THESIS

This is to certify that the

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Effect of Rate and Placement of Phosphorus and Potassium Fertilizers on Yield and Nutrient Content of Beans, Cabbage, Carrot and Lettuce

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EFFECT OF RATE AND PLACEMENT OF PHOSPHORUS AND POTASSIUM FERTILIZERS ON YIELD AND NUTRIENT CONTENT OF BEANS, CABBAGE, CARROT AND LETTUCE

by

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ABSTRACT

The effects of rate and placement of phosphorus and potassium fertilizer application on field and composition of snap beans, cabbage, carrot and lettuce were studied in field and greenhouse experiments.

The field study was established on a Washtenaw silt loam soil high in P and K. The soil used for the greenhouse experiment was a P and K deficient Marlette fine sandy loam.

For both field and greenhouse experiments and for each of the four crops, two rates of fertilization and three methods of fertilizer placement were used. The fertilizer rates were: one hundred percent of the recommendation based on soil analysis and fifty percent of the recommendation. Fertilizer placements used were: band, broadcast and plane.

In the field experiments, one-half of the fertilizer rate applied in a plane was the most effective method and rate for bean and carrot yields. This same rate applied banded was the most effective treatment for cabbage.

Generally, the rates of fertilizer slightly increased the concentration of K and tended to decrease the concentrations of Ca and Mg in the leaves. No effects were observed in P concentrations.

In the greenhouse experiments, plane placement of the fertilizer at the recommended rate resulted in greatest

yields of cabbage and lettuce. The best yields of snap beans and carrots were produced by the recommended rate applied in a band. For all the crops the band placement at one-half rate produced only slightly lower yields than the best treatments.

Generally, fertilizers increased the concentrations of P and K and decreased the concentration of Ca and Mg in shoots and roots. Phosphorus and potassium uptake was increased by all rates of fertilizer application. Banded and planed fertilizers produced higher P and K uptake than broadcast.

One-half the recommended rate slightly increased the soil P level in the soil. The recommended rate increased the available P level by about one-fourth the amount of P added by the fertilizer. Generally soil P in the checks decreased after cropping.

The level of exchangeable K was increased by each level of fertilizer application.

DEDICATION

To my wife Susy.

To my children, Dario Xavier, Juan Diego and Claudia Susana.

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TABLE OF CONTENTS

Tables of Content.--Cont.

Table of Contents.--Cont.

Table of Contents.--Cont.

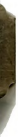

Table of Contents.--Cont.

LIST OF TABLES

List of Tables.--Cont.

INTRODUCTION

It has been well known that as native soil fertility levels are lowered and yield goals are raised, farmers become more dependent upon supplemental fertilizers to supply nutrients for plant growth. This is also true in Ecuador where the rapid growth of population and the demand for a higher standard of living in the rural areas make it imperative to rapidly increase the production of farmers.

The world average use of total $N\text{-}P_2O_5\text{-}K_2O$ per hectare in 1969 was 39.95 kg/ha (FAO 1969). The Ecuatorian average was less than third of this with 11.0 kg/ha, less than one tenth of Europe's at 138.6 kg/ha. In the majority of situations on the highlands of Ecuador, where land is limited fertilizers are not used. The main reason for this is economic.

For Ecuador, as a developing country, fertilizers tend to be more expensive to the farmer than in developed countries and the price received by the farmer for his produce lower; so that one of the essential tasks of the research agronomist in Ecuador is to learn how to maximise fertilizer response.

Net returns from investments in phosphate and potash fertilizers depend largely upon the proportion of the

fertilizer which enters the plant. If it is assumed that only five to fifteen percent of fertilizer phosphorus (Draycott 1972) and about fifty percent of potassium (DeMent and Stanford 1959) applied to the soil are removed by a crop the first year after application: the efficiency of uptake should be affected by placement (Barber 1959).

On soils testing low in available P, band placement is generally very efficient and often produces larger yield increases than an equivalent broadcast rate (Welch et al 1966).

Banding near the seed in the row, or placing the fertilizer in the furrow with the seed and using only a fraction of the amount of fertilizer recommended, are some of the methods that small farmers of the Ecuatorian Andes use to reduce the fertilizer bill. For making fertilizer recommendations in this area, the grower's financial situation is an important consideration.

The efficiency of rates and placement of fertilizer on beans (Phaseolus vulgaris L.), cabbage (Brassica oleraceae var. capitata), carrot (Daucus carota L.) and lettuce Lactuca sativa L.) are of prime concern on the highlands of Ecuador, because: (1) these are the principle areas of cool season vegetable production and; (2) much evidence has been accumulated to show that P deficiencies are common in this horticultural producing region.

The objectives of this study were:

1. Determine the influence of rate and placement of phosphorus and potassium fertilizer application on yield and composition of beans, cabbage, carrot and lettuce.

2. To gain experience with fertilizer placement experiments in vegetable crops.

LITERATURE REVIEW

Phosphorus

Phosphate fertilizer behavior in soils

When granulated fertilizers containing a high percentage of monocalcium phosphate (triple superphosphate) are added to moist soils, water moves into the granule dissolving the phosphate and producing a concentrated phosphate solution; as phosphate moves out of the granules, it interacts with the solid phase of the soil (Fox, 1981 and Tisdale and Nelson, 1975). Lehr et al (1959) observed that upon formation of the nearly saturated solution in and around the fertilizer granule or band, an osmotic potential gradient is established between the concentrated fertilizer solution and the soil water. Huffman and Taylor (1963) demonstrated that the process of inward movement of water and outward movement of solution continues to produce a nearly saturated solution so long as any of the original salt remains.

Lindsay and Stephenson (1959) added superphosphate granules to an acid mineral soil and observed that the solution emerging from the granule had a pH of 1.0 to 1.5, a P concentration of 4 to 4.5 M and a Ca concentration of about 1.4 M. As successive increments of soil are contacted by the

moving front of the fertilizer solution, increasing amounts of Fe, Al and Mn dissolved in acid soils and Ca and Mg in calcareous soils; in time the phosphate of these ions are precipitated.

Factors influencing phosphate availability

Many authors have indicated that the effectiveness of applied fertilizer phosphorus depends on P source, soil type, crop grown, application method and weather.

Olsen and Watanabe (1963) have observed that diffusion rate of P is less in sandy soils than in clay soils. Therefore, soil solution P in a sandy soil has to be higher than a clay soil in order to supply the same amount of P to the plant. They have also stated that the P buffering capacity of sandy soils is less than that of clay soils.

