THE UNIVERSITY OF MANITOBA

A STUDY OF IRON AND MANGANESE DEFICIENCIES OF FIELD PEAS AND SOYBEANS

by

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ABSTRACT

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Various soil treatments and foliar sprays were applied to soybeans and field peas to assess means of controlling iron and manganese deficiency diseases such as chlorosis and marsh spot of peas, which occur on high-lime soils of the Northern Great Plains.

Manganese sulfate applied to plant foliage and elemental sulfur incorporated into the soil were the treatments most effective in increasing manganese content of plant tissue.

Several examples of heavy metal interactions were observed. Manganese uptake by both field peas and soybeans was decreased by Fe EDDHA, and iron accumulation in pea seed was inhibited by fritted trace elements. Zinc behavior due to fritted trace elements was variable; the absorption of zinc by soybeans was increased, but by pea seed, it was decreased.

Foliar applications of both Rayplex Mn and manganese sulfate resulted in a depression in the uptake of iron by the plant roots, perhaps due to a complex interaction of tissue manganese with iron absorption or transport.

Peat moss incorporated into the soil and manganese sulfate soil treatments did not affect micronutrient content of any plant tissue. Fe EDDHA did not change iron levels by either foliar or soil application. Foliar application of Rayplex Mn did not increase the manganese content of plant tissue.

Unusually high levels of iron in chlorotic plant tissue lead to the conclusion that iron was precipitated as the insoluble phosphate in the vascular tissue of leaves, and that, as a plant became unthrifty and chlorotic, mobile nutrients and carbohydrates move from the leaves, resulting in proportionally higher concentrations of less mobile minerals such as iron.

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LIST OF ABBREVIATIONS

DTPA	- diethylenetriamine pentacetic acid.
EDDHA) Sequestrene 138) Chel 138)	- ethylenediamine di-(O-hydroxyphenyl acetic acid).
EDTA	- (ethylenedinitrilo) tetraacetic acid.
Fe 138	- Fe EDDHA.
FTE	- fritted trace elements.
PI	- PI 54619-5-1.
ppm	- parts per million (by weight).
Tween-20	- polyoxyethylene (20) sorbitan monolaurate.

INTRODUCTION

With the increasing emphasis upon plant sources of protein for food and feed, all aspects of legume production are being scrutinized for efficient means of increasing yield. Plant breeding has accelerated; fertilization with major nutrients is well established; and now, with advanced instrumentation available, mineral nutritionists may focus on possible micronutrient deficiencies which could be the limiting factor to plant growth. In this study various soil treatments and foliar sprays were applied to soybeans and field peas to assess means of controlling manganese and iron deficiency diseases such as chlorosis and marsh spot of peas, which occur on high-lime soils of the Winnipeg area.

Iron and manganese are in plentiful supply in the Riverdale clay soil of the Winnipeg area; however, they may be rendered unavailable to plants by a high level of lime in the soil. Poor aeration and lack of internal soil drainage are major contributing factors.

Since iron is relatively immobile in plants, a deficiency becomes apparent in the new growth as chlorosis or yellowing of the interveinal portion of the leaf, then necrosis and death. Known as lime-induced chlorosis, this condition has been recognized as a major problem in horticultural and field crops which are not adapted to high-lime soils.

In the earliest stages manganese deficiency is similar to that of iron; however, due to the mobility of manganese, older leaves also become chlorotic. Necrosis of inner cotyledons of legume seed is also typical of manganese deficiency. This symptom occurs locally as marsh spot of field peas (Figure 1). It is of considerable economic importance to growers because an affected crop may be rejected for soup making.

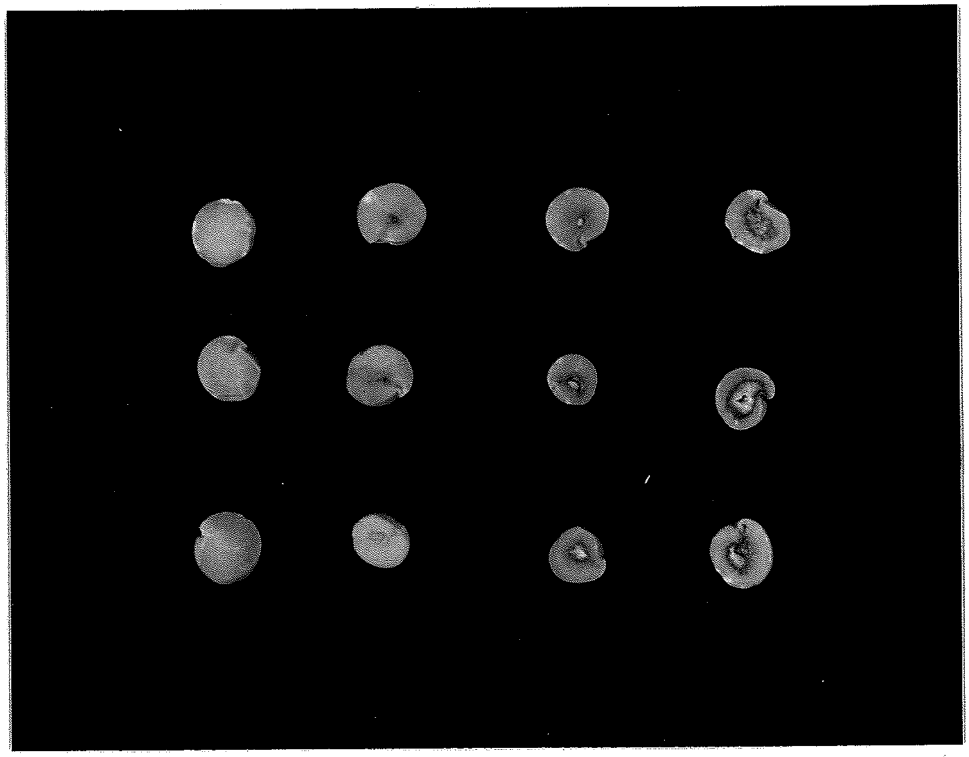

Figure 1. Century field pea seed damaged by marsh spot. Rows from left to right show increasing development of symptoms.

This study was conducted as a field experiment in a poorly drained area of the University of Manitoba Arboretum. The soil is classified as Riverdale clay, with a pH of 6.9 to 8.0. Iron and manganese deficiencies are common. Chlorosis often occurs in horticultural genera such as *Malus*, *Prunus* and *Acer*: in field crops the soybean, *Glycine max* (L.) Merr. is especially subject to this condition. In a 1971 preliminary trial the chlorosis-susceptible soybean PI 54619-5-1 was so chlorotic from the first true leaf stage that most of the plants failed to develop further. Therefore Portage soybean, a Manitoba cultivar, was chosen as a test plant. In locally-grown field peas, *Pisum sativum* L., the manganese deficiency disease, Marsh Spot, has been reported. The susceptible cultivar, Century, was therefore included in the experiment.

Micronutrient deficiencies are sometimes easily detected by specific symptoms; however, often the only indication is poor color and depressed yield. Tissue analysis gives an accurate assessment of the mineral nutrients taken up by a plant. Thus, nutritional problems may be more accurately diagnosed in this way than by soil analysis.

