medium P		High P	
	gms/plant	percent top	gms/plant	percent top	gms/plant	percent top
Swift	.915	64	.719	65	.874	60
Evans	.787	62	.751	66	.926	64
Steele	.828	63	.815	67	.890	63
SRF 150	.765	62	.703	62	.773	61
Hodgson	1.106	59	.939	63	.958	63
Amsoy 71	.911	61	.851	64	.769	65
Beeson	1.032	64	1.053	63	1.057	63
Corsoy	.800	57	.860	59	.800	62
SRF 200	.792	62	.786	63	.697	63

Table 10. Effects of K on total plant dry weights and percent top of total plant averaged over all P treatments

Variety	Potassium treatments					
	Low K		Medium K		High K	
	gms/plant	percent top	gms/plant	percent top	gms/plant	percent top
Swift	.818	64	.849	62	.841	62
Evans	.776	65	.802	63	.897	62
Steele	.860	64	.860	64	.812	64
SRF 150	.739	62	.774	60	.758	62
Hodgson	.978	61	.946	62	1.078	62
Amsoy 71	.843	64	.858	61	.840	64
Beeson	1974	63	1.084	64	1.084	63
Corsoy	.854	59	.781	59	.825	60
SRF 200	.794	62	.708	64	.773	63

of decreases tended to be less for K applications than for the P applications.

The differences in top:root ratios showed correlations to incremental changes in P and K treatments. Figure 1 and 2 and Tables 9 and 10 reveal the effect of incremental treatment changes of P and K treatments on plant dry weights and the percent top of the total plant weight. Decreases in percent tops of 2,1 and 1.5 percent were recorded for the varieties Swift, SRF 150 and Beeson respectively while varieties Evans, Steele, Hodgson, Amsoy 71, Corsoy and SRF 200 revealed increases in percent top of 4.5, 3, 6.5, 5.5, 6 and 1.5 percent respectively due to average P treaments (medium P and high P) as compared to the check. The direct effect of P on reducing root growth may in part be explained by a statement concerning P toxicity of soybeans be deMooy and Pesek (15), as follows: "The direct effects of P may be associated with pathogens; secretion of toxic substances by bacteria due to phosphorus which in turn affects root growth."

The changes in the percent top for the medium K and high K averages, as compared to the check, revealed varieties Swift, Evans, SRF 150 and Amsoy 71 decreasing their percent top by 3, 4, 1.5, and 2 percent respectively, while varieties, Hodgson, Beeson, Corsoy and SRF 200 had increases in top growth of 1, 1, 1, 2.5 percent respectively. These data may suggest that the increase in the percent top may be affected more by P applications for the majority of varieties tested than by K applications, resulting in a smaller root volume which would in turn affect nutrient uptake.

Dry weights of all varieties did not respond in the same direction or magnitude at the various combinations of P and K.

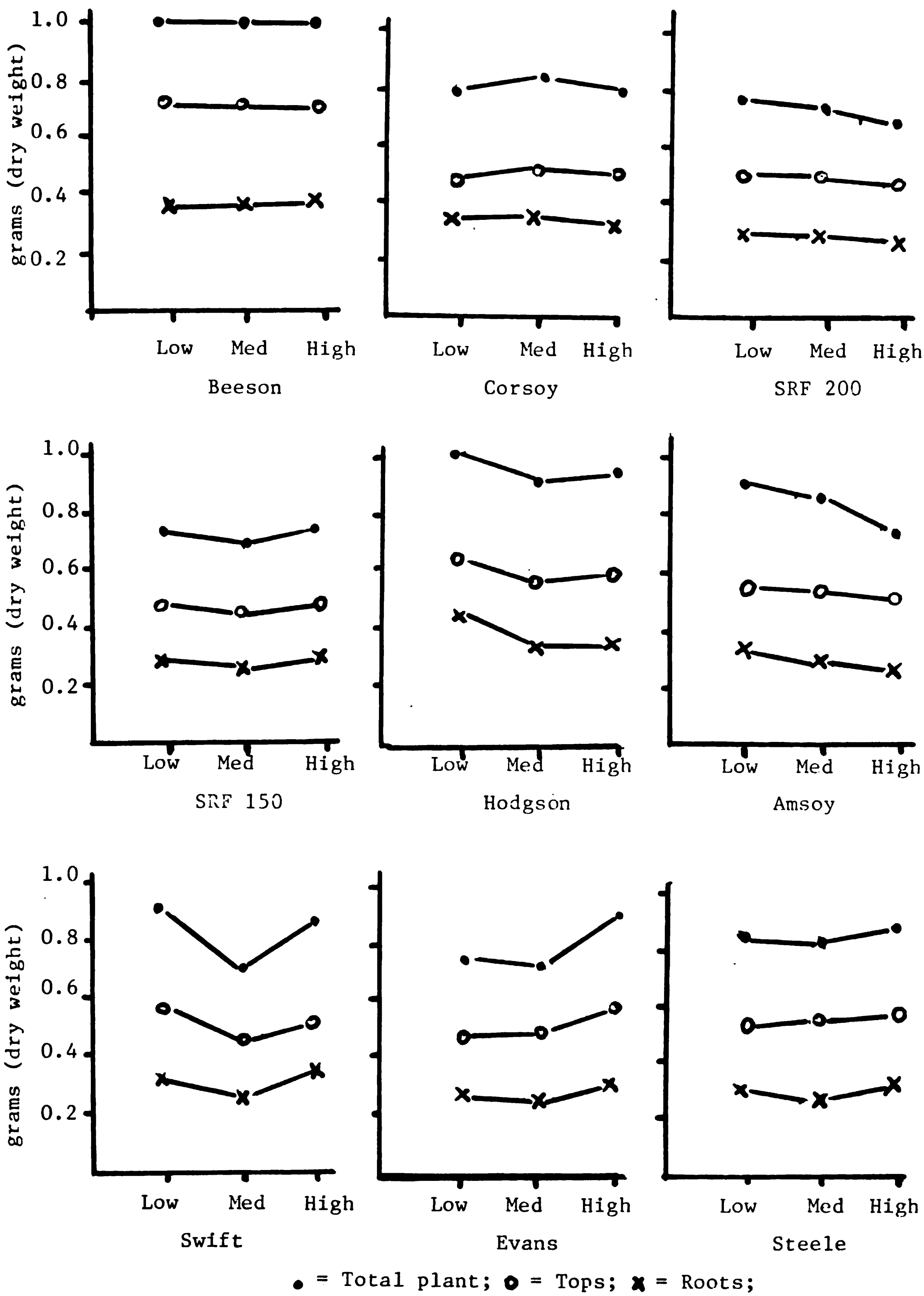
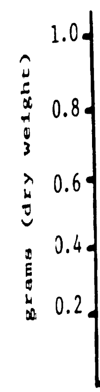
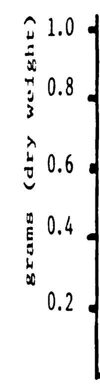


Figure 1. Effect of phosphorous level on the yield of roots, top and total plants averaged over three levels of potassium for nine soybean varieties


grams (dry weight)
1.0
0.8
0.6
0.4
0.2


grams (dry weight)
1.0
0.8
0.6
0.4
0.2

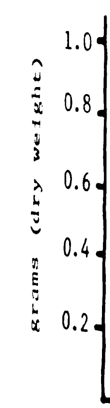

grams (dry weight)
1.0
0.8
0.6
0.4
0.2

Figure 2.

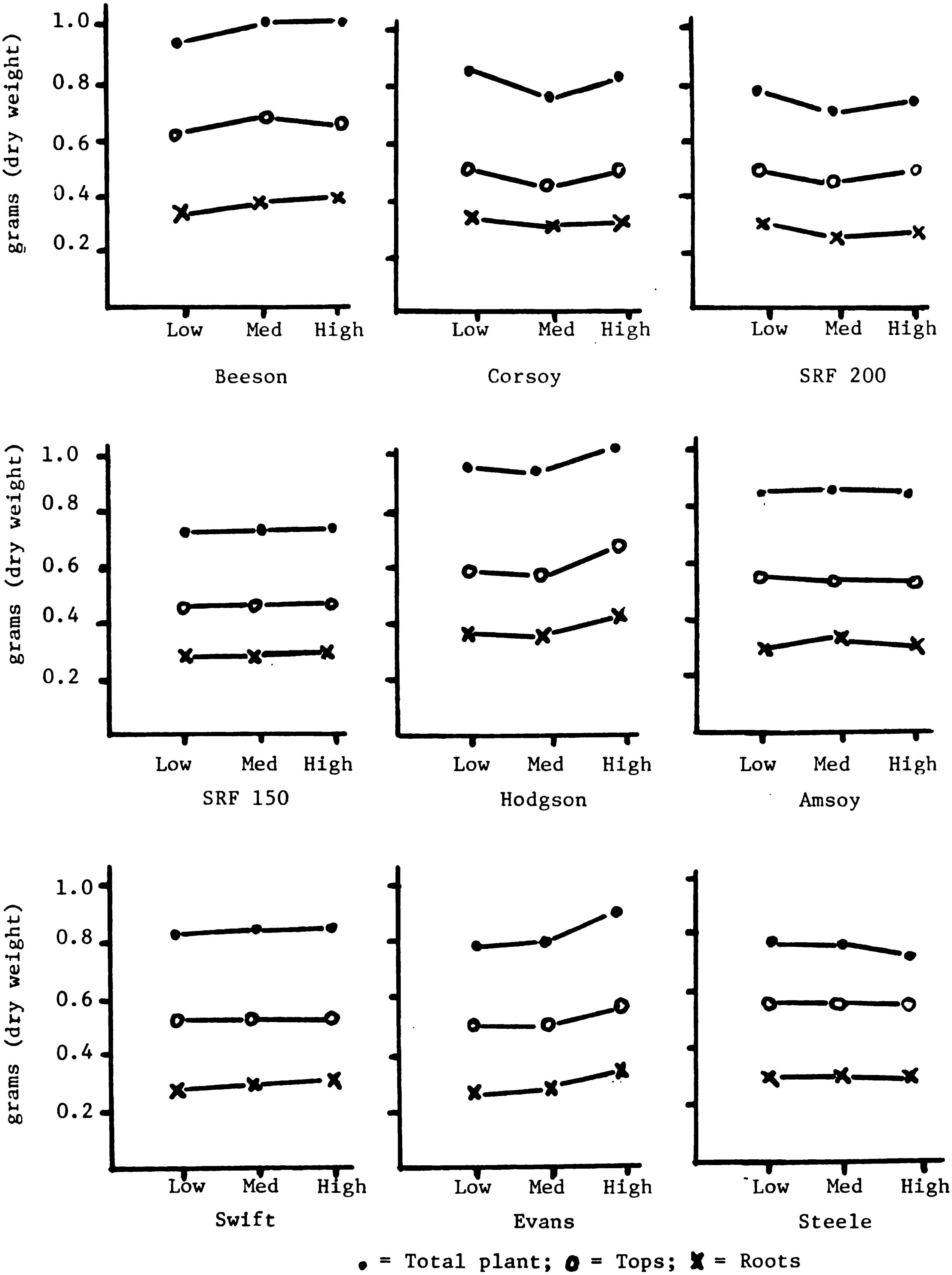


Figure 2. Effect of potassium level on the yields of roots,top and total plants averaged over three levels of phosphorous for 9 soybean varieties.