Phosphorus deficiency symptoms

Phosphorus deficiency results in a decreased rate of respiration before photosynthesis is slowed. When respiration slows down sugars start to accumulate in the tissues. As a result of that accumulation, a purple pigment develops and gives leaves and lower stems one of the characteristics of phosphorus deficiency (Follet et al, 1981).

On vegetables it is usually typified by stunting of the plant and often by dark green and/or purple leaves and stems. The stems are thin and shortened in growth. Poor growth and retarded development are often the only symptoms of P deficiency. In cabbage and lettuce, under severe deficiency

leaf veins may become reddish or purplish (Lorenz and Vittum, 1980). Follet et al (1981) reported that phosphorus deficiency in carrots is best characterized by poor root systems. For beans Vitosh et al (1978) have related that the first symptom of P deficiency is slow growth, later the leaves turn yellow and die. This occurs first on the older leaves.

Maturity is usually delayed in plants which are P-deficient. Lorenz and Vittum (1980) stated that in cabbage (Brassica oleracea var. capitata) and lettuce (Lactuca sativa L.), P-deficient plants often reach harvestable size as much as several weeks later than plants receiving optimum quantities of P. Applications of P beyond those required for optimum growth do not further hasten maturity.

Pattern of nutrient uptake

The vegetables studied are usually grown for a relatively short time and harvested before full maturity.

Zink and Yamaguchi (1962) found that lettuce which was harvested 80 days after seeding was still growing and was rapidly absorbing P at the time of harvest. Similar demand patterns would be exhibited by foliar vegetables such as cabbage (Peck and Stamer, 1970). Peck (1975a) found that snap beans (Phaseolus vulgaris L.) which were harvested 56 days after seeding showed the greatest rate of P accumulation in the last two weeks before harvest.

Rates of fertilizer phosphorus and potassium

The yield level determines largely the amount of phosphorus and potassium taken up by the vegetables. It is evident that recommendations for P and K fertilization should be related to the amount of P and K in soil as determined by a soil test. Foliar analysis is, however, useful for evaluating the adequacy of a fertilizer program.

Warncke and Christenson (1981) established soil response values for many vegetables.

Placement of nitrogen with phosphorus

Grunes (1959), Miller and Ohlrogge (1958) and Olson and Dreir (1956), demonstrated that fertilizer P uptake by a number of crops was enhanced by application of nitrogen fertilizer in a band with phosphorus. Stimulation of fertilizer P uptake was less when the N was applied separately (e.g. broadcast) from the banded P or when N and P were both mixed throughout the soil Also, NO_3 was less effective than NH_4 in stimulating P uptake.

Placement of phosphorus with potassium

Since potassium is readily absorbed on the exchange complex and as observed by many workers alternate wetting and drying of the soil tends to promote fixation of K, there seems to be little reason to separate the placement of K from that of P, at least in soils with high exchange

capacity (Follet et al, 1981). On coarser textured soils with low exchange capacity, movement of K with moisture would be more pronounced and should be similar to that of the ammonium cation (Rich, 1968). On such soils it would appear logical to place K and N similarly.

Potassium

Fertilizer potassium in the soil

Bray and DeTurk (1939) proposed that soils have an equilibrium value for exchangeable potassium. If cropping lowers the exchangeable potassium level, potassium is released with time to the original level; whereas if an excess is applied, potassium is fixed so that the level tends to be maintained.

It appears that in most soils plant availability of potassium fertilizers is influenced by the type and amount of clay mineral present, the soil pH, soil temperature, soil moisture and soil aeration (Volk 1934, Weir 1965, Barshad 1954, Rich and Black 1964).

Deficiency symptoms

The subject of potassium deficiency has been reviewed by many authors (HeWitt 1963). Because the potassium ion is mobile and moves to the younger leaves where the supply is short, the symptoms are more severe on the older than the younger leaves. Vegetables have a high requirement for potassium and deficiency symptoms develop easily. In cabbage and lettuce under severe deficiency, the leaves develop

marginal chlorosis rendering the quality inferior. Carrots show marked changes in growth habit; the plant that normally grows a crown without an extended stem, develops an acute or pointed rosette habit when they are deficient in potassium. Symptoms of K-deficiency in snap beans were described by Cummings and Wilcox (1968) as an intervenal chlorosis of the leaves that progresses from the older to the younger leaves. In cases of extreme K-deficiency, the entire leaf dies.

Fertilizer Placement for Vegetable Crops

Research over the past several decades has found proper methods of placement to be especially important to insure efficiency of fertilizer use, high yields, earliness of harvest and good quality.

Phosphorus is one of the key elements of concern in improving practices of fertilizer placement. The main reason is the general observation that a considerable portion of the fertilizer phosphate after application is not recovered in the crop that is immediately planted.

On the other hand, there apparently is little data on the effect of placement of K as related to these vegetables. The explanation for this situation is that K moves enough in most soils so that positionally it is available and that while fixation may be a problem on some soils, it is not a great one on many soils.

In considering the selection of the rate and placement of fertilizer some variables are involved: the crop characteristics,

soil characteristics, expected yield, climatic conditions and the cost of the fertilizer in relation to the sale price of the crop.

Cummings (1943) has said that "the most efficient and most effective placement of fertilizer is that which provides for an adequate supply of soluble nutrients in a well aerated zone of moist soil occupied by actively absorbing plant roots at the period of growth when the demands of the plants for nutrients are most acute." This has been one of the objectives of most of the work on fertilizer placement; the other major objective has been concerned with the avoidance of injury to the germinating seed and the young seedling.

Since early 1925 until 1967 the National Joint Committee on Fertilizer Application had been studying methods of applying fertilizers. This Committee had been responsible for leadership in experimentation in this area. Suggestions made by this organization are based on experiments conducted in virtually every section of the United States. The 1958 report of that Committee stated that restricted contact of fertilizer with soil lessens fixation of phosphate and potash. It was assumed that lessened fixation would result in greater uptake of phosphorus and potassium by the plant and a corresponding increase in efficiency of fertilizer use. In 1958 the Committee made the following recommendations: for beans, cabbage and lettuce it was recommended to apply P in

a band 5 to 8 cm to the side and 3 to 5 cm below the seed level; for carrots in a band below the row. Some of the K and a small fraction of the N was advised to be applied in the band with P.