REVIEW OF LITERATURE

In the Winnipeg area several factors relating to soil type have a decided effect on the mineral nutrition of plants. The structure of the Riverdale clay results in poor aeration and drainage. The soil is comparatively slow to warm up in spring, thus contributing to nitrogen deficiency because of low bacterial activity. A high level of lime causes iron and manganese to occur in unavailable trivalent and tetravalent forms, respectively. Only the bivalent form of iron and manganese is considered to be available to plants (5, 12). The bicarbonate ion is also reported to be implicated in the oxidation of iron, resulting in decreased availability of iron to plants (47). Phosphorus, which is required in local fertilization practice, ties up iron as insoluble phosphates (4). The more adequate is the phosphorus fertilization, the more detrimental it becomes in terms of iron supply. Also, an imbalance in the ratio of iron to manganese and other micronutrients may occur. A high level of one may result in increased or decreased uptake of another (11, 46).

In field peas and other legumes, manganese deficiency causes a characteristic necrosis of the inner seed. This condition is known as marsh spot (48). Tissue breakdown starts at the center of the seed, progressing outward as a dry rot, uniformly in both cotyledons. The damaged seed in Figure 1 illustrates the severity of marsh spot locally, however, where manganese deficiency is more severe, only empty seed coats develop.

A deficiency of either iron or manganese may result in chlorosis or yellowing of leaves. Because iron is relatively immobile, older leaves of deficient plants remain green, while younger leaves are chlorotic with typical green venation. Since manganese is mobile, a deficiency results in a similar appearance initially, and then older leaves also become chlorotic and somewhat mottled (48). Chlorosis may also be caused by manganese toxicity, and by deficiencies of the major nutrients nitrogen, sulfur, and magnesium (14).

Identification of the cause of chlorosis is often difficult because visual symptoms appear to be non-specific. Multiple deficiencies may exist so that the most limiting factor must be determined and treated first. Bacterial and viral infections, mechanical injury, and environmental conditions may affect the appearance of a plant and make diagnosis difficult (14).

The chemical composition of a plant varies according to the supply of nutrients available for its growth. This may be determined by tissue analysis. For a given leaf or group of leaves mineral contents differ and ratios alter in a systematic way during the growing season (12). Optimum levels of nutrients are listed specifically by crop at a certain physiological age and period of growth and are used to indicate fertilizer requirements. The critical level is the lowest nutrient content associated with maximum yield (12). For example, critical levels for soybean are 30 ppm iron and 20 ppm manganese, using the youngest mature leaf at early bloom stage (27). The manganese content of pea seed varies from 4 to 22 ppm (18, 21).

Wallace and Lunt (47) stressed the inconsistency of iron levels in chlorotic leaves. Older chlorotic tissues accumulated iron, yet remained chlorotic; chlorosis was corrected without a corresponding increase in iron content in the plant; tissue analysis of green and chlorotic trees of the same cultivar revealed essentially equal iron contents, indicative of non-functional iron in chlorotic leaves (47). Other studies using radionuclides confirm these results (39). Rutland and Bukovac (34) reported treatment of chrysanthemum leaves with labelled iron: chlorotic leaves continued to absorb iron at such a high rate that, when calculated on a weight basis, the iron level of the chlorotic leaves would become almost three times that of the green leaves. Generally, however, low iron content of healthy plant tissue indicates deficient nutrient status, as often occurs in lime-induced chlorosis (4).

Study of the genetic regulation of nutrient uptake is the most promising means of obtaining plant material suitable to specific problem soils such as those with characteristics that contribute to nutritional deficiencies. Just as the vast untapped store of germ plasm in the "cradle sites" of cereal crops is now recognized as invaluable to plant breeders as a source of vigor and disease resistance; so there may be ecotypes or species which would provide breeders with solutions to specific nutritional problems. Wallace and Lunt (47) reviewed all aspects of lime-induced chlorosis, stressing the variation in susceptibility both among and within species. Munns *et al.* (30) observed consistent varietal differences in manganese concentration of oat shoots. These differences persisted in the shoots despite variations in season and such substrate properties as pH, nitrogen source, calcium concentration, iron supply, and concentration of manganese supplied. However, the varietal differences in the roots disappeared or even reversed at high pH or low temperature of the substrate. In other research both species and cultivars were found to influence manganese content of whole plant cereals at silage stage (40). A single locus was found to determine the variation in ability of soybean cultivars to translocate chlorides (1). Foliar uptake of manganese by apples was reported to vary with the cultivar: one of six cultivars responded differently to foliar treatment with micronutrients (26). Kleese *et al.* (20) found that a consistent correlation occurred in the accumulation of phosphorus, magnesium, calcium, strontium, and manganese, suggesting that seed accumulation of this group of elements may be controlled by a coordinated genetic system. These examples illustrate the possibilities provided by the genetic approach to nutritional problems.

Chlorosis and nutrition problems have been a concern of the Western Canadian Society for Horticulture (44). Using the genetic approach, breeders at the University of Manitoba and the Research Station, Morden selected *Malus* clones for chlorosis-resistant rootstocks (25). Soybean PI 54619-5-1, which had a gene-conditioned inability to absorb iron (50), has been used to indicate the availability of iron in chlorosis test plots (24). And, because much chlorosis-susceptible plant material is grown, remediation procedures warrant further study. In trials at the University of Manitoba, Fe EDDHA increased dry weight yield of PI and Hawkeye soybeans (23). In a further experiment, yield of PI soybean was increased and chlorosis corrected by soil application of Fe 138 and by incorporation of elemental sulfur and peat moss into the soil before seeding (55). The following year the same plots were reseeded to assess the residual effect, using PI soybean and Portage soybean, a Manitoba cultivar. Tissue analysis of these leaf samples indicated that iron content of both cultivars was above the critical level, but that manganese content was low (7). This indication that manganese deficiency may be implicated in lime-induced chlorosis lead to the present study.

Sulfur lowers the pH of alkaline soil, resulting in improve plant growth because of increased availability of micronutrients (5). In southern Manitoba sulfur was observed to increase the vigor of a raspberry planting for six years following application (32). Yield and protein content of soybeans were also increased by sulfur (36).

When a micronutrient deficiency seems evident, successful treatment with a specific nutrient depends upon supplying it in a form that is available to plants. Inorganic compounds commonly used often participate in chemical reactions in the soil solution; thus the nutrient becomes inactivated or fixed in unavailable form. On alkaline soil iron in the sulfate form is less effective than as the chelate with EDDHA [ethylenediamine di-(O-hydroxyphenylacetic acid)], (23, 44, 55), known as Sequestrene 138. DTPA (diethylenetriamine pentacetic acid) or Sequestrene 330 is suitable only for acid soil. Rayplex formulations are complexes of polyflavonoids derived from hemlock bark in which phenolic hydroxyls are primarily responsible for the metal complexing action. They are available as iron, manganese, zinc, and copper complexes, and are claimed to be five to twelve times more effective than the inorganic forms, depending upon the metal and the environmental conditions. Rayplex manganese has been found to be comparable to manganese sulfate in overcoming manganese deficiencies in some species (52, 17).

In recent years much research has been focused upon synthetic chelating compounds, notably EDDHA, which has the ability to supply available iron to plants growing in calcareous soils, as previously discussed. "Chelate" is a term derived from the Greek word meaning claw, indicating the tendency of chelates to hold tightly certain cations that are attracted to them. A chelate is characterized by a cyclic structure usually containing five or six atoms in a ring in which a central metallic ion is held in coordination complex by one or more groups, each of which can attach itself to the central ring by at least two bonds. Metals bound in chelate rings have essentially lost their cationic properties. Therefore, for soil application chelates are valuable for the correction of iron or manganese chlorosis because the organic cation-chelate combination is less liable to take part in reactions with other soil constituents than is an organic compound. The chelate retains the cation in a form that is available to plants, especially in alkaline soil, where ionic forms precipitate.