Figures 3 and 4 show varieties Steele and SRF 200 having reduced plant heights from medium and high applications of K as compared to the check. Average reductions in dry weights for both varieties for the total plant were 8 percent from low to medium K, 7 percent from medium to high K and 15 percent from the low to high K treatments as shown in Table 11. Reiss and Sherwood (55) also observed reductions in dry weight yields of soybeans when K was applied alone. However, Figure 4 shows increases in plant height due to incremental increases in K fertility for the variety Beeson. Table 11 reveals that Beeson had an increase of 28 percent in the total plant dry weight from the check to the high K treatment. Table 11 also reveals that the check levels of fertility produced total plant dry weights which were as high or higher than the majority of treatments for Evans, Steele, SRF 150, Hodgson, Beeson and SRF 200.

It was not possible to relate the dry weight characteristics to the differential P x K responses and the percent top to total plant for all varieties because of inconsistencies within varieties, but general trends were noted for some varieties. The results presented in Figure 5 show the balanced nutrient effects of P and K on plant heights for the variety Beeson for the check and for the medium and high application rates. These effects may be attributed more to K than to P. The results presented in Table 11 and Figure 5 also show the correlation of increased plant height with increased dry weights. Total plant dry weights were 0.977, 1.246 and 1.250 grams for the low P-low K, medium P-medium K and high P-high K treatments, respectively for Beeson and .855, .796 and .805 grams for Corsoy. The K application also decreased the percent top to total plant by

Figure

Figure 3. Plant height as affected by increasing levels of potassium applications on Steele soybeans at the low level of phosphorus.

Figure 4. Effect of increasing levels of potassium on plant height between varieties SRF 200 and Beeson soybeans at the low level of P.

Table 11.

Variety	Pl pa
Swift	To
	Re
	To
	%
Evans	T
	Re
	To
	%
Steele	To
	Re
	To
	%
SRF 150	To
	Re
	To
	%
Hodgson	To
	Re
	T
	%
Amsoy71	T
	R
	T
	%
Beeson	T
	R
	T
	%
Corsoy	T
	R
	T
	%
SRF 200	To
	Ro
	To
	%

Table 11. Dry weights and the percent top of total plant for all soybean varieties and all P and K fertility combinations.

Variety	Plant part	P and K levels								
		LL	LM	LH	ML	MM	MH	HL	HM	HH
		gms								
Swift	Top	.560	.577	.630	.562	.505	.330	.455	.530	.600
	Root	.320	.315	.365	.312	.287	.160	.255	.353	.440
	Total	.880	.872	.995	.895	.782	.490	.700	.883	1.040
	% top	64	64	64	64	64	67	64	60	58
Evans	Top	.520	.422	.503	.485	.480	.516	.516	.600	.650
	Root	.290	.275	.333	.280	.253	.270	.236	.350	.420
	Total	.810	.717	.836	.765	.733	.786	.753	.956	1.070
	% top	64	62	60	63	65	66	66	63	61
Steele	Top	.577	.520	.465	.547	.537	.545	.530	.603	.552
	Root	.320	.322	.280	.287	.252	.275	.320	.346	.320
	Total	.897	.842	.745	.835	.790	.820	.850	.950	.872
	% top	64	62	62	66	68	66	62	63	63
SRF 150	Top	.472	.482	.482	.465	.443	.407	.433	.463	.516
	Root	.257	.307	.292	.310	.246	.237	.280	.280	.338
	Total	.730	.780	.775	.775	.690	.645	.713	.713	.854
	% top	65	61	62	60	64	63	61	61	60
Hodgson	Top	.642	.570	.750	.620	.622	.526	.522	.556	.720
	Root	.450	.405	.503	.402	.330	.316	.300	.356	.420
	Total	1.092	.975	1.253	1.022	.952	.843	.822	.913	1.140
	% top	59	58	60	61	65	62	64	61	63
Amsoy71	Top	.517	.585	.555	.590	.500	.545	.516	.486	.502
	Root	.357	.390	.330	.292	.340	.317	.256	.273	.272
	Total	.875	.975	.885	.882	.840	.862	.773	.760	.775
	% top	59	60	63	67	60	63	67	64	65
Beeson	Top	.607	.655	.715	.620	.776	.600	.620	.645	.720
	Root	.370	.365	.385	.390	.470	.303	.315	.342	.530
	Total	.977	1.020	1.100	1.010	1.246	.903	.935	.987	1.250
	% top	62	64	65	61	62	66	66	65	58
Corsoy	Top	.455	.455	.462	.567	.480	.482	.490	.447	.550
	Root	.366	.335	.332	.417	.336	.305	.272	.297	.345
	Total	.815	.790	.795	.985	.810	.787	.762	.745	.895
	% top	56	58	58	58	59	61	64	60	61
SRF 200	Top	.515	.485	.482	.495	.506	.480	.455	.370	.500
	Root	.340	.290	.265	.300	.290	.285	.277	.185	.305
	Total	.855	.715	.747	.795	.796	.767	.732	.555	.805
	% top	60	63	65	62	64	63	62	67	62

Figure 5. Plant height as affected by P x K fertility treatments at low, medium and high rates on Beeson soybeans.

12 percent in the high P high K treatment as compared to the high P low K treatment for Beeson.

Potassium applications applied at medium and high rates without P resulted in average total plant dry weight yield reductions of 15 percent over the check treatment for the variety SRF 200 as shown in Table 11. When K was in balance with P at low, medium and high K treatment combinations, dry weight yields increased by an average of 10 percent compared to the average of the six imbalanced treatments for SRF 200. Also for SRF 200, the average percent top for the three balanced combinations decreased 3 percent when compared to the six imbalanced combinations. Table 11 also reveals that the varieties Swift, Evans, Steele, SRF 150, Hodgson and Corsoy had higher average total plant dry weights of 12, 9, 2, 3, 9, and 4 percent respectively, at the three balanced treatment combinations as compared to the six imbalanced treatment combinations. Changes of percent top to total plant weight were either small or inconsistent for these varieties.

Tissue Analysis

Statistical analysis was not performed since the plant tissue data were obtained from composite samples of combined replicates. Due to changes in P and K content with dry weight yield, phosphorus and potassium content could not be used as an indicator for plant dry weight responsiveness. Table A1 and A2 of the appendix reveal no correlation between the varieties or treatment levels and average dry weight yield responses due to the K:P ratio.

Figure 6 and Table A3 of the appendix reveals average concentrations of P for each level of K application averaged over all soybean varieties. Phosphorus treatments increased P concentration in the plant tissue 37 percent from low to medium P and 12 percent from low to high P. Potassium, however, reduced P content 7.5 percent at the average high P rate as compared to the check level of P. This reduction may have been caused by a dilution effect. Figure 7 and Table A3 of the appendix shows that the application of P had no apparent effect on K concentration in plant tissue. However, K fertility applications increased K concentrations by 62 and 97 percent at the medium and high rates respectively, averaged over all levels of P as compared to the average low K level. Concentrations of P and K compared between balanced and imbalanced fertility rate applications showed no apparent differences.

Potassium fertility applications resulted in a decreased concentration of Ca and Mg as shown in Figure 8 and 9 and Table A3 of the appendix. Reductions of 7 and 11 percent occurred in the level of Ca in plant tissue from the average medium and high K applications, respectively, as compared to the average low K level. Reductions of 27 and 38 percent occurred in Mg concentrations from the average medium and high K applications respectively, as compared to the average low K level. P supply had no observed effects for either Ca or Mg concentrations. The average high rate of P applications reduced Mn concentrations 13 percent as compared to the average low P level as shown in Figure 10 and Table A3 of the appendix. The average high levels of K applications reduced Mn concentrations 4 percent as compared to both the average low level and medium K application. Brown and Jones (9) also observed similar effects of reduced Mn uptake by soybean roots due to P applications.