Samman (1963) working on soils with levels of residual P below 3 kg/ha found that yields of beans were improved by applying superphosphate in a band at up to 67 kg/ha. Applying phosphatic fertilizers in a band 5 cm below and 5 cm to the side of bean seeds was superior to row placement in increasing plant growth and yields.

Cooke and Widdowson (1953) reported that beans given a simple side dressing of placed fertilizer in a band 7.5 cm below the soil surface and 5 cm to the side of the seed were equal to, or greater than, those of plants given double dressings of broadcast fertilizer. No advantage was gained by placing fertilizer at the side of the seed in the case of carrots.

Hipp (1969) in a clay soil with a relatively high initial P level demonstrated the early growth of carrot tops was increased with P placement 7.5 cm directly below the seed but was not increased if P was placed 7.5 cm below and 10 cm to the side of the seed. P placed below the seed slightly reduced the Mn concentration but increased that of P in the plant top. The yield of marketable carrots or carrot size was not influenced by the treatments.

The placement of fertilizer in a narrow strip (plane) below the seed, with the fertilizer coming in contact with

10-30% of the top soil volume, was found effective in low fixing soils by Barber (1974).

A study by Geissler (1966) showed that applications of phosphate, magnesium phosphate and superphosphate at 50 kg P_2O_5/ha around newly planted cabbage and lettuce on a phosphate-fixing lowland marshy soil increased yields and fertilizer utilization as compared with broadcast applications of equal or double quantities. Superphosphate gave the best results.

Research by Cooke (1955) in England showed that P-K fertilizer placed near the seed produced higher yields of beans than the same quantity broadcast. Higher yields were obtained from placed than from broadcast complete fertilizer in experiments on lettuce and cabbage; a further advantage in placement was that it induces earlier maturity. Root growth of most crops was stimulated by side dressings of mixed fertilizers placed near the seed. Cooke (1956) also found that placement of complete fertilizer in bands 5 cm to the side of the seed gave higher yields of cabbage and lettuce than broadcasting. Placing fertilizer at a low rate (112 kg/ha) gave higher yields than broadcasting at a high rate (124 kg/ha). Fertilizer placement made most of the crops grow more rapidly in the early stages than broadcasting, and this often resulted in earlier maturity.

In a summary prepared by a Russian researcher Zurbicki (1966) the best methods of fertilizer placement were

established in application of 10% of N P K in a band 3 cm below and 5 cm to the side of the seeds and the rest in a band between the rows. The coarser the soil, the greater was the amount of soil with which the fertilizer should be mixed. In a coarse soil a ratio of one part fertilizer to 50 parts soil was found satisfactory.

Several experiments conducted by Laws Agricultural Trust (1951) from Rothamsted England reported that granular fertilizer containing 14% P_2O_5 and 14% K_2O banded for beans resulted in higher yields than when broadcast. In 1951 the same institution demonstrated that granulated P-K fertilizer placed beside beans gave higher yields than broadcasting.

In two experiments with beans conducted by Amaral (1971) in Brazil, the following methods of fertilizer placement were compared: (a) as a top dressing in two bands at the sides of the rows, (b) incorporated in the soil in the rows, (c) below the seeds, but not in contact with them, (d) in direct contact with the seeds, (e) above the seeds, but not in contact with them, (f) below and to the side of the seeds in two bands, and (g) below and to the side of the seeds in one band. Method (f) and (g) were the best. Both experiments were carried out on an alluvial soil high in P and K, of different textures: loamy sandy and clayey sandy soil respectively.

Peck (1975b) in New York reported the results of nine field experiments which were high in both P and K, the average yield of snap beans, without P fertilizer was 5040

kg/ha whereas with 39 kg P_2O_5/ha banded 5 cm to the side and 5 cm below seed level, the average yield was increased to 5610 kg/ha.

Lucas and Vittum (1976) in a recent investigation summarized the information available on fertilizer placement for vegetable crops. This summary reflects the well-known fact that plants require more nutrients at early stages of growth. They recommend that most of the P and some of the N and K (up to 336 kg/ha of 10-40-10, 10-30-10, 8-32-16 or 10-34-0) be placed in bands 3 to 6 cm to the side and 5 cm below the seed level of cabbage and lettuce; for snap beans 5 cm to the side and 7.5 cm below the seed; for carrots they suggested a straight phosphorus fertilizer such as 0-46-0 (up to 34 kg of P_2O_5 per hectare) near or in direct contact with the seed. If more fertilizer is needed it is recommended to plow down the remainder of the phosphate/potassium fertilizer and sidedress one or two times with nitrogen.

The tropical literature offers examples indicating that banded P is not always the most efficient placement. According to Sanchez (1976) in soils with moderate fixation capacity, small annual amounts of superphosphate broadcast or banded once a year are normally the best placement. Kamprath (1967) working with corn and Yaptenco, (Fox, 1981) have demonstrated that banded P applications are more efficient than broadcast in certain high-fixing soils. In acid soils with high phosphorus fixation capacity the way to cope with high P fixation

has been to apply the fertilizer in bands in order to satisfy the fixation capacity in a small soil volume.

On extremely P deficient soils the results are different. Studies by Kratky and Tamimi (1974) in Hawaii in an extremely high fixation capacity soil indicated that banded phosphorus was an ineffecient use of fertilizer for potatoes. Work with corn by Yost et al (1979) on a Brazilian oxisol lead to the same conclusion. In this work Yost indicated that the very limited root development around the bands caused the plants to be less resistant to periods of moisture stress. Sanchez and Uehara (1980) have postulated that the best alternative for these soils is a combination of an initial broadcast application followed by small annual banded maintenance applications.

It has been shown that the advantage of localized placement diminishes as the plants age and may disappear by the time the plant reaches maturity. Most of the above data for tropical soils were obtained with corn which is notable for being able to overcome, during later stages of growth an initial phosphorus deficiency. The vegetables that are involved in this investigation are harvested at an immature stage of growth and are still growing actively and rapidly absorbing P at the time of harvest (Peck 1975 b, Zink and Yamaguchi 1962) and do not behave as corn does.

METHODS AND MATERIALS

Field and greenhouse experiments were designed to determine the most effective method of fertilizer application for profitable production of green snap beans (Phaseolus vulgaris L.), cabbage (Brassica oleracea var. capitata), carrots (Daucus carota L.) and leaf lettuce (Lactuca sativa L.).