The stability of metal chelates varies. For a given chelating agent, the following order of decreasing stability has been observed with bivalent ions: copper, nickel, cobalt, iron, manganese (46). This influences their behavior. For example, it is possible that manganese chelates may lose effectiveness because iron, being more stable, may substitute for the manganese ion and be absorbed by the plant. For a given metal, the various chelating compounds also have specific levels of stability. For iron, some chelating compounds in order of decreasing stability are: EDDHA, EDTA, citrate, lactate.

Naturally occurring compounds may serve as iron and manganese chelators in the uptake and transport of these ions by the plant. Wallace and Lunt (47) suggested that the excretion of chelating agents by plants may be a possible means by which plants are able to utilize iron from calcareous soil. When grown in calcareous soil, Hawkeye soybean may be green while PI becomes chlorotic. Wallace (46) has suggested that qualitative differences in natural chelating agents in the roots may be the reason for decreased movement of iron to leaves of PI compared to that of Hawkeye.

Foliar application of chemical fertilizers is standard practice for Pascal type celery, which is unable to absorb sufficient magnesium through the root system, and for crops in Arctic regions, where permafrost retards root growth (54). Foliar feeding is common with citrus. Recently, concerning manganese deficiency of citrus, Chapman (8) stated that only in cases of severe deficiency, with dieback, was there a significant yield response to manganese treatments; if the deficiency were slight to moderate, the only response was improved color. Formulations combining several micronutrients (26, 31) and a complete fertilizer (10) have also been used. Recent Canadian work (26) indicates that a mixture containing 45 percent ziram, 15 percent ferbam and 15 percent manganous dimethyldithiocarbamate may be more effective than any other method in common use. The mixture applied at 14 pounds per acre in 60 to 100 gallons of water, resulted in a large increase in the foliar concentration of zinc. Untreated leaves averaged 20 ppm zinc compared with an average of 83 ppm for sprayed leaves. Increases of iron and manganese were much lower.

Compared to soil application, foliar feeding is less expensive because less chemical is used (42), and application may be combined with regular pest control (54). Response is rapid, free from complicated soil reactions, and no irrigation is required to promote uptake. Disadvantages are the need for repeated application and a greater chance of plant damage due to toxicity (51). Concerning rate of application, the difference between toxicity and insufficiency may be slight and variable. Favorable light, temperature, and moisture regimes promote uptake from foliar feeding, whereas stress factors reduce both vigor and absorption. Physical injury or any situation that results in reduction in metabolism, may produce stress factors and changes in nutrient absorption. Time of day effects vary; highest absorption has been reported during the daytime (13), and at night (43). It is usually recommended that sprays be applied when leaves are turgid, morning or evening (53). High humidity lengthens the time that foliar applied nutrients are available for absorption (13), and may also cause dried droplets to go back into solution (28) to again allow nutrient absorption.

Temperature is a very important factor in plant metabolism. All permeation and transport rates are related to temperature. A lowering of root temperature was reported to result in leaves that were less fully expanded and less hydrated, with thicker cuticle. These changes in leaf anatomy of beans and peas had a pronounced effect on both absorption and transport of labelled calcium and phosphorus (33).

The uptake of nutrient sprays appears to be governed by various plant characteristics. When leaf morphology was modified by chemical means, a significant change in nutrient uptake occurred (29). Differences in leaf thickness produced differences in absorption of labelled rubidium by tomato leaves, but not by bean leaves. Stomate frequency had a positive influence on uptake (19), however, absorption is also reported to take place through the cuticle in the absence of stomates (9). According to Franke (15), iron applications to chlorotic leaves resulted in greening of tissues at mechanical breaks in the cuticle. He considered ectodesmata to be implicated in foliar absorption. Wallace and Lunt (47) found that iron sprays were effective only in cells under a spray droplet, apparently because of the immobility of iron. Since chelating compounds vary in regard to both absorption and translocation, a more effective carrier for iron may be found (35).

MATERIALS AND METHODS

This experiment was designed to assess methods of controlling or correcting micronutrient deficiencies common to high-lime soils. Test plants were Portage soybean, a chlorosis-susceptible species, and Century field pea, which is susceptible to marsh spot, a manganese deficiency disease. Various treatments were tested. Peat moss adds organic matter and helps neutralize high-lime soil. Elemental sulfur also acidifies soil, but to a greater degree, rendering micronutrients in the soil more available to plants. Manganese was supplied as the inorganic sulfate, for soil and foliar treatments, and also as Rayplex Mn, an organic compound, manufactured on a base of hemlock bark. Although Rayplex formulations are recommended for either soil or foliar use, only the later use was tested in this study. Fe EDDHA, (Sequestrene 138), was used as an iron source for foliar and soil treatments. It will be referred to as Fe 138 in this thesis. FTE, (fritted trace elements), supplies iron, manganese, zinc, copper, boron, and molybdenum in a slow-release silicate base for soil application.

The soil was prepared by discing and harrowing. Twelve treatments (Table 1) were applied, replicated four times, in a randomized complete block design. A plot consisted of four rows, one each of Century field pea and Portage soybean, bounded by a guard row of Portage soybean on each side. Rows were ten feet long and two feet apart in each plot.

The sulfur and peat moss treatments were broadcast then incorporated into the soil to a depth of six inches with a rotary tiller. On June 12 the seed was mixed with suitable strains of *Rhizobium* inoculum to supply the specific strain of nitrogen-fixing bacteria required

TABLE 1

Soil and Foliar Treatments

Treatment	Method of Application	Rate (per acre)
1. Control, soil	---	---
2. S, elemental	incorporated	2000 lb.
3. Peat moss	incorporated	65 cu. yd.
4. Fe 138	banded	20 lb.
5. Fe 138	banded	40 lb.
6. $MnSO_4$	banded	60 lb.
7. FTE	banded	100 lb.
8. Control, foliar	---	---
9. $MnSO_4$	sprayed	3 lb.
10. $MnSO_4$	sprayed	12 lb.
11. Rayplex Mn	sprayed	2 lb.
12. Fe 138	sprayed	0.75 lb.

TABLE 2

Sources of Supply of Fertilizers and Soil Amendments

Treatment	Source
Sulfur	Standard Chemicals Ltd.
Peat moss	Sunshine brand
Fe 138	Ciba-Geigy
$MnSO_4$	Park Products Ltd.
FTE	Ferro Corp.
Rayplex Mn	Rayonier Inc.

by each species. Dry Captan was also added to control damping off disease, and the treated seed was planted with a Planet Junior seeder. The following day the banded soil treatments were applied to each four row plot in a trench dug by hand hoe, two inches to the side of the row and an inch below the seed. Peas emerged on June 20; however, soybean germination was unsatisfactory due to cool temperatures and adverse soil conditions, so they were reseeded on June 29. At the first true leaf stage plants were thinned to 10 inches apart, and one irrigation was applied on July 11.