Figures 11 and 12 and Table A3 of the appendix reveal that Fe and Zn concentrations were reduced 14 and 9 percent respectively, by

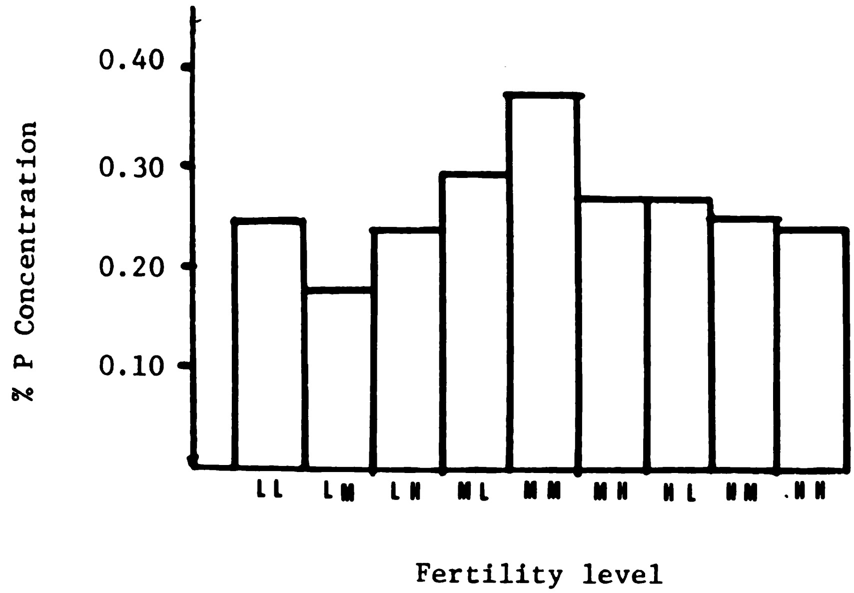


Figure 6. Phosphorous concentrations in leaf and stem tissue averaged over all soybean varieties for 9 fertility levels.

L denotes low; M denotes medium; H denotes high;
First letter denotes P; second letter denotes K;

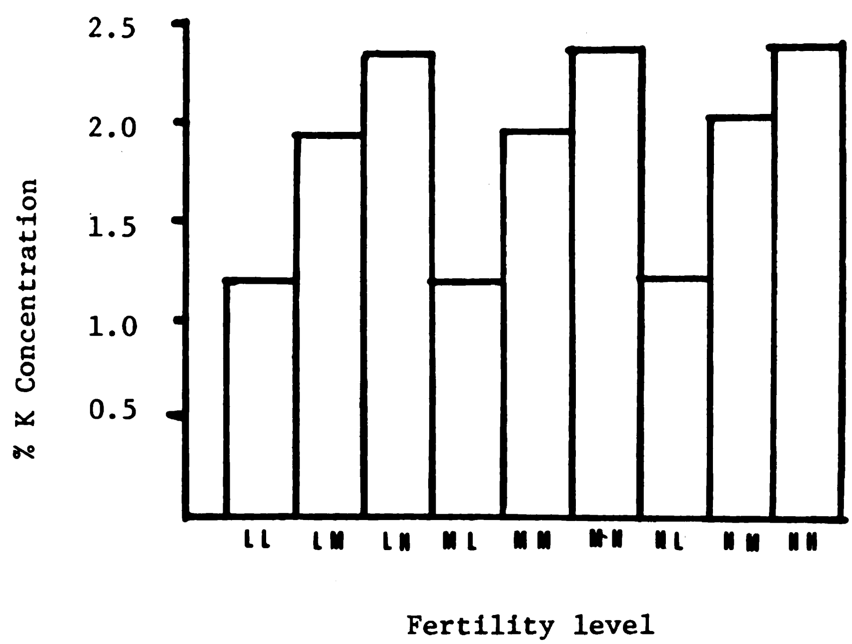


Figure 7. Potassium concentrations in leaf and stem tissue averaged over all soybean varieties for 9 fertility levels.

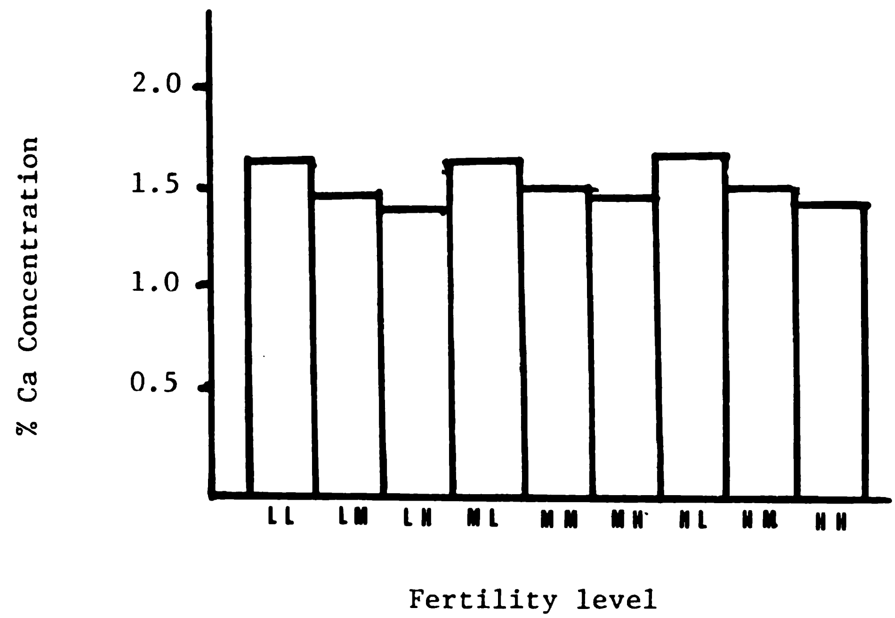


Figure 8. Calcium concentrations in leaf and stem tissue averaged over all soybean varieties for 9 fertility levels.

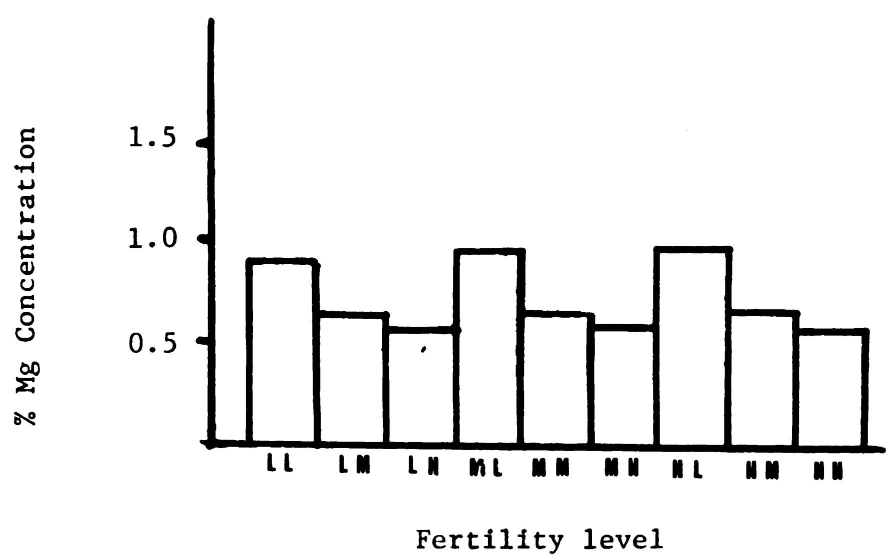


Figure 9. Magnesium concentrations in leaf and stem tissue averaged over all soybean varieties for 9 fertility levels.

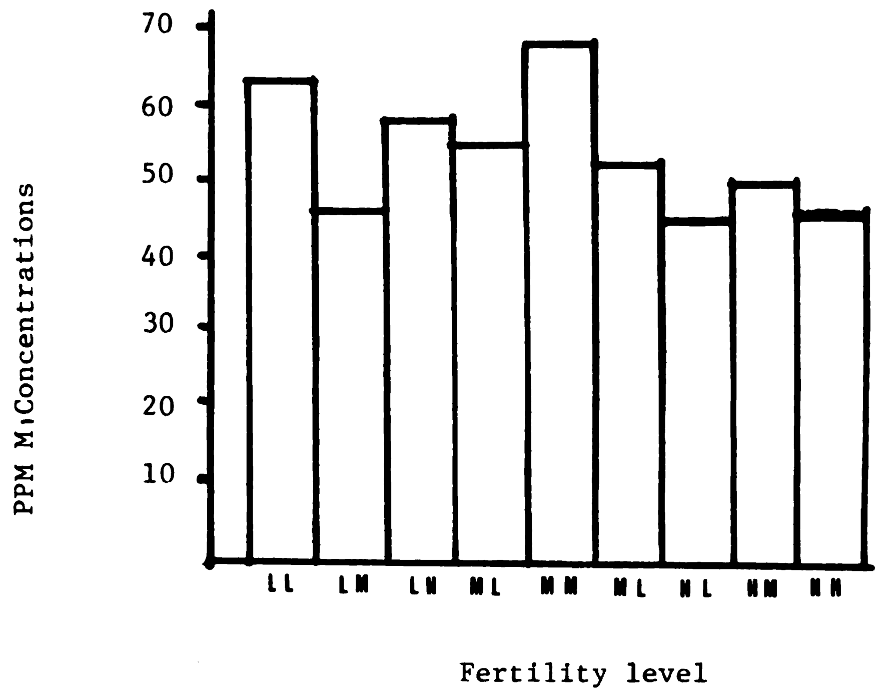


Figure 10. Manganese concentrations in leaf and stem tissue averaged over all soybean varieties for 9 fertility levels.

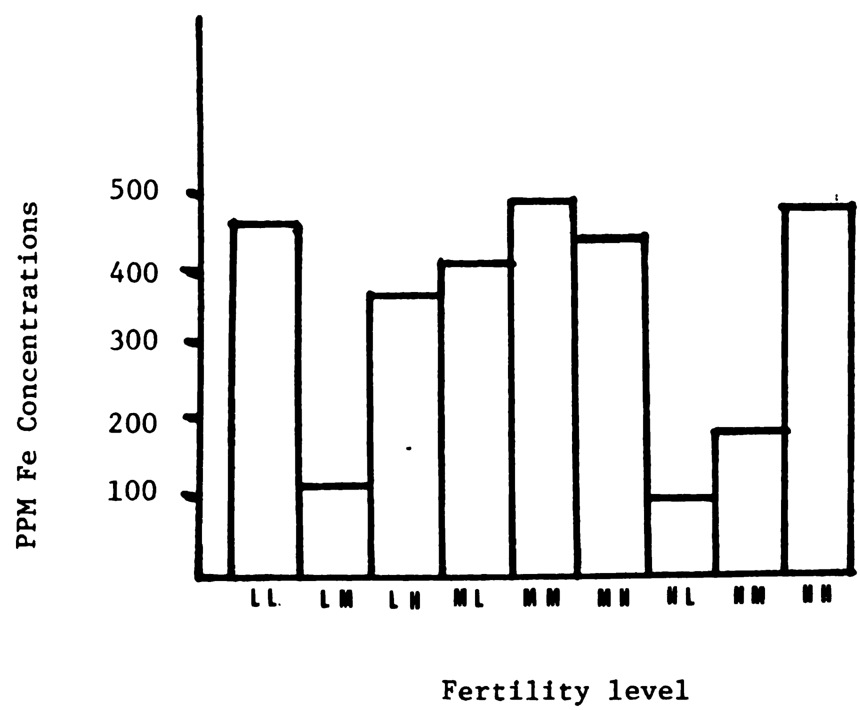


Figure 11. Iron concentrations in leaf and stem tissue averaged over all soybean varieties for 9 fertility levels.

average high P applications as compared to the average low P level. However, at the average medium P rate, Fe and Zn concentrations were increased 41 and 21 percent respectively as compared to the average low P level. Potassium reduced Fe concentration 16 percent at the average medium K level but increased Fe 32 percent at the average high K level when compared to the average low K level. Potassium increased Zn concentrations 12 percent at the average medium K rate but decreased Zn concentration 7.5 percent at the average high K rate when compared to the average low K levels.