Field Procedures

A field study was established on a Washtenaw silt loam soil (Aeric Fluvaquents; fine-loamy, mixed, nonacid, mesic) at the Michigan State University Horticulture Research Farm. For each crop the experiment consisted of a comparison of three methods of fertilizer placement and two rates of fertilizer application at each placement. These six treatments were arranged in a randomized block experiment replicated four times. Two additional no fertilizer treatments were included to show the basic fertility level of this soil.

Soil in the experimental area had the following properties: pH - 5.9; Bray 1 extractable phosphorus (P) - 110 kg/ha; exchangeable potassium (K), calcium (Ca) and magnesium (Mg) of 412, 3024 and 454 kg/ha respectively. Only the rates of P and K were varied. The rates of fertilizer P and K used were the rates recommended based on soil analysis

and one half the recommended rate. The recommended fertilizer rates for the four crops were: beans - 225 kg of 8-32-16 plus 110 kg of 45-0-0 per ha (N-68; P_2O_5-72; K_2O-36 kg/ha); carrots - 280 kg of 8-32-16 plus 200 kg 45-0-0 per ha (N-112; P_2O_5-90; K_2O-45 kg/ha); cabbage - 335 kg 8-32-16 plus 200 kg 45-0-0 per ha (N-117; P_2O_5-107; K_2O-54); lettuce - 280 kg 8-32-16 plus 260 kg 45-0-0 per ha (N-139; P_2O_5-90; K_2O-45 kg/ha). Nitrogen (N) was applied sidedress uniformly to all treatments.

After fertilizer application the soil was formed up into raised beds or ridges approximately 30 cm across the top. The three different methods of applying fertilizer which were compared in this experiment were as follows.

1. Band - After the soil was formed into ridges the fertilizer was applied in a narrow band approximately 4 cm wide and 8 to 10 cm deep.

2. Broadcast - The fertilizer was applied uniformly over the soil surface in the plot area and incorporated into the top 15 to 20 cm of soil before ridging.

3. Plane - The fertilizer was uniformly applied on the soil surface in a 0.30 m wide band. When the soil was thrown up to form the ridge the fertilizer remained undisturbed forming a horizontal plane of fertilizer 8 to 10 cm deep.

Each plot consisted of one row 0.76 m apart and 7.2 m long.

Plant rows were placed over the center of the fertilizer bands; banded and plane fertilizer was placed approximately 5 to 8 cm below the seed.

Beans were planted 2.5 cm deep and 7 cm apart. Cabbage, carrots and lettuce were seeded about 1 cm deep; one seed

of cabbage and lettuce and two of carrots were planted each five centimeters.

Planting conditions: A light rain the previous night of the first seeding made the conditions of planting excellent.

Plant material

Beans: A snap bean variety Bush Blue Lake 274 that is grown for the edible immature pod.

Cabbage: Hybrid variety Headstart

Carrots: Spartan Fancy 80

Lettuce: A leaf lettuce variety, Tania

Care during growth: Mechanical removal was the method for controlling weeds, cutting off the weeds just below the surface with a sharp hoe. Diseases and insects were controlled as necessary with fungicide and insecticide sprays.

Plant samples for chemical analyses were taken at the following stages of growth: beans--first pod set, cabbage--just prior to initiation of heading, lettuce--the plants were large enough for use, at sixty eight, seventy four and forty days respectively after seeding.

Ten to fifteen of the youngest fully developed leaves were sampled at random from each plot, dried at $60^{o}C$ and ground in a Wiley mill.

Harvest

Snap beans were harvested when the pods were still young. At this time the plant was pulled up, the pods were removed and the tops and the pods weighed separately.

Cabbage heads were harvested after the heads had become firm. The twenty largest heads of each plot were weighed.

Carrots were harvested as soon as the roots were 2 to 3 cm in diameter at the upper end. Tops were removed before weighing the tap roots; the number of well formed carrots as well as forked carrots were recorded and weighed separately.

Leaf lettuce was allowed to develop to full size before being harvested. Lettuce and cabbage were cut with a knife.

Plant analyses

For the determination of phosphorus and cations in the leaves, 0.5 gram samples of material were ashed in a muffle furnace which was maintained at 450°C for eight hours. The ash was dissolved in 5.0 ml of 6 N HNO_3, transferred and filtered into a ten ml volumetric flask and made up to volume with deionized water. For P analysis an aliquot was diluted 50:1 and the P content determined using the ammonium nolybdate-ascorbic acid procedure. The K, Ca and Mg content was determined using a Technican autoanalyzer.

Soil analyses

Soil samples were collected from the experimental area, air-dried and ground to pass a 10 mesh sieve. Exchangeable cations (K, Ca and Mg) were extracted with 1N neutral ammonium acetate method.

Available P was extracted for five minutes using the Bray-1 reagent (0.025 N HCl + 0.03 N NH_4F) at a 1:8 soil: solution ratio.

Soil pH was determined in a 1:1 soil:water suspension, using a glass electrode potentiometer.

Greenhouse Procedure

The soil used for this study was collected from the Ap horizon (0-15 cm depth) of a P and K deficient soil. This was a Marlette fine sandy loam (Glossoboric Hapludalfs; fine-sandy, mixed, mesic).

This soil had the following properties: pH - 5.6; Bray 1 extractable P - 18 kg/ha; exchangeable K, Ca and Mg equal 85, 1296 and 192 kg/ha respectively.

For each of the four crops, two rates of fertilization and three methods of fertilizer placement were used, making a total of six treatments, as described for the field experiments, one additional treatment namely a check was added making a total of seven treatments which were arranged in a completely randomized design replicated four times. The fertilizer rates were: (1) one hundred percent of the recommendation based on soil analyses, 150 and 200 kg/ha of P_2O_5 and K_2O respectively and (2) fifty percent of the recommendation.

Methods of fertilizer application

Broadcast: The granulated fertilizer was thoroughly mixed into soil. Enough soil for four experiments, 16 pots, were prepared by mixing in sufficient fertilizer for one hundred percent of the recommendation as it rotated in a cement mixer for five minutes. The same procedure was followed for fifty percent of the recommendation.

Three kilograms of soil was placed in appropriate pots. This mixed or broadcast placement would simulate broadcasting and disking into the soils under field conditions.

Plane and Band: Two kilograms of soil was added to the pots and the fertilizer was then applied uniformly to the leveled surface of the soil in each pot. For the band placement, the fertilizer was applied in a thin band approximately 0.4 cm wide across the middle of the pot, seeds were later placed following the same direction as the fertilizer band. For the plane placement the fertilizer was applied uniformly over the surface. Finally the remaining one kilogram of soil was added to the pots.