Foliar treatments were applied with a Green Cross hand sprayer at the indicated rates (Table 1). Redistilled water with Tween-20 [polyoxyethylene (20) sorbitan monolaurate] a commercial wetting agent, was used according to label directions for the foliar control plots, while the treated plots received the same mixture plus the manganese or iron compound as indicated. Peas were treated three times at about 15 day intervals, July 22, August 10, and August 23. Soybeans developed quickly during abnormally warm weather so were treated only twice, August 5 and August 19, then leaf samples were taken at the early bloom stage, August 25.

From the seven soil treatment plots, pea leaves were sampled on July 15, soybean leaves on August 25. Leaf samples were taken at regular intervals, omitting one foot at each end of the row. The youngest mature leaf was sampled; the whole leaf of field peas and the blade only of soybeans, according to the method of Frazier *et al.* (16). On September 15 and 16 pea seed was harvested and stand and yield data were recorded.

Immediately after sampling, the plant tissue was washed by the following method, which is a modification of other workers (3, 23, 49).

Leaves or seeds were dipped quickly into containers of distilled water until free of soil, next for 15 seconds into 0.1N hydrochloric acid, then three rinses with deionized water. Washing time totaled 1.5 minutes. Moisture was shaken and drained off, and the tissue was dried in an oven set at 60C. Samples were stored in tins in a cool dark location.

Mineral nutrient content was determined in the Tissue Analysis Laboratory, Department of Plant Science, University of Manitoba, according to methods used by the Nova Scotia Agricultural College, Truro, Nova Scotia (6). The Perkin-Elmer model 403 atomic absorption spectrophotometer was used to measure potassium, calcium, magnesium, iron, manganese, zinc, and copper. Phosphorus was analyzed by colorimetry and nitrogen content was determined in the Kjeldahl Laboratory. The data was analyzed for significance of results by Analysis of Variance and Duncan's Multiple Range Test according to Steele and Torrie (38).

RESULTS AND DISCUSSION

The present study was undertaken to assess means of controlling manganese and iron deficiency diseases which occur on calcareous soils. Since soybeans are susceptible to lime-induced chlorosis, Portage, a Manitoba cultivar, was chosen for this study. Recently a local crop of field peas was rejected for soup purposes because of marsh spot, a manganese deficiency disease. Therefore the affected cultivar, Century, was selected as a second test plant.

Various soil treatments and foliar sprays were applied, and the micronutrient levels were determined by atomic absorption spectrophotometry.

Soil Characteristics

The location for this study was selected in the University of Manitoba Arboretum where iron and manganese deficiencies had occurred causing chlorosis of susceptible horticultural plants such as *Malus*, *Prunus*, and *Acer ginnala*. The soil is classified as Riverdale clay. Growing conditions in the year of the experiment were somewhat unusual. After two months of comparative drought, heavy downpours occurred on August 15 and 20, resulting in severe compaction, poor aeration and waterlogging. Such a physical condition of the soil often limits growth of plants such as soybeans.

The pH, conductivity, and calcium carbonate equivalent readings sampled at harvest time (September 15), are presented in Table 3. Each value is the mean of four replicates. Separate plot readings are listed in the Appendix, Table 6.

TABLE 3

Soil Characteristics and Yield of Plants

	Soil Characteristics			Yield (g)		
				Field Peas		Soybeans
Treatment	pH	Conductivity (mmhos)	$CaCO_3$ Equiv. (%)	Dry Matter	Seed	Dry Matter
1. Soil control	7.49	0.30	0.61	718	214	333
2. Sulfur	5.63	1.46	0.26	820	275	249
3. Peat Moss	7.13	0.29	0.26	709	209	361
4. Fe 138 20 lb/A	7.30	.29	0.20	664	203	266
5. Fe 138 40 lb/A	7.24	.30	.14	664	199	364
6. $MnSO_4$	7.30	.27	.16	713	212	325
7. FTE	7.35	.29	.20	621	164	351
8. Foliar control	7.29	.26	.25	882	278	315
9. $MnSO_4$ 3 lb/A	7.38	.32	.19	715	193	328
10. $MnSO_4$ 12 lb/A	7.31	.26	.35	795	234	318
11. Rayplex Mn	7.28	.27	.26	900	268	374
12. Fe 138	7.34	.25	.48	790	220	320

The pH ranged from 5.00 to 8.02, and conductivity ranged from 0.17 to 2.18. The calcium carbonate equivalent ranged from 0.00 to 1.23%; there were 15 plots with a 0.00% reading.

Sulfur treatment lowered the soil pH to 5.6 from 7.5. The conductivity was increased substantially, (from 0.3 to 1.5); this is important, because such values indicate a salt level high enough to be damaging to plants. The high conductivity induced by sulfur treatment appeared to have a direct effect on dry matter yield of soybeans, which was lowest in sulfur treated plots (Table 3).

Yield

Throughout the summer, growth of field peas appeared to vary according to location in the field; the better drained area, toward one side and through replication B, producing more vigorous plants. Dry weight yield of pea plants and seeds at harvest confirmed this observation. In Figure 2 the shaded areas represent plots in which the dry weight yield was above the mean for all plots. Seed weight yield followed a similar pattern. These results concur with those of similar experiments reported by Heilman (17). He concluded that heterogeneous soil conditions appeared to confound yield data with manganese-deficient peas growing in acid soil that had been over-limed.

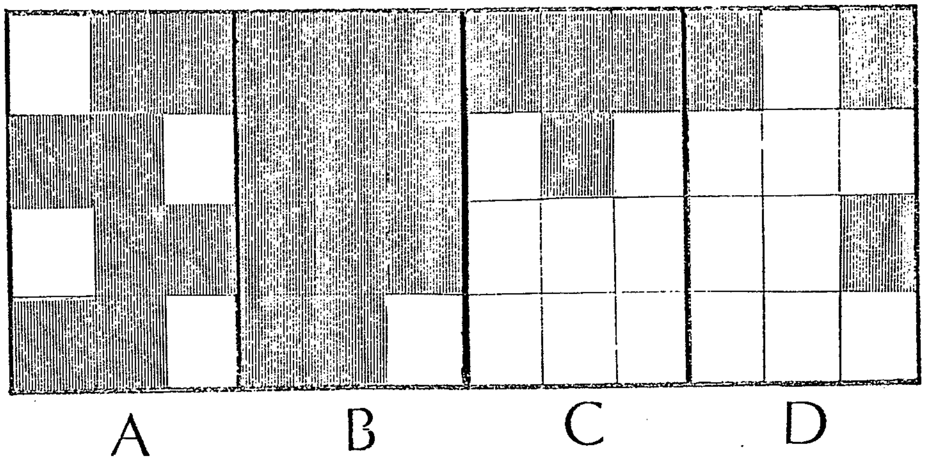

Figure 2. Yield of peas according to location in field.

Yield of field peas and soybeans is listed with corresponding soil characteristics in Table 3. No treatment produced a statistically significant difference in yield, however, there were significant replication differences for both dry matter and seed of field peas. This further illustrates the high variability within the experimental field. Statistical data are in the Appendix, Table 7a.

Micronutrient Uptake

The uptake of iron, manganese and zinc respectively by test plants, Century field pea and Portage soybean, is presented in Tables 4, 5, and 6. Micronutrient analysis of field pea leaves and seed and of soybean leaves are presented as the means of four replicates. Results from soil treatments and from foliar treatments were analyzed separately by Duncan's Multiple Range Test (38). Values followed by the same letter are not significantly different at the 5 percent level of confidence.