The B concentrations also revealed inconsistent levels between treatments as shown in Figure 13 and A3 of the appendix. The average medium rate of P caused B content to increase 6 percent whereas B content was decreased 7 percent at the average high P application rate as compared to the average low P level. Potassium applications, however, revealed a consistent reduction in B concentration of 15 and 24 percent for the average medium and high K applications respectively, as compared to the average low K level.

The data concerning B concentration reduction due to K applications are similar to that reported by Woodruff et al. (63). However, research be Beeson et al. (5), and Miller et al. (47), involving Fe concentrations in soybean plant tissue revealed that high rates of P reduced Fe concentrations. Weber and Caldwell (61) revealed that high P and K plants contained considerably more Fe and lower Zn than the control. The contrasts between observations of these investigators may suggest varietal differences in soybeans for concentrating Fe, Zn and B as reported by Brown et al. (8) and Paulsen and Rotimi (53).

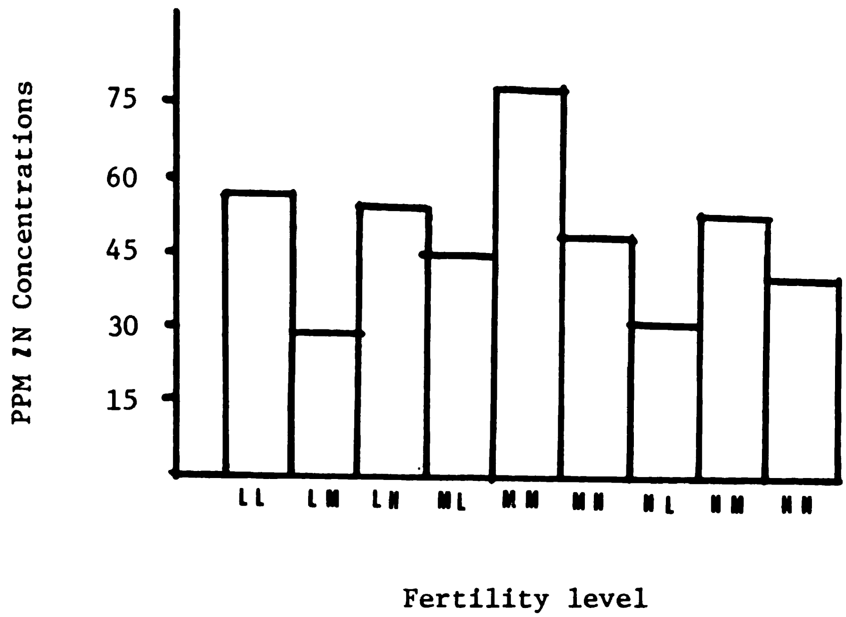


Figure 12. Zinc concentrations in leaf and stem tissue averaged over all soybean varieties for 9 fertility levels.

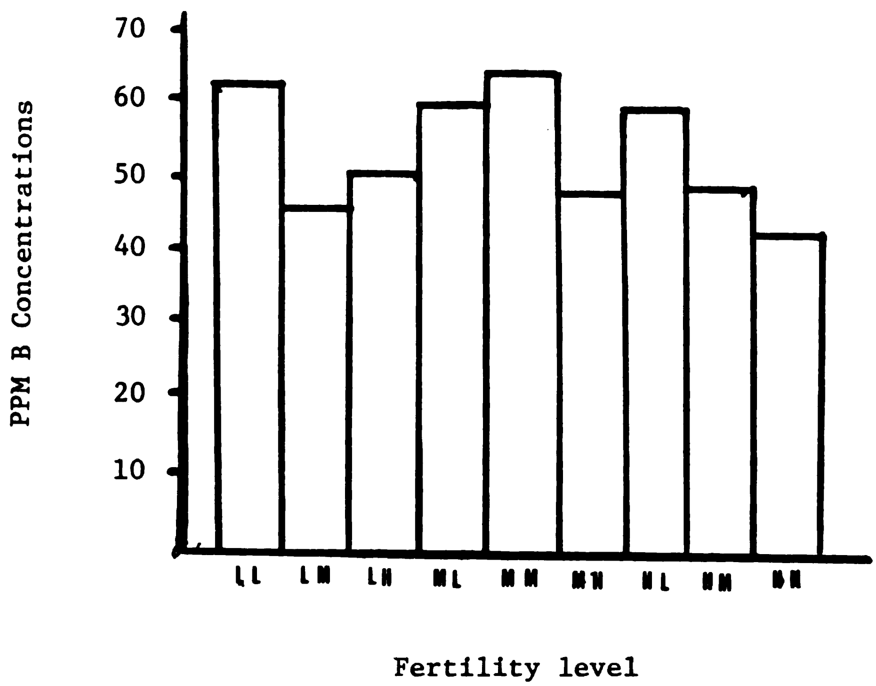


Figure 13. Boron concentrations in leaf and stem tissue averaged over all soybean varieties for 9 fertility levels.

In Table A4 of the appendix it is of interest to note that the varieties Steele, Amsoy 71, Beeson, Corsoy and SRF 200 had treatments showing 0.35 percent or more P concentrations in plant tisuse which resulted in very noticeable incraeases in Fe, Zn and B. Data in Table A5 of the appendix reveal that these values generally exceed the sufficiency concentrations as shown by Nelson and Barber (57).

Also, Table A4 reveals that, except for Amsoy 71 and Corsoy, P concentrations for the check treatment levels were below the sufficiency recommendation levels. K concentrations for the check were lower than sufficiency recommendations levels for all varieties, however, dry weight yields at the low treatment combination were comparable to or better than dry weight yields for many treatment levels where P and K concentrations were nearer the sufficiency recommendations as shown in Table 11.

On the basis of dry weight responses it did not appear in this experiment, that P or K concentrations in plant tissue could be used to identify soybean varieties that are more potentially responsive to P and K applications.

Field Study

Soil moisture content at planting time was adequate, resulting in good germination and early plant growth, but the lack of rain during August and early September reduced seed yield. In this experiment, fertilizer treatments did not cause lodging to any noticeable extent on any varieties.

Fertilizer treatment effects were not as great as expected due to the unusually dry weather conditions during the growing season. The general yield level of all varieties was low as evidenced by the poor performance of normally high yielding varieties. The yields of the ten varieties averaged over all fertility treatments are shown in Table A6 of the appendix. Yields for these cultivars are usually in the 35-45 bu/acre range in normal years in Michigan.

Early varieties maturing prior to the middle of September may have been at a disadvantage, because of not being able to utilize early fall rains. Rain fall data are presented in Table A7 of the appendix. It would appear that the later maturing varieties may have yielded better due to more moisture during pod-filling. Figure 14 shows the difference in maturity between Maturity Group 0 and Maturity Group II soybeans in early September.

The analysis of variance for the field study is presented in Table 12. The phosphorus (P), phosphorus x potassium interaction (P x K) and the variety effects (V) were all statistically significant for seed yield at the 1 percent probability level. Figure 15 shows the effects of phosphorus and potassium averaged over all varieties. Any response in seed yield was primarily due to phosphorus. Averaged over all varieties, P applications resulted in increases in yield of 2.1 bu/acre from low P to medium P, 2.7 bu/acre from medium P to high P and 4.9 bu/acre from low P to high P as shown in Table 13. Potassium responses were small and not significant as shown in Table 14. These results are similar to those reported by Anthony (3) and Boswell and Anderson (7).

Seed yield effects due to P x K interaction are shown in Figure 16 and Table 15. Yield increases were greatest when phosphorus and potassium were in balance combinations at either low, medium or high

Figure 14. Soybean variety plots showing difference in maturity between Maturity Groups 0, I and II.

Table 12. Analysis of variance for the seed yield in the 1976 variety study conducted in the field at Eaton County, Charlotte, Michigan.

Source	df	Mean square	F
Rep	2	721.31	15.05
P	2	531.86	11.10**
Error (a)	4	47.90	
K	2	6.70	0.25
P x K	4	190.34	6.98**
Variety (V)	9	155.86	5.72**
P x V	18	27.50	1.00
K x V	18	35.89	1.32
P x K x V	36	24.20	0.88
Error (b)	174	27.25	

**Denotes significance at the 1 percent probability level.

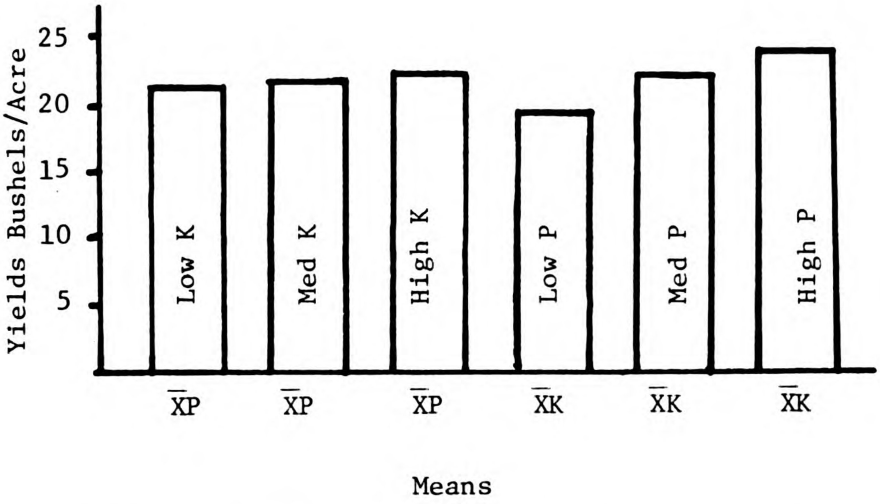


Figure 15. Yields as affected by phosphorous and potassium averaged over all varieties.