Fertilizers: Sources of N, P and K were respectively urea 45-0-0, superphosphate 0-46-0 and potassium chloride 0-0-60.

Beans, carrots and cabbage were grown in a rectangular 3025 cc plastic pots, having an inside length of 17.75 cm, a width of 14.95 cm and a height of 11.4 cm. Clay pots of 16 cm diameter and 19 cm height were used for lettuce. All the pots received 3000g of air dry soil and were arranged randomly in different areas of a greenhouse bench for each crop. Pots were re-randomized weekly.

Plant material: The same varieties were used as in the field experiment.

Seeding: After the surface soil was leveled, twelve seeds of beans, sixteen of cabbage and twenty two each of carrots and lettuce were sown, by punching them into the soil to a depth of one centimeter for the bean seeds and about one

half centimeter for the rest of the vegetable seeds, the seeds were placed in two rows four centimeters apart.

After emergence the seedlings were thinned to six plants for beans and lettuce; eight for cabbage and ten for carrots. One half of the plants were in each row. The soil was then wetted to near the point of saturation.

Pots were watered daily with deionized water, using 50 to 100 ml of water for plastic pots and 100 to 150 ml for clay pots. Pots were weighed weekly and watered to the original moisture content. Thus the pots were watered when approximately fifty percent of the available moisture had been used.

Plant root and tops were harvested 55, 106, 116, and 80 days after planting, respectively, for beans, cabbage, carrots and lettuce. The bean plants were grown to bloom stage, the rest of the crops were at a stage where further development was not evident.

Shoot and root fresh and dry weights were measured. Roots were rinsed free of soil in deionized water. The plants were dried at 60°C. The dried samples were ground in a Wiley mill to pass through a 40-mesh screen and analysed for phosphorus, potassium, calcium and magnesium. The same methods as in the field experiment for both plant and soil analyses were used.

Soil analyses after harvesting: After harvesting soil samples were taken from each of the broadcasted fertilizer

pots as well as from the check pots. These samples were analyzed for P, K, Ca and Mg.

Statistical Analyses

Data were statistically analysed utilizing the statistical program of the Vector graphic computer in the Soil Science Building of Michigan State University.

The field experiment data were analysed in a randomized complete block design with four replications per treatment. Data from the greenhouse experiment were analysed in a completely randomized design with four replications per treatment.

The Duncan multiple range test was calculated from the results of the analyses of variance from both the field and the greenhouse experiment.

RESULTS AND DISCUSSION

Field Experiments

Effect of treatments on yield

The yield data expressed in kg/ha as an average of four replications is shown in Table 1. For the purposes of this discussion, the rates of fertilizer appliacation will be referred to as "recommended" and "one-half rate," for the rates recommended based on soil analyses and one-half the recommended rate, respectively. Due to severe damage from heavy rains and runoff on the lettuce plots that resulted in very poor stands in almost all the plots and deer damage meaningful data was not collected.

Snap Bean pods: Fertilizer rate and placement had no effect on yield of bean pods, however, the yields were slightly higher with one-half the fertilizer rate than with the recommended rate. Plane placement performed slightly better than the other placements compared at the same rates. All fertilizer treatments produced higher yields than the checks, but the differences were not significant. It is apparent from the high yields obtained on the check plots that the soil was fertile.

Bean plants: The highest yield of bean plants was obtained from plots where one-half rate was applied in a plane. The next two best yields were obtained from the plots

Table 1. Influence of Fertilizer Rate and Placement of Application on Beans, Cabbage and Carrot Yields

Rate of Fertilizer	Placement	Beans		Cabbage	Carrot
		pods	plants		
		kg/ha			
0	--	18083 a	14328 a	44426 c	37157 ab
Recommended[1]	Band	19438 a	14882 a	50100 ab	36155 ab
½ Recommended	Band	20853 a	14997 a	52795 a	36583 ab
0	--	17681 a	14653 a	45150 bc	35875 ab
Recommended	Broadcast	20654 a	15995 a	48927 abc	34780 ab
½ Recommended	Broadcast	21018 a	15787 a	48832 abc	38407 ab
Recommended	Plane	20670 a	15589 a	50577 ab	31369 b
½ Recommended	Plane	21025 a	16074 a	47060 bc	38951 a

Each number is an average of four replications.

The small letters indicate Duncan's multiple range groupings of treatments which do not differ significantly at the 5% level.

[1]Recommended rates of fertilizer were:

beans: 225 kg/ha of 8-32-16 plus 110 kg of 45-0-0 per ha;

carrot: 280 kg/ha of 8-32-16 plus 200 kg 45-0-0 per ha;

cabbage: 335 kg/ha of 8-32-16 plus 200 kg 45-0-0 per ha.

on which fertilizer was applied broadcast at recommended and one-half rate respectively. There were no statistical differences between treatments. The lowest yields were obtained from the checks.

Cabbage: One-half rate applied in a band produced the highest cabbage yield followed closely by plane and band at recommended rate. Cabbage yields were lowest in the check plots and were statistically different from the treatments mentioned, however, only slightly lower than the rest of the treatments.

Carrots: As shown by data presented in Table 1, one-half rate applied in a plane was significantly better than the check and had a slight yield advantage over the rest of treatments.

Forked carrots: It may be noted by the data presented in Table 2 that the percent of forked carrots tended to increase with increasing rates of fertilizer. The average from the two checks, 7.1 percent, was significantly lower than 14.4 percent of forked carrots that was produced where the recommended rate was applied in a band. There was no consistent difference among methods of placement.

Summarizing the results of the yield experiments, it appears that for snap beans and carrots, one-half of fertilizer rate applied in a plane was the most effective treatment. This same rate applied banded was the most effective treatment for cabbage. It would appear that the difference

Table 2. Influence of Fertilizer Rate and Placement of Application on Percentage of Forked carrots

Rate of Fertilizer	Placement	Forked %[1]
0	--	6.96 b
Recommended	Band	14.40 a
½ Recommended	Band	8.05 b
0	--	7.20 b
Recommended	Broadcast	11.03 ab
½ Recommended	Broadcast	8.80 ab
Recommended	Plane	10.16 ab
½ Recommended	Plane	7.63 b

The small letters indicate Duncan's multiple range groupings of treatments which do not differ significantly at the 5% level.