TABLE 4

Iron Content (ppm) of Plant Tissue

	Field Pea Leaves July 15	Field Pea Seed Sept. 15	Soybean Leaves Aug. 25
a. Soil Treatments			
Control	146 a	68.25 b	213 a
Sulfur	151 a	83.75 c	231 a
Peat Moss	152 a	76.50 bc	232 a
Fe 138, 20 #/A	151 a	71.75 b	235 a
Fe 138, 40 #/A	158 a	73.75 b	241 a
$MnSO_4$	157 a	71.00 b	216 a
FTE	149 a	51.75 a	249 a
b. Foliar Treatments			
Control		42.25 ab	255 c
$MnSO_4$, 3 #/A		46.25 b	225 ab
$MnSO_4$, 12 #/A		41.75 ab	245 bc
Rayplex Mn		36.50 a	204 a
Fe 138		43.50 b	252 bc

Means followed by the same letter are not significantly different at the 5 percent level of confidence.

TABLE 5

Manganese Content (ppm) of Plant Tissue

	Field Pea Leaves July 15	Field Pea Seed Sept. 15	Soybean Leaves Aug. 25
a. Soil Treatments			
Control	14.25 a	8.95 bc	37.75 b
Sulfur	30.25 b	10.45 c	107.75 c
Peat Moss	13.50 a	8.50 b	33.75 ab
Fe 138, 20 #/A	11.75 a	7.75 ab	29.50 ab
Fe 138, 40 #/A	12.00 a	6.75 a	26.50 a
$MnSO_4$	11.75 a	9.00 bc	31.75 ab
FTE	12.25 a	7.25 ab	32.75 ab
b. Foliar Treatments			
Control		8.25 a	38.00 a
$MnSO_4$, 3 #/A		13.00 bc	578.00 b
$MnSO_4$, 12 #/A		15.00 c	899.00 b
Rayplex Mn		10.25 ab	120.00 a
Fe 138		9.50 a	43.00 a

Means followed by the same letter are not significantly different at the 5 percent level of confidence.

TABLE 6

Zinc Content (ppm) of Plant Tissue

	Field Pea Leaves July 15	Field Pea Seed Sept. 15	Soybean Leaves Aug. 25
a. Soil Treatments			
Control	20.75 ab	31.75 b	16.00 a
Sulfur	31.50 c	39.75 c	30.75 c
Peat Moss	23.00 b	33.25 b	19.25 ab
Fe 138, 20 #/A	17.25 a	28.00 a	17.75 ab
Fe 138, 40 #/A	18.00 a	31.00 ab	19.00 ab
$MnSO_4$	20.50 ab	32.50 b	17.00 a
FTE	17.00 a	27.75 a	23.75 b
b. Foliar Treatments			
Control		27.25 ab	18.75 ab
$MnSO_4$, 3 #/A		29.75 b	16.75 a
$MnSO_4$, 12 #/A		27.00 ab	22.50 b
Rayplex Mn		24.00 a	16.50 a
Fe 138		28.00 ab	19.50 ab

Means followed by the same letter are not significantly different at the 5 percent level of confidence.

Pattern of Manganese Absorption

Additional sampling was done at earlier stages of growth to investigate the pattern of manganese absorption (Table 7). Composite samples of the four replications were taken; in the case of field peas, at thinning stage (July 5), using the above ground portion of the plant, and on July 25, using the youngest mature leaf. For soybean samples plant tops at thinning time (July 15) and the cotyledonary leaf on July 25 were used. Including data which are presented in Table 5, this constitutes a complete record of tissue levels at ten day intervals during July, and at harvest time.

Both field peas and soybeans were consistent in their pattern of manganese uptake, with the sulfur treated plots showing considerably greater levels at all stages of growth. It was concluded that tissue analysis at thinning time is a reasonably reliable indicator of the nutrients available to the plant, and appears to be useful to guide fertilization practice for that season.

Soil Treatments

The rate of growth varied slightly among treatments until thinning time. Incorporation of peat moss resulted in more vigorous seedlings. Sulfur treatment had a stunting effect on the soybeans, and plant stand was reduced. After late July there was no observable difference in plant growth. As mentioned previously, growth of the peas appeared to be affected by heterogeniety of soil conditions. Results of tissue analysis indicated variations in nutrient uptake according to soil treatment.

TABLE 7

Pattern of Manganese Absorption (ppm)

	Plant Tops July 5	Leaf July 15	Leaf July 25	Seed Sept. 15
a. Field Peas				
Control	17	14.25	11	8.95
Sulfur	33	30.25**	29	10.45
Peat Moss	14	13.50	13	8.50
Fe 138, 20 #/A	15	12.25	13	7.75
Fe 138, 40 #/A	15	12.00	10	6.75*
$MnSO_4$	13	11.75	12	9.00
FTE	16	11.75	10	7.25

	Plant Tops July 15	Cotyledonary Leaf July 25	Leaf Aug. 25
b. Soybeans			
Control	30	30	38
Sulfur	445	60	108**
Peat Moss	33	27	34
Fe 138, 20 #/A	27	26	30
Fe 138, 40 #/A	21	27	27*
$MnSO_4$	21	29	33
FTE	21	29	33

* Significant at the 5% level.

** Significant at the 1% level.

a. Sulfur. Sulfur treatment resulted in a significant increase in leaf manganese; it was doubled in pea leaves and almost tripled in soybean leaves. Pea seed manganese was also highest in the sulfur treatment, but the difference over the control level was not significant (Table 5).

The other micronutrients reacted to this treatment in a similar way. The iron level of pea seed and the zinc content of all plants were significantly increased by the sulfur (Tables 4 and 6 respectively).

In this study the root systems of the peas perhaps extended beyond the acidifying effect of the sulfur before much seed development had taken place, thus a deficiency of available manganese due to alkalinity could have affected seed levels in spite of high leaf manganese in mid-July. Manganese levels as high as 22 ppm have been reported in pea seed (21), so the levels obtained in this study were well below those possible.

The increase in availability of most micronutrients due to acidification is well documented (5, 12). Only molybdenum is more available in alkaline soil than it is in acid soil. However sulfur treatment as a means of acidification appears to have definite disadvantages. On areas treated the previous year several volunteer species and spinach plants were stunted; soil structure, and perhaps also soil microorganisms, appeared to be adversely affected. Increased soil conductivity as discussed under Soil Characteristics, may be involved in these detrimental effects of sulfur treatment. Therefore sulfur treatment must be recommended for small scale use, preferably mixed with organic matter such as peat moss or compost, and incorporated deeply into the soil near the feeder roots.

b. Peat moss. There were no significant changes in micronutrient uptake by test plants grown in plots into which peat moss had been incorporated. Increased vigor occurred at the seedling stage in treated plots, but this difference was outgrown by early August, probably because the feeder roots had grown beyond the treated soil.

Incorporation of peat moss is common practice on clay soils, and because organic matter decomposes quickly, application must be repeated every two or three years. It is practical to include sharp sand or perlite with the peat moss for more permanent improved aeration.

c. Fe 138. Application of Fe 138 (Fe EDDHA) did not affect iron levels of any plant tissue (Table 4); however, it did result in significant decreases in uptake of other micronutrients. Soil treatment with this iron chelate reduced both the manganese content of soybean leaves (Table 5) and the zinc content of pea seed (Table 6).