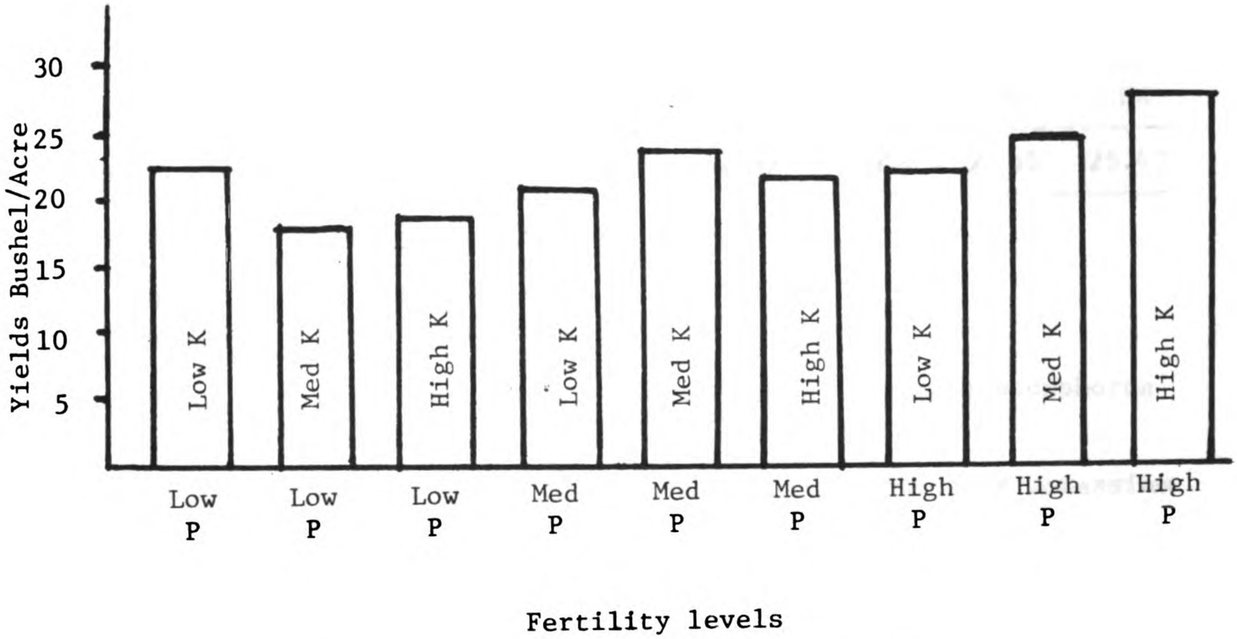


Figure 16. P X K interaction averaged over all vareities.

Table 13. Yields bu/acre due to phosphorus averaged over all varieties

Fertility treatment		
Low P	Medium P	High P
19.60	21.71	24.45
$LSD_{.05} = 1.65$		

Table 14. Yields bu/acre due to potassium averaged over all varieties

Fertility treatment		
Low K	Medium K	High K
21.60	21.9	22.1

Table 15. Yields bu/acre due to P x K interaction averaged over all varieties

P and K levels								
LL	LM	LH	ML	MM	MH	HL	HM	HH
22.46	17.88	18.48	20.36	23.11	21.64	22.08	24.83	26.42

Note. L = low, M = medium, H = high

1st letter denotes phosphorus
2nd letter denotes potassium

$LSD_{.05}$ for comparing two potassium means at the same phosphorus level = 2.64

$LSD_{.05}$ for comparing two phosphorus levels at the same potassium level = 2.81

increments. Also, certain imbalances of P and K resulted in actual decreases in yield. Seed yields of LM and LH treatments were 4.7 and 4.0 bu/acre less than the LL treatment. Potassium reduced yields more when applied alone than phosphorus. Table 15 reveals that the average seed yield decrease from medium and high K applied alone was 4.5 bu/acre and that the average medium and high rates of P applied alone only reduced yields 1.24 bu/acre as compared to the check. Miller et al. (48) revealed that soybean seed yield responses from P were obtained only when K was adequate. Howell and Bernard (33) also observed that the balance of nutrient elements contributes to optimum yields. While Table 15 reveals that medium increments proved beneficial, the high increments resulted in slightly higher yields as compared to the medium fertility rates. It is also evident that phosphorus seemed to increase seed yields more than potassium, although the majority of soybean research literature reveals a higher response to potassium than to phosphorus. Lutz, et al. (43) observed that the use of phosphorus fertilizer increased the amount of water present in the soil root zone and that crop yields were closely related to increased water content of the soil. It is possible that the shortage of soil moisture encountered in this experiment during the seed set stage may have been less severe due to the presence of adequate phosphatic fertilizer. This may partially explain the greater response to P than K.

Although much variability exists between treatments, data in Table 16 and 17 reveal that increasing P and K fertility resulted in a general increase in seed yields and number of pods in the 0.3 m row sample. When P and K were in balanced ratios the average seed yield and number of pods were 59.16 grams and 208 pods as compared to 56.0 gr and 199 pods average for the six imbalanced treatments. It also appears that the applied phosphorus was more responsible for increases in the number of pods and seed yields than applied potassium. Variability in this data might have been reduced by more rates of applied P and K and more observations per replication. Yield increases were also due to increased seed size as shown in Table 18. Although inconsistencies exist, it is evident that applied P and K are dually responsible for seed size increases. The average increases in seed size for all P and K treatments were 0.9 gm/100 seeds as compared to the check treatment.

Yield data in Figures 17-19 and Table A8 of the appendix suggest that an interaction might be present even though the original analysis of variance did not show evidence of a V x P, V x K or V x P x K interaction. The data also show that the varieties were not similar in their response to applied P and K. Correlations of seed yield response to numbers of pods and seed set revealed inconsistencies for each treatment of each variety as shown by Tables A9 of the appendix. More observations per plot might have reduced inconsistencies as irregularities of plant populations within the row were evident. The combined data for seed yields and number of pods for each variety averaged over all fertility treatments shown in Tables 19 and 20 do however correlate with the higher yields of the higher yielding varieties; Evans Maturity Group 0, Hodgson Maturity Group I and Corsoy Maturity Group II as shown in Tables A6 and A9 of the appendix. The data in Table 21 reveal that the varieties with the largest seed sizes do not correlate with the highest seed yields.

Figure 19 and Table A9 of the appendix show that varieties differ disproportionately in yield response to incremental changes in

Table 16. Seed weight in gms per 0.3 m row section sample averaged over all varieties with 9 P and K fertility treatments

P and K level								
LL	LM	LH	ML	MM	MH	HL	HM	HH
55.4	56.3	48.5	49.0	59.2	50.3	59.3	72.9	62.9

Table 17. Total number of pods per 0.3 m row section sample averaged over all varieties with 9 P and K fertility treatments

P and K level								
LL	LM	LH	ML	MM	MH	HL	HM	HH
200	208	172	179	215	190	209	233	209

Table 18. Average gm/100 seeds per 0.3 m row section sample averaged over all varieties with 9 P and K fertility treatments

P and K level								
LL	LM	LH	ML	MM	MH	HL	HM	HH
13.3	14.1	14.5	14.3	14.3	14.0	14.4	14.0	14.0