[1]Calculated as a percent of total yields

in response between these two groups of vegetables could be due to the differences in root systems habits. Carrots and beans have a deeper, more extensive root system and better foraging capacity than cabbage.

The slightly greater effectiveness of band applied fertilizer compared to broadcast might be attributed to the less contact of fertilizer with soil when applied in a band. This reduces fixation reactions and loss of available P and K. When the fertilizer was broadcast it was at once in considerable surface contact with soil and thus some of the phosphate and potassium could become fixed more readily.

Plane placement which is a compromise between banding and broadcasting is probably the best alternative of application for carrots and snap beans. In soils with low fixing capacity, Barber (1974) found plane applications very effective. It should be pointed out that these experiments were located on soil of fairly high fertility.

Phosphorus concentrations in leaves

The phosphorus concentrations of beans, cabbage and lettuce leaves are reported as percentage of phosphorus on a dry weight basis (Table 3). Carrot leaves were not sampled. With all treatments in the three crops, the concentration of phosphorus in leaves tended to be at high levels. Even leaf samples from the check plots contained adequate levels of phosphorus according to Geraldson et al (1973), indicating phosphorus was not limiting. No significant differences

Table 3. Influence of Fertilizer Rate and Placement of Application on Phosphorus Concentrations in Leaves.

Rate of Fertilizer	Placement	Beans	Cabbage	Lettuce
		%P		
0	--	0.592 a[1]	0.628 a	0.458 a
Recommended	Band	0.609 a	0.596 a	0.570 a
½ Recommended	Band	0.568 a	0.623 a	0.516 a
0	--	0.598 a	0.610 a	0.520 a
Recommended	Broadcast	0.580 a	0.631 a	0.568 a
½ Recommended	Broadcast	0.581 a	0.680 a	0.415 a
Recommended	Plane	0.572 a	0.687 a	0.547 a
½ Recommended	Plane	0.560 a	0.655 a	0.501 a

[1]Means followed by the same letter are not significantly different (Duncan's Multiple Range Test $P > 0.05$).

were observed among treatments.

Potassium concentrations in leaves

Potassium, calcium and magnesium concentrations are reported as percentage of the element on a dry weight basis (Tables 4, 5 and 6).

Beans: The potassium content in the leaves was increased by each succeeding level of fertilizer application. When fertilizer was banded, K in the leaves tended to be higher than when planed or broadcast, but this difference was not statistically significant.

Cabbage: Potassium concentration was the greatest in the plots where the recommended rate of fertilizer was applied. The concentration tended to be higher in those plants grown with band placement at both rates of fertilizer. However the level of leaf K in the band treatment was significantly greater than the plane treatment only at the recommended rate.

Lettuce: The level of K in the leaves from the unfertilized plots were already sufficient according to the data reported by Knott (1957). No concentration differences were observed among treatments.

Calcium concentrations in leaves

Beans: As shown by data presented in Table 5 the calcium content in the leaves were slightly reduced as fertilization increased. There were not significant differences.

Cabbage and Lettuce: The calcium concentration of these two crops were not affected by any of the rates or

Table 4. Influence of Fertilizer Rate and Placement of Application on Potassium Concentrations in Leaves (Dry Weight Basis).

Rate of Fertilizer	Placement	Beans	Cabbage	Lettuce
		%K		
0	--	1.71 d[1]	3.25 c	3.32 a
Recommended	Band	2.14 a	3.77 a	3.75 a
½ Recommended	Band	1.97 abc	3.35 bc	3.47 a
0	--	1.88 bcd	3.22 c	3.47 a
Recommended	Broadcast	2.07 ab	3.60 ab	3.42 a
½ Recommended	Broadcast	1.89 bcd	3.20 c	3.25 a
Recommended	Plane	2.08 ab	3.35 bc	3.50 a
½ Recommended	Plane	1.74 cd	3.17 c	3.62 a

[1]Means followed by the same letter are not significantly different (Duncan's MR test, $p > 0.05$).

Table 5. Calcium Concentration in the Leaves (Dry Weight Basis) as Influenced by Fertilizer Rate and Placement

Rate of Fertilizer	Placement	Beans	Cabbage	Lettuce
		%Ca		
0	--	2.65 a[1]	2.12 a	2.07 a
Recommended	Band	2.20 a	2.17 a	2.17 a
½ Recommended	Band	2.42 a	2.07 a	2.17 a
0	--	2.67 a	2.15 a	2.12 a
Recommended	Broadcast	2.22 a	2.10 a	2.12 a
½ Recommended	Broadcast	2.40 a	2.20 a	2.07 a
Recommended	Plane	2.22 a	2.45 a	2.12 a
½ Recommended	Plane	2.32 a	2.05 a	2.17 a

[1]Means followed by the same letter are not significantly different (Duncan's MR test, $p > 0.05$).

Table 6. Magnesium Concentration in the Leaves (Dry Weight Basis) as Influenced by Fertilizer Rate and Placement

Rate of Fertilizer	Placement	Beans	Cabbage	Lettuce
		%Mg		
0	--	0.352 a[1]	0.403 a	0.615 a
Recommended	Band	0.365 a	0.413 a	0.525 b
½ Recommended	Band	0.368 a	0.408 a	0.508 b
0	--	0.375 a	0.428 a	0.543 ab
Recommended	Broadcast	0.343 a	0.403 a	0.458 b
½ Recommended	Broadcast	0.353 a	0.430 a	0.505 b
Recommended	Plane	0.365 a	0.405 a	0.488 b
½ Recommended	Plane	0.338 a	0.453 a	0.523 b

[1]Means followed by the same letter are not significantly different (Duncan's MR test, $p > 0.05$).

fertilizer placement. The levels found were extremely uniform.

Magnesium concentration in leaves

Beans and Cabbage: The magnesium concentration in cabbage and bean leaves was not affected by rate or placement of fertilizer (Table 6).

Lettuce: Magnesium concentration of the two checks were definitely higher than the concentration when fertilizer was applied.

It has been frequently reported that increasing the supply of one cation in the soil can depress the levels of other cation species in the plant (Lucas and Scarseth 1947, Rains et al 1964).

In the results shown in these experiments the Ca and Mg concentration in plant leaves were not consistently depressed by applications of fertilizer containing K (8-24-16). This could be due to the fact that P plays a key role in the supply of these cations. Peck (1975a) has demonstrated that concentrated superphosphate decreased the concentration of K and increased the concentration of Mg in snap bean plants. The same was true in cabbage (Peck and Stamer 1970).