Although these results were unexpected, they do concur with reports by Wallace (46) who stated that iron chelates can compete with or inhibit the uptake of manganese and other micronutrients by plant roots. He also suggested that this phenomenon could make possible the control of manganese toxicity.

The experimental results also appear to conflict with the proven ability of this formulation to increase yield by addition of available iron to deficient plants (46, 12, 23).

Iron levels of chlorotic leaves are notoriously inconsistent, according to Wallace and Lunt (47). Iron may become non-functional - precipitated as insoluble phosphate in the vascular tissue (4, 50). This has been confirmed by the use of labelled iron (34, 39). In this study preliminary experiments revealed veinal tissue of healthy PI leaves to contain over 60% more iron than did interveinal tissue. When a plant becomes unthrifty, mobile nutrients move from the leaves resulting in proportionally higher concentrations of less mobile elements such as iron and calcium. Thus many factors including sampling, preparation (washing), and handling techniques, can contribute to unexpectedly high levels of iron in plant tissue.

d. $\underline{MnSO_4}$. Soil application of manganese sulfate did not significantly affect nutrient content of test plants. The rate of application may have been too low for the conditions in this experiment.

e. FTE. The effect of soil application of fritted trace elements varied with the test plant zinc content of soybean leaves was significantly increased (Table 6); while, in the case of field peas, both zinc and iron levels of the seed were significantly decreased (Tables 6 and 4).

FTE contains iron, manganese, zinc, copper, boron and molybdenum in a slow-release silicate base. There have been several formulations of FTE, each containing different proportions of nutrients, and recently the manufacturer has publicized an acid-base frit more suitable for calcareous soils. Since there were variable results in this study, further trials with other formulations and an assessment of residual effect over two to four years are recommended. Also, different formulations may be useful for different crops.

Foliar Treatments

Fertilization of crops by foliar application requires considerably less plant food than does soil treatment. In calcareous soil, where heavy metal interactions and fixation problems occur, foliar treatment may be the most dependable means of correcting micronutrient deficiencies. Considering growth responses, yield increase, and alleviation of nutritional disorder symptoms, studies have shown foliar sprays to be most effective (54).

a. $MnSO_4$. Foliar application of manganese sulfate at either level significantly increased the manganese content of field pea seed, and resulted in a large increase in soybean leaf manganese (Table 5).

This concurs with literature reports concerning the effectiveness of $MnSO_4$ sprays for the correction of manganese deficiencies (14). Increasing the manganese level of pea seed was considered to imply successful correction of manganese deficiency diseases such as chlorosis and marsh spot.

A depression of iron accumulation by soybean leaves appeared to result from foliar application of $MnSO_4$ (Table 4). This may have involved a complex interaction of tissue manganese with iron absorption or transport.

b. Rayplex Mn. At the recommended rate of application as used in this study, Rayplex Mn was not effective in significantly increasing manganese content of any plant tissue (Table 5).

Depressed accumulation of iron by soybean leaves resulted from foliar application of Rayplex Mn, as was also the case with $MnSO_4$ (Table 4).

c. Fe 138. Foliar application of Fe 138 did not increase iron levels or result in any other changes in the nutrient content of plant tissue.

Heavy Metal Interactions

a. Soil Treatments. Soil application of one heavy metal may cause inhibited uptake of another metal. This phenomenon, known as a heavy metal interaction, is well documented (5), and also has been recognized when synthetic chelating compounds are involved (46, 47).

In this study manganese absorption by both test plants was decreased by Fe 138, and iron accumulation by pea seed was inhibited by FTE. The behavior of zinc in response to FTE treatment was variable; the accumulation of zinc by soybean leaves was increased, but by pea seed was decreased.

b. Foliar Treatments. An apparent depression in iron uptake by plant roots resulted from foliar application of manganese in two forms, Rayplex Mn and manganese sulfate. This was unexpected; however, in a similar type of interaction, Labanauskas (22) reported that zinc sprays with manganese increased the zinc content of citrus peel to a significantly greater extent than did the zinc sprays without added manganese.

Nutrient Content of Chlorotic Horticultural Plants

As a result of some of the anomalies evident in the data from tissue analysis of green and chlorotic soybeans, it was decided to take samples from other chlorotic species growing in the University of Manitoba Arboretum and in the Field Laboratory. Plants selected for this survey had chlorosis symptoms reasonably typical of iron deficiency, that is, leaves were yellow with green veins. The stage of chlorosis was rated from 1 to 4 denoting, respectively, green, chlorotic, chlorotic with necrosis, and necrotic to non-functional (Table 8).

TABLE 8

Nutrient Content of Some Chlorotic Horticultural Plants

	Stage of Chlorosis*	Fe ppm	Mn ppm	Fe/Mn	Zn ppm	Cu ppm	N %
Glycine max, PI 54619-5-1	1	160	173	0.9	-	-	5.1
	2	184	102	1.8	-	-	5.1
	3	276	141	1.9	-	-	4.6
	4	842	136	6.2	-	-	4.6
Acer ginnala (July sampling)	1	56	26	2.2	-	-	-
	2	54	38	1.4	-	-	-
	3	130	45	2.8	-	-	-
Acer ginnala (August sampling)	1	60	22	2.8	18	6	2.1
	2	73	35	2.1	20	7	2.4
Amelanchier alnifolia	1	85	74	1.1	17	15	2.2
	2	97	55	1.8	16	12	2.1
	3	83	30	2.8	17	12	2.2
Cotoneaster lucida (May sampling)	1	102	23	4.4	42	24	3.4
	2	111	16	6.9	39	16	3.8
Cotoneaster lucida (August sampling)	1	79	25	3.2	38	28	-
	2	49	22	2.2	50	50	-
Populus deltoides (Clone no. 1)	1	69	37	1.9	28	9	2.7
	2	58	35	1.7	29	9	2.7
	3	65	36	1.8	40	13	-
Populus deltoides (Clone no. 2)	1	63	43	1.5	17	8	3.1
	2	65	40	1.6	15	10	2.8
	3	70	36	1.9	28	14	3.5
Rubus, Killarney	1	74	29	2.6	51	82	3.5
	2	62	18	3.5	49	82	3.3
	3	74	20	3.7	66	51	3.6
Viburnum lantana	1	61	12	5.1	17	9	2.8
	2	65	10	6.5	11	9	2.7
Viburnum sargenti, seed	1	22	5	4.4	11	12	1.5
	3	20	5	4.0	20	33	-

* Stages 1 to 4 denote respectively, green, chlorotic, chlorotic with necrosis, and necrotic to non-functional.

All samples within a species were taken from the same plant or clone with the exception of *Acer ginnala* and PI soybean. The *A. ginnala* samples were from three separate plants growing in the chlorosis test area. Those plants rated as stage 3 were removed before the August sampling. Samples consisted of the blade and petiole of the youngest mature leaf for all plants except *Rubus*, for which only the blade was used. Seed of *Viburnum sargenti* was from separate green and severely chlorotic branches. PI values were the means of two samples; the remainder were single samples consisting of at least ten leaves.

Since nitrogen levels were quite consistent within species regardless of stage of chlorosis, a deficiency of nitrogen did not seem to be involved. There was considerable variation among the micronutrient levels, however, some trends were observed. Iron content of the samples appeared to increase, or remain constant, as chlorosis increased; however, in several species manganese level decreased, indicating a manganese deficiency. On the basis of seed manganese, chlorosis of *V. sargenti* did not appear to involve seed manganese.