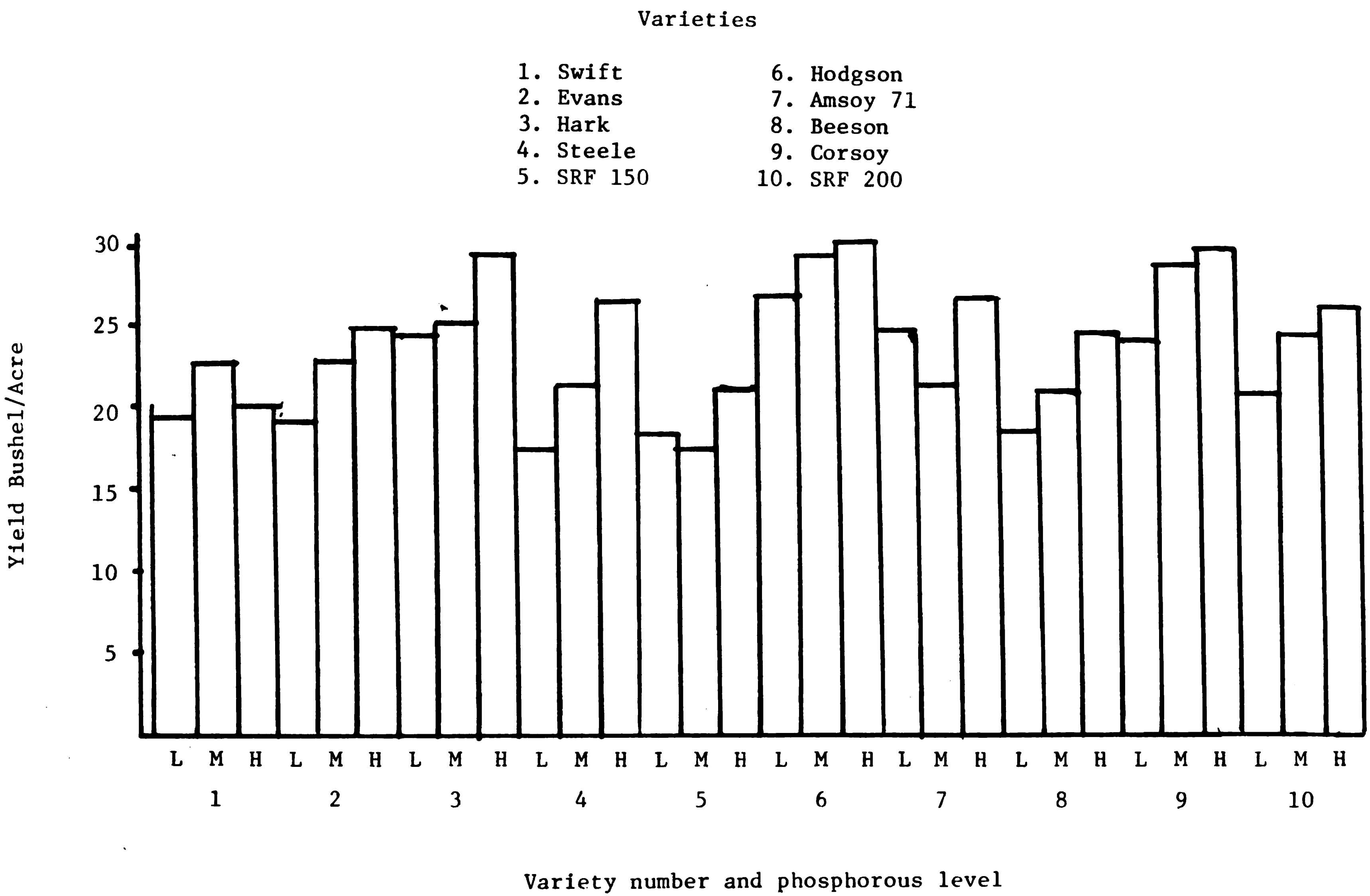


Figure 17. Varietal differences in yield as influenced by phosphorous.

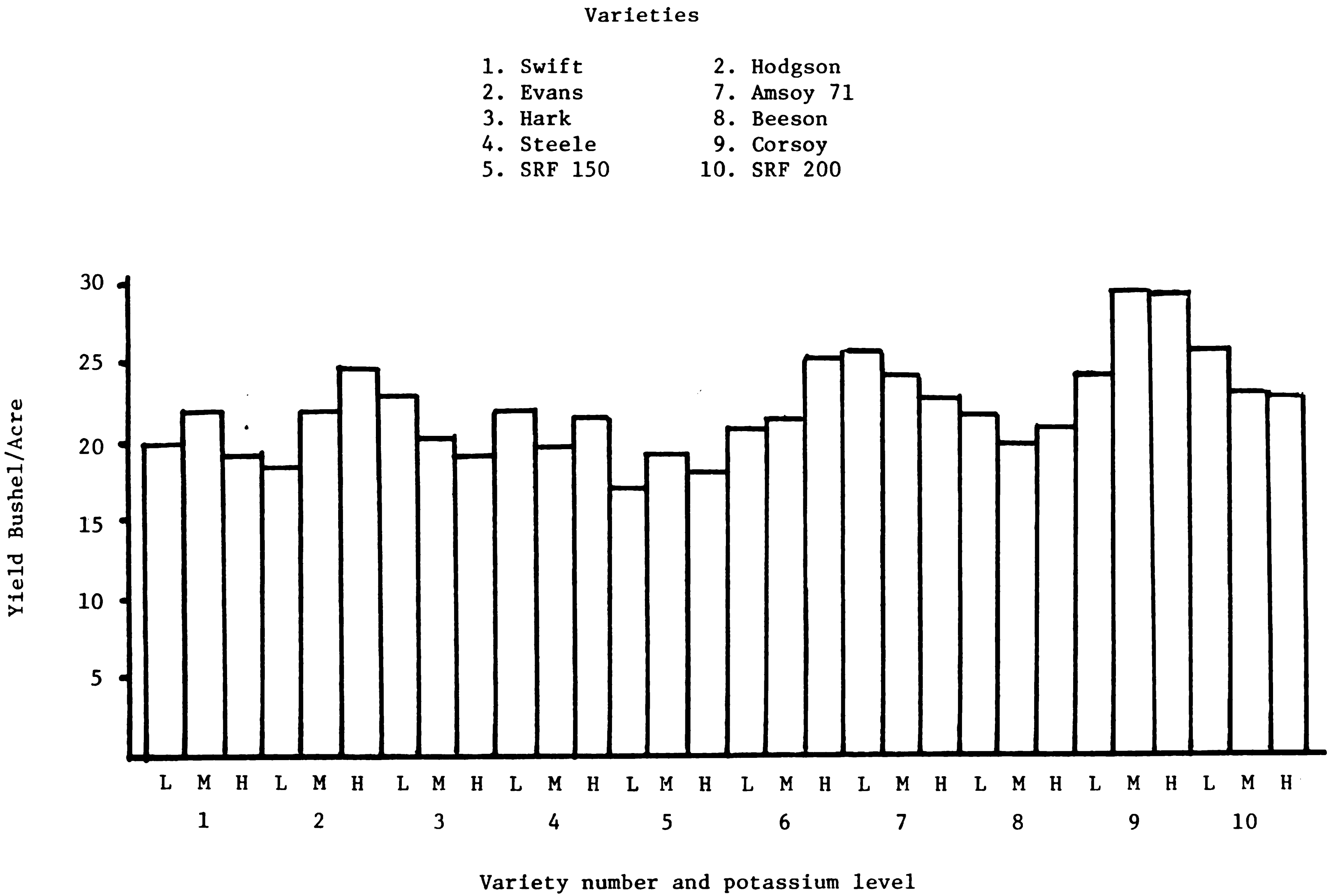


Figure 18. Varietal differences in yield as influenced by potassium.

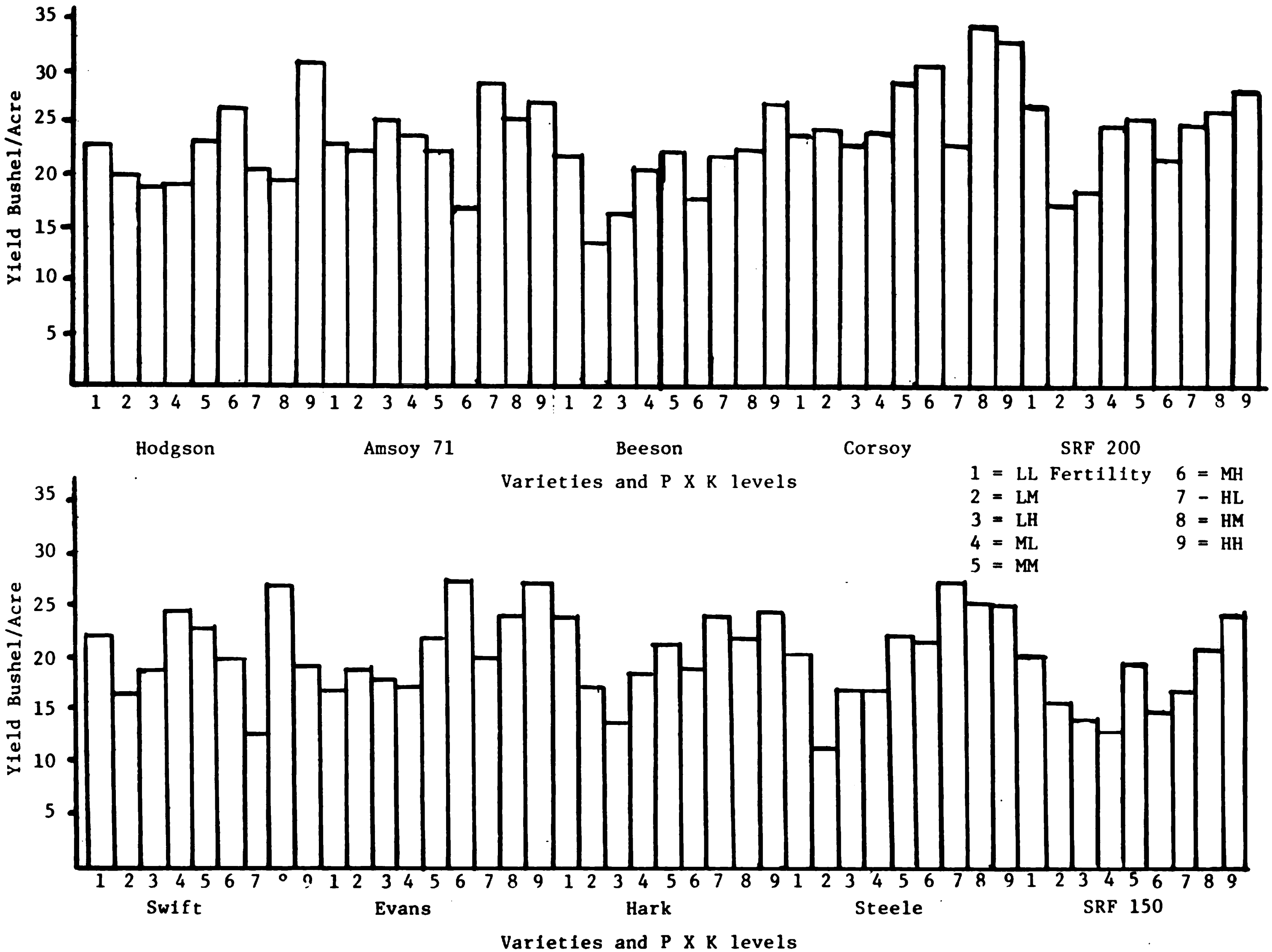


Figure 19. Varietal differences in yield as influenced by P X K fertility.