Greenhouse Experiments

The soil chosen for this experiment was a fine sandy loam deficient in phosphorus and potassium. The low fertility level of the soil used in this experiments is apparent from the low yield of pots receiving no fertilizer (Table 7).

Table 7. Effect of Fertilizer Rate and Placement of Application on Fresh Top Weights.

Rate of Fertilizer	Placement	Beans	Cabbage	Carrot	Lettuce
		g/pot			
0	--	24.5 d	13.11 d	4.19 c	2.67 e
Recommended	Band	45.12 a	32.15 b	8.47 a	24.07 ab
½ Recommended	Band	37.85 bc	35.44 ab	7.36 ab	17.25 c
Recommended	Broadcast	41.70 ab	29.84 bc	7.58 ab	23.70 ab
½ Recommended	Broadcast	36.72 c	24.58 c	7.75 ab	10.49 d
Recommended	Plane	41.85 ab	40.13 a	8.12 ab	26.13 a
½ Recommended	Plane	36.42 c	31.67 b	7.03 b	19.76 bc

[1]Means followed by the same letter are not significantly different (Duncan's Multiple Range Test, $P > 0.05$).

Effect of treatments on yield

Yields of beans, cabbage, carrot and lettuce are reported as grams per pot.

Top Yields

Bean Tops

Fresh weight: As shown by the data presented in Table 7 the yields increased with each additional increment of fertilizer. All fertilized treatments at recommended rate produced significantly higher yields than the treatments at one-half rate, compared at the same placements. Band placement resulted in greater yields at both rates, however the differences among the different placements at the same rate of fertilizer were not significant. All fertilized treatments produced significantly higher yields than the check.

Dry weight: As was the case with fresh weight, dry weight yields tended to increase with increasing rates of fertilizer application. Again all fertilizer treatments produced significantly higher yields than the no fertilized treatments (Table 8).

Cabbage Tops

Fresh weight: The highest yield resulted from the recommended rate applied in a plane and this yield was significantly higher than the rest of the treatments, except as compared with one-half recommended rate applied in a band. Band at one-half rate which produced the second highest yield was considerably better than the rest of treatments but only

Table 8. Effect of Fertilizer Rate and Placement of Application on Dry Top Weights

Rate of Fertilizer	Placement	Beans	Cabbage	Carrot	Lettuce
		g/pot			
0	--	4.91 b	2.03 d	1.16 d	0.46 e
Recommended	Band	6.76 a	4.51 abc	2.39 bc	4.25 ab
½ Recommended	Band	6.43 a	5.18 ab	2.34 bc	2.85 c
Recommended	Broadcast	6.65 a	4.46 bc	2.84 a	4.42 ab
½ Recommended	Broadcast	6.34 a	3.71 c	2.11 c	1.57 d
Recommended	Plane	6.21 a	5.58 a	2.54 b	4.81 a
½ Recommended	Plane	5.94 a	4.28 bc	2.24 c	3.58 bc

Means followed by the same letter are not significantly different (Duncan's Multiple Range Test, $P > 0.05$).

significantly better than broadcast at one-half rate. Broadcast at high and moderate rates produced the lowest yields among the fertilized pots (Table 7).

Dry weight: Data in Table 8 shows that plane application of the fertilizer resulted in greater yields when the recommended amount of fertilizer was applied. At one-half the fertilizer level band application was superior. A significant difference was evident when comparing the band and plane treatments to broadcast at the same one-half rates of fertilizer application.

There were significant differences in the yields (fresh and dry), obtained as a result of the two rates of fertilizer application. In both fresh and dry weights the recommended rate was significantly better than one-half rate when the plane placement fertilizer were compared. The prominent observation is that, one-half rate applied in a band produced consistently higher yields than the same placement at recommended rate, in both fresh and dry weights, but this difference was not significant. All fertilized treatments significantly increased fresh and dry yields as compared with the checks (Tables 7 and 8).

Lettuce Tops

Fresh and dry weight: There was a definite influence of rate and placement on yields of fresh and dry top weights. Fresh and dry weights increased with each additional increment of applied fertilizer. All treatments at recommended rate produced significantly higher yields compared with the

same placement at one-half rate. The best yields, fresh and dry were produced by plane placement at the recommended rate, followed by band and broadcast at the same rate. At one-half rate the best yield was produced by plane placement followed by band placement. Broadcast at one-half rate, was significantly lower than plane and band placements at the same moderate rate of fertilizer application.

Fresh weight increased from 2.67 to 26.14 g/pot while dry weight increased from 0.46 to 4.81 g/pot. The lowest yields were always from the checks while the largest yields were from the recommended rate applied in a plane (Tables 7 and 8).

Carrot Tops

Fresh weight: As shown in Table 7 the recommended rate of fertilizer applied in a band produced the highest carrot fresh top yields followed closely by the same rate applied in a plane. However at the moderate rate of application the plane placement performed poorly and was significantly lower as compared with the rest of the fertilized pots. Top yields were lowest in the check pots.

Dry weight: Contrary to the results shown with the other vegetable crops fertilizer applied broadcast gave the best yield at the higher rate of application. However at the moderate rate this method yielded the lowest among the fertilized pots. The reason for the difference from the fresh top data is not readily apparent. All fertilized

treatments significantly increased yields as compared with the check.

Dry Roots:

Beans: Pots fertilized in a plane at both rates, gave the highest yields followed closely by the band treatments. However only the plane placement at the recommended rate produced a yield significantly higher than broadcast treatments at both rates and the check (Table 9).

Cabbage: An inspection of the data in Table 9 reveals that the weight of cabbage roots increased as the rate of fertilizer increased. Plane placement at high and moderate rates performed better than the other placements compared at the same rates; broadcast was lowest at both rates. The broadcast treatment at one-half rate was only slightly higher than the check.

Lettuce: All fertilized pots produced significantly higher quantities of roots than the unfertilized pot. Broadcast fertilizer at both rates and plane applied fertilizer at one-half rate were the lowest among fertilized pots. Differences were not significant.