Chlorotic tissue of several species was observed to contain comparatively high levels of zinc or copper, suggesting adverse heavy metal interactions or toxicities. The high content of copper and zinc in *Rubus* leaves was also of interest.

Evaluation of Tissue Analysis

A nutrient deficiency or toxicity is indicated by a comparison of tissue analysis readings with the known optimum range for the specific plant and index tissue. In this study the iron and manganese levels of the soybean leaves were well within the sufficiency range. The range for iron is 51 to 350 ppm (48) and for manganese it is 21 to 100 ppm (16). Pea leaves are reported to become chlorotic at 15 ppm manganese (2), so although it was not visually obvious in the present study, pea plants were probably manganese-deficient in all plots but the sulfur treatment.

Samples were taken from a shipment of Century pea seed that had been rejected because of marsh spot. The results of tissue analysis are in Table 9.

TABLE 9

Nitrogen (% dry weight) and Micronutrient content (ppm) of samples of Century peas

	N	Fe	Mn	Zn	Cu
Marsh Spot	3.96	48	4	34	9
No Marsh Spot	3.76	50	8	32	8

Seed with marsh spot disease contained 4 ppm manganese while unaffected seed contained 8 ppm manganese. It is notable that the protein content of rejected seed is not changed by the marsh spot disease.

In the thesis experiment, seed harvested from several plots contained marsh spot, notably those treated by soil application of Fe EDDHA. Seed used for this study was unaffected by the disease.

Results of a preliminary experiment using PI soybean gave definite indication of an iron deficiency, however iron content of the leaves was well within the sufficiency range. PI has a gene-conditioned inefficiency for iron absorption (50). Where soil pH was above 7.3, PI thrived only in sulfur-treated plots, as shown in Figure 3, center. Other soil or foliar treatments using iron or manganese or both, failed to improve vigor. Iron, rendered available by the acidifying effect of sulfur treatment, caused a phenomenal improvement in the growth rate of the plants. Although one would assume that this improved growth would be due to increased uptake of iron, the tissue analysis did not support this hypothesis.

Plant metabolism governs movement of nutrients within a plant. Unthriftiness or normal senescence may result in loss of mobile nutrients and metabolites from the leaves, thus changing the proportions of less mobile nutrients. For example, as a plant responds to iron deficiency by stunted growth and decreased accumulation of carbohydrates in the leaves, there is an increase in the actual ppm of the less mobile iron in the dry weight of the leaves. Thus the technique of tissue analysis, (based on weight), is less accurate than the use of radionuclides to assess the uptake of iron.

Figure 3. PI 54619-5-1 soybean. The sulfur treated plot is near the center of the photograph.

SUMMARY AND CONCLUSIONS

1. Since sulfur incorporated into the soil and manganese sulfate sprayed on the foliage of field peas and soybeans increased the manganese content of the plant tissue, it was concluded that these treatments would control manganese deficiency diseases such as chlorosis and marsh spot of peas.

2. Sulfur was the most effective soil treatment, apparently because its acidifying effect increased the availability of micronutrients present in the soil. Iron, manganese and zinc levels of tissue were all increased by incorporation of sulfur.

3. Manganese sulfate applied twice as a foliar spray effectively controlled manganese deficiencies of field peas and soybeans.

4. Incorporation of peat moss into the soil increased the vigor of the plants at the seedling stage, however there was no significant difference in dry weight yield at harvest nor was there a change in nutrient levels in the tissues due to the peat moss treatment.

5. Soil application of manganese sulfate did not affect the micronutrient content of those plant tissues studied.

6. Foliar treatment with Rayplex manganese did not increase the manganese level of plants.

7. Neither soil nor foliar application of Fe 138 affected the iron content of field peas or soybeans.

8. Fritted trace elements effected nutrient changes that varied with the test plant; zinc content of soybean leaves was increased, while both zinc and iron levels of pea seed were decreased.

9. Although soil application of Fe 138 did not affect iron levels,

it inhibited accumulation of both manganese and zinc by pea seed, thus contributing to the manganese deficiency disease, marsh spot.

10. It was concluded that heavy metal interactions were involved in the inhibition of micronutrient uptake resulting from soil treatments with FTE and Fe 138.

11. Foliar applications of both manganese sulfate and Rayplex Mn effected a depression in iron uptake by plant roots. This may have involved a complex interaction of tissue manganese with iron absorption or transport.

12. A study of the pattern of manganese uptake showed that nutrient levels of plants at thinning time may be useful as a guide to fertilization practices for the crop that season.

13. Based on nutrient contents of green and chlorotic leaves of various horticultural species, it is suggested that high levels of zinc and copper and a possible manganese deficiency may be involved in lime-induced chlorosis.

14. Leaves of chlorotic plants may contain high levels of iron that are non-functional - precipitated as insoluble phosphate in the vascular tissue. Mobile nutrients and metabolites move from unthrifty leaves, resulting in proportionally higher concentrations of less mobile elements such as iron. Thus an iron level within the optimum range, as determined by tissue analysis, is not always indicative of an iron-sufficient plant.

15. This study of the micronutrient content of plants treated for possible iron or manganese deficiencies, indicated that tissue analysis results must be evaluated with prudence based on the knowledge of the physiology of plant-soil interactions.

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APPENDIX - TABLE 1

Nutrient Composition of Pea Leaves, Soil Treatments
(Mean of 4 replications)

	N %	P %	K %	Ca %	Mg %	Cu ppm
Control	4.13	.203	3.50	1.68	0.98	7.75
Sulfur	4.13	.188	3.48	1.73	1.10	8.00
Peat	3.95	.198	3.25	1.60	0.93	8.75
Fe 138 20 lb/A	3.98	.173	3.33	1.73	1.00	7.50
Fe 138 40 lb/A	4.10	.190	3.33	1.63	0.90	9.00
$MnSO_4$	3.83	.188	3,10	1.50	0.93	7.25
FTE	3.90	.180	3.13	1.60	0.90	7.75
Experimental Mean	4.00	.188	3.30	1.64	0.96	8.00
Coef. of Var.	4.4%	10.1%	11.2%	13.3%	13.0%	17.7%
l.s.d. (.05)						
l.s.d. (.01)						
F Value	1.83	1.11	0.71	0.55	1.33	0.83

APPENDIX - TABLE 2

Nutrient Composition of Pea Seed, Soil Treatments
(Mean of 4 replications)

	N %	P %	K %	Ca ppm	Mg %	Cu ppm
Control	4.63	.375	1.00	597	0.30	5.50
Sulfur	4.43	.378	0.88	765**	0.30	9.50**
Peat	4.65	.403	0.94	555	0.30	7.25*
Fe 138 20 lb/A	4.48	.368	0.95	535	0.29	7.25*
Fe 138 40 lb/A	4.85	.398	0.99	540	0.30	7.25*
$MnSO_4$	4.50	.358	1.05	485*	0.29	7.00*
FTE	4.50	.323**	0.98	460**	0.29	8.00**
Experimental Mean	4.58	.371	0.97	563	0.30	7.39
Coef. of Var.	6.7%	5.0%	4.8%	10.7%	2.9%	13.6%
l.s.d. (.05)		.028		89.6		1.5
l.s.d. (.01)		.038		112.8		2.0
F Value	0.92	8.23**	0.04	9.00**	0.52	5.88**

* Significant at the 5% level.