Table 19. Seed yields in gms for each variety averaged over all fertility treatments obtained from 0.3 m sample

Variety									
Swift	Evans	Hark	Steele	SRF 150	Hodgson	Amsoy 71	Beeson	Corsoy	SRF 200
53.3	63.7	50.6	55.3	55.2	60.1	56.0	54.2	61.5	60.2

Table 20. Number of pods for 10 soybean varieties obtained from 0.3 m sample of combined fertility treatments

Variety									
Swift	Evans	Hark	Steele	SRF 150	Hodgson	Amsoy 71	Beeson	Corsoy	SRF 200
210	239	166	201	184	222	171	171	250	178

Table 21. Average gm/100 seeds for all fertility treatments of soybean varieties

Variety									
Swift	Evans	Hark	Steele	SRF 150	Hodgson	Amsoy 71	Beeson	Corsoy	SRF 200
13.1	14.2	14.0	14.7	12.6	14.7	14.8	17.0	12.8	13.1

fertility level. These data might indicate that certain varieties (e.g., Swift, Hark and SRF 200) may demonstrate their highest yielding capacity at relatively low fertility levels. Although Evans, Steele, Hodgson, Beeson, and Corsoy show relatively high yields at low fertility levels, these varieties may not be approaching their highest potential at this low level of fertility. Thus, it would appear that these varieties may possess a greater ability to increase their yields at higher fertility levels, whereas other varieties exhibit their highest yielding ability at fairly low fertility parameters. Varieties which yield well at low soil fertility may be more efficient in nutrient uptake and utilization resulting in larger quantities of nutrients in their plant tissue. Yields of Swift, Hark and SRF 200 at the high P x K combination were similar to yields at the low P-low K level of fertility. These lower yielding varieties may not possess the genetic capability to respond to high soil fertility levels.

In Michigan State University trials, the varieties Corsoy and Hodgson have consistently proven to be in the top 40 percent for seed yield. These varieties with proven high seed yields may be relatively well adapted to low fertility conditions, but also possess the potential to respond more favorably to increased fertility than other varieties. Since yield is a product of several yield components the higher yields of Corsoy and Hodgson are attributed mainly to greater numbers of pods and seed set.

SUMMARY AND CONCLUSIONS

The response of seed yields and dry matter accumulation of soybeans to fertility were studied by applying nine combinations of P and K fertility to ten soybean varieties. Conclusions related to questions stated in the Introduction may be summarized as follows:

1. There were no differences between varieties in the effects of P and K on seed yield and yield components (field results) and dry matter accumulation (greenhouse results).
2. P and K fertilizer increments, when applied in balanced combinations, increased seed yield when averaged over all varieties. Certain imbalanced combinations of P and K fertility resulted in actual decreases in seed yield (field results).
3. The effects of phosphorus on seed yields averaged over all varieties were greater than the effect of potassium (field results).
4. Reductions in seed yield were obtained from medium and high applications of K at low P levels when averaged over all varieties as compared to the check (field results).
5. Rates of seedling emergence were inversely affected by incremental increases in P and K fertility (greenhouse results).
6. Dry matter accumulations averaged over all varieties were greater under the balanced P and K combinations than under

the imbalanced combinations (greenhouse results).

7. Phosphorus applied alone at both medium and high rates reduced root growth when averaged over all varieties (greenhouse results).

8. Varying the P level in the subtrate affected plant tissue concentrations of P, Mn, Fe, Zn, and B but not K (greenhouse results).

9. Varying the K level in the substrate affected plant tissue concentrations of P and K as well as Ca, Mg and B (greenhouse results).

When considering the many factors involving macro-element fertility it is also very significant to consider other management, cultural and general nutritional requirements to provide a better understanding of underlying interactions of dependent characters. For it is not one or two environmental conditions which govern plant growth and yields but a combination of interactive factors, and that one factor cannot be considered irrespective of the others. The high yields obtained through the research process represent yields which are possible when the use of good management practices is accompanied by a very rare and fortuitous combination of favorable environmental conditions.

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LITERATURE CITED

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APPENDIX

Table A1. Total plant dry weights, percent top to total plant and ratio of K/P averaged over all treatment levels.

	Varieties								
	Swift	Evans	Steele	SRF 150	Hodgson	Amsoy 71	Beeson	Corsoy	SRF 200
Dry weight	.836	.825	.844	.747	1.001	.847	1.047	.820	.758
% top	63	64	64	62	61	63	63	59	63
K:P	7.8	9.3	7.7	9.8	9.5	6.3	5.2	6.5	5.2

Table A2. Plant dry weights averaged for nine treatment levels of P and K.

	P and K levels								
	LL	LM	LH	ML	MM	MH	HL	HM	HH
Dry weight	.881	.861	.903	.882	.849	.767	.782	.833	.966
% top	61	61	62	62	63	64	64	63	61
K:P	4.8	10.4	9.6	4.2	5.3	9.2	4.8	8.2	10.1

Table A3. Nutrient concentrations averaged over all varieties for nine treatment combinations of P and K.

Fertility treatments		Nutrient concentrations							
P	K	P	K	Ca	Mg	MN	Fe	Zn	B
		%				ppm			
L	L	.25	1.19	1.61	.82	63	464	60	62
L	M	.18	1.88	1.48	.63	48	115	32	44
L	H	.24	2.32	1.43	.54	57	376	40	48
M	L	.29	1.21	1.61	.89	55	408	42	58
M	M	.37	1.98	1.52	.65	68	485	70	60
M	H	.26	2.39	1.48	.59	53	451	48	45
H	L	.26	1.24	1.65	.96	48	115	33	56
H	M	.25	2.06	1.53	.66	50	225	50	46
H	H	.24	2.43	1.42	.54	48	477	37	41

Table A4. Tissue analysis of total plant tops of nine soybean varieties as influenced by nine nutrient combinations of P and K fertility treatments

Fertility P	Fertility K		P	K	Ca	Mg	Mn	Fe	Zn	B
			%				ppm			
Variety:	Swift									
L	L		.18	1.17	1.58	.99	62	215	32	70
L	M		.19	1.74	1.41	.74	58	186	28	54
L	H		.21	2.28	1.49	.68	61	136	34	53
M	L		.27	1.11	1.60	1.12	66	252	34	53
M	M		.22	1.95	1.49	.75	48	111	25	49
M	H		.29	2.76	1.60	.71	38	64	24	40
H	L		.34	1.30	1.95	1.32	71	243	58	76
H	M		.25	1.96	1.61	.81	52	126	27	57
H	H		.22	2.58	1.57	.61	49	96	26	46
		$\overline{X}$	.24	1.87	1.59	.86	56	159	32	57
Variety:	Evans									
L	L		.18	1.38	1.71	.73	51	160	29	50
L	M		.21	2.27	1.59	.54	47	100	28	41
L	H		.19	2.38	1.51	.52	55	272	29	43
M	L		.25	1.48	1.77	.77	43	85	25	46
M	M		.22	1.97	1.63	.62	55	205	38	41
M	H		.23	2.53	1.64	.55	50	111	28	43
H	L		.28	1.44	1.68	.80	42	100	23	48
H	M		.22	2.02	1.49	.62	52	274	25	39
H	H		.16	2.98	1.53	.51	47	100	22	36
		$\overline{X}$	.22	2.05	1.62	.63	49	156	27	43
Variety:	Steele									
L	L		.15	1.04	1.57	.82	52	183	40	51
L	M		.18	1.96	1.62	.72	52	110	31	50
L	H		.35	2.46	1.52	.66	84	1933	84	70
M	L		.22	1.19	1.76	.95	54	219	32	60
M	M		.23	1.91	1.61	.78	56	139	28	52
M	H		.26	2.45	1.59	.64	46	250	38	47
H	L		.24	1.20	1.75	1.02	50	142	28	66
H	M		.22	2.22	1.68	.71	54	406	94	48
H	H		.29	2.30	1.51	.62	66	1648	64	56
		$\overline{X}$	.24	1.86	1.62	.77	57	559	49	56

Table A4. Continued

Fertility			Nutrient concentrations							
P	K		P	K	Ca	Mg	Mn	Fe	Zn	B
			--------	%	--------		--------	ppm	--------	
Variety:	SRF 150									
L	L		.21	1.52	1.91	.92	48	107	34	61
L	M		.14	1.96	1.60	.65	47	85	24	45
L	H		.21	2.62	1.60	.59	54	127	24	45
M	L		.27	1.46	1.85	.94	46	102	24	54
M	M		.24	2.70	1.63	.61	45	84	23	41
M	H		.15	2.48	1.55	.54	48	147	21	41
H	L		.23	1.32	1.77	.92	49	100	26	57
H	M		.19	2.48	1.65	.62	48	82	17	40
H	H									
		$\overline{X}$	.21	2.07	1.70	.72	48	104	31	48
Variety:	Hodgson									
L	L		.15	1.08	1.66	.89	64	393	57	52
L	M		.14	1.73	1.55	.74	55	171	31	46
L	H		.15	2.26	1.50	.54	40	87	23	36
M	L		.22	1.02	1.68	1.03	60	409	53	57
M	M		.16	1.78	1.58	.69	52	364	26	41
M	H		.18	2.00	1.57	.74	50	183	31	44
H	L		.23	1.24	1.73	1.10	48	100	26	51
H	M		.21	1.74	1.42	.66	50	232	33	39
H	H		.22	2.64	1.46	.58	28	68	24	36
		$\overline{X}$	.18	1.72	1.57	.77	50	223	34	45
Variety:	Amsoy 71									
L	L		.63	1.20	1.50	.78	110	1373	179	101
L	M		.17	1.64	1.28	.55	48	82	31	35
L	H		.17	2.24	1.27	.49	47	87	31	35
M	L		.26	1.24	1.55	.86	44	85	28	47
M	M		.21	1.88	1.34	.62	45	77	23	37
M	H		.22	2.26	1.34	.54	48	75	34	37
H	L		.24	1.04	1.50	.85	41	73	26	57
H	M		.41	1.86	1.39	.61	70	601	152	60
H	H		.20	2.54	1.27	.49	44	81	24	32
		$\overline{X}$	.28	1.77	1.38	.64	50	282	59	49

Table A4. Continued

Fertility		Nutrient concentrations							
P	K	P	K	Ca	Mg	Mn	Fe	Zn	B
Variety: Beeson									
L	L	.17	1.12	1.42	.65	42	72	26	52
L	M	.15	1.82	1.31	.48	40	90	32	41
L	H	.13	1.98	1.15	.40	40	83	23	36
M	L	.46	1.24	1.41	.68	72	639	84	75
M	M	.88	1.86	1.41	.57	130	1903	307	122
M	H	.40	2.03	1.32	.47	79	1445	164	67
H	L	.22	1.18	1.46	.74	40	78	26	51
H	M	.19	1.98	1.31	.50	38	74	22	39
H	H	.34	2.26	1.25	.45	60	1530	73	56
	$\bar{X}$	.33	1.72	1.34	.55	55	657	84	60
Variety: Corsoy									
L	L	.36	1.16	1.62	.86	90	1583	92	76
L	M	.19	2.02	1.50	.63	43	72	32	39
L	H	.18	2.26	1.38	.55	49	80	30	35
M	L	.23	1.02	1.59	.87	50	254	30	43
M	M	.24	1.66	1.54	.71	53	108	48	42
M	H	.40	2.53	1.45	.55	67	1701	58	49
H	L	.29	1.26	1.68	.97	48	112	33	47
H	M	.27	1.90	1.80	.77	51	126	41	49
H	H	.26	2.14	1.47	.59	53	224	28	36
	$\bar{X}$	.27	1.77	1.56	.72	56	474	44	46
Variety: SRF 200									
L	L	.18	1.08	1.51	.70	45	93	25	49
L	M	.21	1.78	1.45	.66	49	138	34	46
L	H	.55	2.38	1.45	.46	87	578	217	79
M	L	.42	1.16	1.24	.79	63	1625	83	65
M	M	.89	2.02	1.40	.55	124	1373	153	114
M	H	.22	2.46	1.25	.53	47	87	27	35
H	L	.28	1.18	1.33	.87	39	87	25	48
H	M	.26	2.36	1.43	.64	38	103	26	40
H	H	.19	2.40	1.30	.50	37	70	21	31
	$\bar{X}$	.36	1.87	1.37	.63	59	462	56	56

Table A5. Sufficiency nutrient concentrations recommended by Nelson and Barber as reported in 'Soybeans. Improvement and use.' Agronomy No. 16.

Nutrients	Nutrient concentrations of total plant top							
	P	K	Ca	Mg	Mn	Fe	B	Zn
	%				ppm			
Concentration	0.3	2.5	1.5	0.6	24-49	30	20-100	16

Table A6. Yields for ten varieties of soybeans averaged over all fertility treatments (Eaton County)

Number	Variety	Maturity Group	Yield	
			bu/acre	kg/ha
1	Swift	0	20.5	1379
2	Evans	0	21.5	1446
3	Hark	I	20.8	1399
4	Steele	I	21.1	1419
5	SRF 150	I	18.0	1211
6	Hodgson	I	22.3	1500
7	Amsoy 71	II	23.9	1607
8	Beeson	II	20.5	1379
9	Corsoy	II	26.9	1809
10	SRF 200	II	23.6	1581

$LSD_{.05} = 1.96$

Table A7. Average monthly rainfall in inches for Eaton County, Michigan

May	June	July	August	September
3.05	4.35	3.02	1.46	2.67

Table A8. Yields in bushels per acre for ten varieties of soybeans as influenced by nine levels of P and K fertility

Variety	P and K levels								
	LL	LM	LH	ML	MM	MH	HL	HM	HH
Swift	22.0	16.5	18.7	24.8	22.9	20.0	13.0	26.9	19.8
Evans	17.2	19.1	17.9	17.3	22.3	27.7	20.2	24.3	27.3
Hark	24.5	17.3	14.2	18.9	21.7	19.7	24.4	22.5	24.6
Steele	20.8	11.4	17.6	17.6	22.8	21.7	27.5	25.4	25.3
SRF 150	21.1	16.0	14.5	13.0	20.0	15.0	17.0	21.4	24.5
Hodgson	23.0	20.0	18.6	18.7	23.2	26.5	20.2	19.8	30.3
Amsoy 71	23.7	22.9	25.3	23.9	22.3	17.0	28.7	25.2	26.1
Beeson	22.0	13.9	16.3	20.5	22.1	17.6	22.1	23.1	27.1
Corsoy	23.7	24.4	22.7	24.4	28.7	30.4	22.7	33.2	32.0
SRF 200	26.4	17.3	18.9	24.9	25.1	21.5	24.9	26.3	27.1
$\bar{X}$	22.4	17.8	18.4	20.3	23.1	21.6	22.0	24.8	26.4

Table A9. The relationship of number of pods, weight of total seeds in gm, gm/100 seeds in 0.3 m row samples to yield in bu of soybeans/acre as influenced by 9 levels of P and K fertility

Variety	Fertility			0.3 m sample of plants/plot			Yield
	P	K		# pods	Total seed wt	gm/100 seeds	bu/acre
Swift	L	L		175	53	12.5	22.0
	L	M		237	54	13.0	16.5
	L	H		244	56	13.2	18.7
	M	L		181	50	13.0	24.8
	M	M		189	41	13.8	22.9
	M	H		230	61	13.8	20.0
	H	L		200	51	13.0	13.0
	H	M		204	50	12.8	26.9
	H	H		237	68	13.0	19.8
			$\bar{X}$	210	54	13.1	20.5
Evans	L	L		261	65	13.2	17.2
	L	M		245	63	13.8	19.1
	L	H		207	58	15.1	17.9
	M	L		200	43	12.8	17.3
	M	M		249	54	14.2	22.3
	M	H		194	46	14.3	27.7
	H	L		289	97	15.7	20.2
	H	M		261	90	13.8	24.3
	H	H		247	58	14.9	27.3
			$\bar{X}$	239	63	14.2	21.5
Hark	L	L		158	37	12.0	24.5
	L	M		239	62	15.0	17.3
	L	H		161	41	13.0	14.2
	M	L		200	52	15.0	18.9
	M	M		226	65	14.2	21.7
	M	H		199	52	13.9	19.0
	H	L		173	52	16.0	24.4
	H	M		162	46	13.0	22.5
	H	H		160	49	14.2	24.6
			$\bar{X}$	186	50	14.0	20.8

Table A9. Continued

Variety	Fertility		0.3 m sample of plants/plot			Yield
	P	K	# pods	Total seed wt	gm/100 seeds	bu/acre
Steele	L	L	190	46	14.5	20.8
	L	M	221	68	14.8	11.4
	L	H	138	37	15.9	17.6
	M	L	189	43	14.2	17.6
	M	M	196	57	15.0	21.7
	M	H	189	50	15.0	21.7
	H	L	198	45	14.0	27.5
	H	M	277	86	15.0	25.4
	H	H	221	66	14.0	25.3
		$\overline{X}$	201	55	14.7	21.1
SRF 150	L	L	266	78	12.2	21.1
	L	M	158	42	11.8	16.0
	L	H	161	43	12.5	14.5
	M	L	129	40	13.8	13.0
	M	M	228	67	13.9	20.0
	M	H	138	39	12.2	15.0
	H	L	195	58	12.0	17.0
	H	M	193	71	13.0	21.4
	H	H	196	59	12.0	24.5
		$\overline{X}$	184	55	12.5	18.0
Hodgson	L	L	207	55	14.0	23.0
	L	M	248	67	15.0	20.0
	L	H	192	57	15.8	18.6
	M	L	167	48	15.2	18.7
	M	M	220	57	14.0	23.2
	M	H	242	55	14.0	26.5
	H	L	176	39	13.8	20.2
	H	M	343	102	14.5	19.8
	H	H	206	61	15.9	30.3
		$\overline{X}$	222	60	14.7	22.3

Table A9. Continued

Variety	Fertility			0.3 m sample of plants/plot			Yield
	P	K		# pods	Total seed wt	gm/100 seeds	bu/acre
Amsoy 71	L	L		176	56	14.2	23.7
	L	M		160	53	14.5	22.9
	L	H		210	72	16.5	25.3
	M	L		159	51	15.1	23.9
	M	M		130	44	15.0	22.3
	M	H		172	46	14.5	17.0
	H	L		137	47	14.5	28.7
	H	M		174	57	14.6	25.2
	H	H		227	78	14.2	26.1
			$\bar{X}$	171	56	14.7	23.9
Beeson	L	L		153	53	16.2	22.0
	L	M		119	38	17.5	13.9
	L	H		73	24	18.0	16.3
	M	L		184	54	17.5	20.5
	M	M		248	80	17.0	22.1
	M	H		210	61	16.8	17.6
	H	L		201	64	18.2	22.1
	H	M		188	63	16.2	23.1
	H	H		164	51	16.0	27.1
			$\bar{X}$	171	54	17.0	20.5
Corsoy	L	L		214	50	12.0	23.7
	L	M		304	67	13.0	24.4
	L	H		154	42	13.0	22.7
	M	L		259	68	13.8	24.0
	M	M		275	65	12.4	28.7
	M	H		178	42	12.8	30.4
	H	L		314	74	12.2	22.7
	H	M		324	81	13.0	33.2
	H	H		230	65	13.0	32.0
			$\bar{X}$	250	61	12.8	26.9

Table A9. Continued

Variety	Fertility		0.3 m sample of plants/plot			Yield
	P	K	# pods	Total seed wt	gm/100 seeds	bu/acre
SRF 200	L	L	214	50	12.0	23.7
	L	M	304	67	13.0	24.4
	L	H	154	42	13.0	22.7
	M	L	259	68	13.8	24.0
	M	M	275	65	12.4	28.7
	M	M	178	42	12.8	30.4
	H	L	314	74	12.2	22.7
	H	M	324	81	13.0	33.2
	H	H	230	65	13.0	32.0
		$\overline{X}$	250	61	12.8	26.9

Table A10. Soil test results for field and greenhouse experiments

Soil	pH	lbs/acre				ppm		% Base		
		P	K	Ca	Mg	Zn	Mn	K	Ca	Mg
Alcoma Sandy loam	7.2	17	80	3341	364	5	25	1	83.5	15.3
Celina Loam	6.5	13	80	2395	286	4	22	1.4	82.3	16.1