** Significant at the 1% level.

APPENDIX - TABLE 3

Nutrient Composition of Soybean Leaves, Soil Treatments
(Mean of 4 replications)

	N %	P %	K %	Ca %	Mg %	Cu ppm
Control	5.28	.438	1.43	1.85	1.58	5.25
Sulfur	5.23	.435	1.45	1.73	1.58	4.50
Peat	5.25	.438	1.55	1.73	1.48	5.25
Fe 138 20 lb/A	5.15	.420	1.40	1.88	1.60	5.25
Fe 138 40 lb/A	5.40	.380	1.48	1.90	1.60	5.25
$MnSO_4$	5.50	.428	1.58	1.73	1.55	5.75
FTE	5.08	.410	1.48	1.68	1.50	5.75
Experimental Mean	5.27	.421	1.48	1.78	1.55	5.29
Coef. of Var.	10.6%	16.8%	8.9%	12.6%	8.4%	9.3%
l.s.d. (.05)						0.7
l.s.d. (.01)						
F Value	0.26	0.35	0.94	0.65	0.56	2.90*

* Significant at the 5% level.

APPENDIX - TABLE 4

Nutrient Composition of Pea Seed, Foliar Treatments
(Mean of 4 replications)

	N %	P %	K %	Ca ppm	Mg %	Cu ppm
Control	4.45	.405	1.03	570	.239	5.75
$MnSO_4$ 3 lb/A	4.57	.405	1.05	540	.243	6.25
$MnSO_4$ 12 lb/A	4.66	.398	1.03	558	.237	4.75
Rayplex Mn 2 lb/A	4.49	.398	1.05	548	.234	5.00
Fe 138 3/4 lb/A	4.55	.398	1.03	583	.238	5.50
Experimental Mean	4.54	.401	1.04	560	.238	5.45
Coef. of Var.	7.3%	4.2%	4.4%	8.1%	3.7%	14.1%
l.s.d. (.05)						
l.s.d. (.01)						
F Value	0.23	0.25	0.36	0.57	0.62	2.41

APPENDIX - TABLE 5

Nutrient Composition of Soybean Leaves, Foliar Treatments
(Mean of 4 replications)

	N %	P %	K %	Ca %	Mg %	Cu ppm
Control	5.56	.433	1.48	1.83	1.58	6.25
$MnSO_4$ 3 lb/A	5.19	.430	1.48	1.72	1.49	5.00
$MnSO_4$ 12 lb/A	5.75	.508*	1.58	1.70	1.47	7.00
Rayplex Mn 2 lb/A	5.60	.438	1.45	1.84	1.59	6.00
Fe 138 3/4 lb/A	4.87	.480	1.40	1.80	1.48	5.75
Experimental Mean	5.40	.458	1.48	1.78	1.52	6.00
Coef. of Var.	12.2%	7.6%	9.1%	10.7%	8.9%	15.7%
l.s.d. (.05)		.054				
l.s.d. (.01)						
F Value	1.19	3.97*	0.91	0.45	0.75	2.38

* Significant at the 5% level.

APPENDIX TABLE 6

Soil Characteristics of Experimental Plots

Replication	Treatment No.	pH	Conductivity (mmhos)	$CaCO_3$ Equiv. (%)
A	1	8.02	0.36	1.23
	2	5.75	2.18	0.59
	3	7.21	0.40	0.50
	4	7.40	0.46	0.47
	5	7.20	0.38	0.24
	6	7.22	0.32	0.15
	7	7.37	0.40	0.29
	8	7.15	0.32	0.18
	9	7.25	0.46	0.00
	10	7.35	0.28	0.53
	11	7.20	0.32	0.50
	12	7.30	0.27	0.35
B	1	7.25	0.41	0.21
	2	6.76	0.39	0.00
	3	7.10	0.32	0.00
	4	7.22	0.29	0.00
	5	7.30	0.36	0.18
	6	7.27	0.34	0.47
	7	7.22	0.26	0.41
	8	7.22	0.28	0.32
	9	7.22	0.39	0.32
	10	7.30	0.31	0.00
	11	7.15	0.30	0.00
	12	7.15	0.24	0.21
C	1	7.30	0.22	0.29
	2	5.00	2.10	0.00
	3	7.15	0.22	0.00
	4	7.27	0.20	0.00
	5	7.22	0.26	0.00
	6	7.30	0.19	0.00
	7	7.35	0.26	0.00
	8	7.30	0.17	0.00
	9	7.50	0.20	0.00
	10	7.20	0.22	0.41
	11	7.42	0.21	0.21
	12	7.32	0.22	0.64
D	1	7.40	0.22	0.70
	2	5.00	1.15	0.44
	3	7.05	0.21	0.53
	4	7.30	0.21	0.32
	5	7.25	0.19	0.15
	6	7.40	0.21	0.00
	7	7.45	0.24	0.09
	8	7.50	0.27	0.50
	9	7.55	0.24	0.44
	10	7.40	0.22	0.44
	11	7.35	0.24	0.32
	12	7.60	0.26	0.73

APPENDIX TABLE 7

Supplementary Statistical Data

(a) Yield

	Treatment	Experimental Mean (g)	Error Mean Square	F Value		Coeff. of Var. (%)
				Treatments	Replications	
SOYBEAN, Dry Matter	Soil	321	6147.72	1.37	0.68	22.4
	Foliar	331	5816.98	0.42	0.35	23.0
FIELD PEAS, Dry Matter	Soil	701	23790.30	0.67	3.29*	22.0
	Foliar	816	3365.35	0.96	2.67	7.1
FIELD PEAS, Seed	Soil	211	1870.28	2.32	4.23*	20.5
	Foliar	239	23814.48	1.45	2.53	64.6

* Significant at the 5% level.

APPENDIX TABLE 7

Supplementary Statistical Data

(b) Micronutrient Content

	Element	Experimental Mean (ppm)	Error Mean Square	F Value	Coeff. of Var. (%)
Field Pea Leaves					
soil treatments	Fe	152.00	409.51	0.18	13.3
	Mn	15.10	34.38	5.29**	38.8
	Zn	21.20	8.04	12.73**	13.4
Field Pea Seed					
soil treatments	Fe	71.00	36.94	10.50**	8.6
	Mn	8.50	1.19	5.84**	12.9
	Zn	32.00	4.42	14.60	6.6
foliar treatments	Fe	42.00	15.74	3.22	9.4
	Mn	11.20	3.94	7.66**	17.7
	Zn	27.25	10.69	1.63	12.0
Soybean Leaves					
soil treatments	Fe	321.00	727.75	0.91	11.9
	Mn	42.75	39.66	83.90**	14.7
	Zn	20.50	14.24	7.47**	18.4
foliar treatments	Fe	236.00	311.18	6.03**	7.4
	Mn	335.00	36395.09	16.41**	54.5
	Zn	18.75	11.31	2.09	17.9

* Significant at the 5% level.

** Significant at the 1% level.

APPENDIX TABLE 8

Mean Yield (g) by Replication

Replication	Field Peas		Soybeans
	Dry Matter	Seed	Dry Matter
A	765	203	323
B	865	263	307
C	710	229	330
D	654	193	338
Experimental Mean	748.5	222.0	325.1