Carrot: At the recommended rates banded fertilizer produced more roots than plane placed fertilizers and significantly better yields than broadcast fertilizer. At the one-half rate banded fertilizer was significantly better than the other placement methods. The outstanding observation is the good results obtained from banding one-half the recommended rate (6.1 g/pot). The yield of the unfertilized pot

Table 9. Effect of Fertilizer Rate and Placement of Application on Dry Root Weight

Rate of Fertilizer	Placement	Beans	Cabbage	Carrot	Lettuce
		g/pot			
0	--	1.01 b	1.20 c	1.52 d	0.09 b
Recommended	Band	1.47 ab	3.42 a	6.53 a	1.53 a
½ Recommended	Band	1.39 ab	2.93 ab	6.09 ab	1.44 a
Recommended	Broadcast	1.13 b	3.39 a	5.26 bc	1.36 a
½ Recommended	Broadcast	1.08 b	1.68 bc	4.14 c	1.36 a
Recommended	Plane	1.86 a	4.36 a	5.97 ab	1.40 a
½ Recommended	Plane	1.52 ab	3.24 a	4.30 c	1.36 a

Means followed by the same letter are not significantly different (Duncan's Multiple Range Test, $P > 0.05$).

was only 1.52 g/pot.

Phosphorus Concentrations in Shoots and Roots

As for the field experiment the phosphorus concentrations are reported as percentage of phosphorus on a dry weight basis (Tables 10 and 11).

Bean shoots: Concentrations of P in bean shoots increased as the rate of applied fertilizer increased. Concentrations of P in broadcast applications are considerably lower when compared to plane and band applications. All fertilized pots gave significantly higher P concentrations over the check.

Bean roots: Phosphorus concentrations increased slightly as the rate of fertilizer increased. Band and plane treatments resulted in higher concentration than broadcast fertilizer (Table 11).

Cabbage shoots: The concentration of P increased from 0.79 percent in the check to 0.97 percent when the one-half rate was applied in a plane or the recommended rate was banded. Broadcast fertilizer resulted in lowest P concentration among the fertilized pots (Table 10).

Cabbage roots: Fertilizer caused a slight increase in the percentage of P in the cabbage roots. Band and plane placement when applied at the recommended rate produced the highest concentrations. Applying one-half the recommended rate in a band did not affect the level.

Lettuce shoots: The concentration of P in all the fertilized pots were significantly higher than the check, and tended to increase with increasing rates of fertilizer

Table 10. Effect of Fertilizer Rate and Placement of Application on Phosphorus Concentration in the Shoots

Rate of Fertilizer	Placement	Beans	Cabbage	Carrot	Lettuce
		%P			
0	--	0.593 d	0.799 d	0.703 b	0.472 b
Recommended	Band	0.905 ab	0.971 a	0.910 a	0.895 a
½ Recommended	Band	0.860 bc	0.889 bc	0.926 a	0.878 a
Recommended	Broadcast	0.840 bc	0.924 abc	0.925 a	0.904 a
½ Recommended	Broadcast	0.776 c	0.874 c	0.912 a	0.782 a
Recommended	Plane	0.954 a	0.950 ab	0.898 a	0.882 a
½ Recommended	Plane	0.853 bc	0.975 a	0.914 a	0.842 a

Means followed by the same letter are not significantly different (Duncan's Multiple Range Test, $P > 0.05$).

Table 11. Effect of Fertilizer Rate and Placement of Application on Phosphorus Concentrations in the Roots

Rate of Fertilizer	Placement	Beans	Cabbage	Carrot	Lettuce
		%P			
0	--	0.864 b	0.696 bc	0.750 c	0.120 d
Recommended	Band	0.951 a	0.848 a	0.886 ab	0.934 a
½ Recommended	Band	0.947 a	0.652 c	0.815 bc	0.839 c
Recommended	Broadcast	0.917 ab	0.744 abc	0.906 a	0.920 ab
½ Recommended	Broadcast	0.869 b	0.766 ab	0.888 ab	0.872 bc
Recommended	Plane	0.938 a	0.816 a	0.901 a	0.911 ab
½ Recommended	Plane	0.916 ab	0.792 ab	0.882 ab	0.874 bc

Means followed by the same letter are not significantly different (Duncan's Multiple Range Test, $P > 0.05$).

application. There were no significant differences among the fertilized treatments.

Lettuce Roots: Data presented in Table 11 again show that P cencentration in the roots increased with each additional increment of applied fertilizer.

Carrot Shoots: The concentration of phosphorus in carrot shoots grown in fertilized pots were appreciably higher (level 0.05) than when no fertilizer was used.

Carrot roots: Increasing rates of P showed a trend toward higher P concentrations in the roots. Broadcast fertilizers produced the highest concentrations, when compared with the other placement methods, at both recommended and one-half rates. As always the no fertilized pot showed the lowest P concentration.

Potassium concentrations in shoots and roots

Potassium as well as calcium and magnesium concentrations are reported as percentage of the element on a dry weight basis (Tables 12, 13, 14, 15, 16 and 17).

Bean shoots: Apparently plants took up less K from broadcast applications of fertilizer. Broadcast at the one-half rate contained significantly less K than all the other fertilized treatments. All fertilized treatments produced significantly higher K concentrations than the check (Table 12).

Bean roots: Broadcast placement at recommended rate showed the highest concentration of K, followed by banded at the same rate. Fertilizer application, however, reduced K content in some pots as compared to the check level of K.

Table 12. Effect of Fertilizer Rate and Placement of Application on Potassium Concentrations of Shoots (Dry Weight Basis)

Rate of Fertilizer	Placement	Beans	Cabbage	Carrot	Lettuce
		%K			
0	--	1.77 c	2.76 b	2.07 b	3.47 a
Recommended	Band	3.10 a	3.56 a	3.06 a	3.33 a
½ Recommended	Band	3.10 a	2.72 b	2.32 b	3.38 a
Recommended	Broadcast	3.01 a	2.74 b	3.03 a	2.81 a
½ Recommended	Broadcast	2.31 b	2.88 b	2.25 b	3.22 a
Recommended	Plane	3.25 a	3.71 a	2.98 a	3.35 a
½ Recommended	Plane	2.94 a	2.90 b	2.76 a	3.01 a

Means followed by the same letter are not significantly different (Duncan's Multiple Range Test, $P > 0.05$).

Table 13. Effect of Fertilizer Rate and Placement of Application on Potassium Concentrations of Roots (Dry Weight Basis)

Rate of Fertilizer	Placement	Beans	Cabbage	Carrot	Lettuce
		%K			
0	--	1.21 bc	0.39 ab	1.38 c	2.01 a
Recommended	Band	1.44 ab	0.48 a	2.09 a	1.45 ab
½ Recommended	Band	1.06 bc	0.37 ab	1.83 ab	1.42 ab
Recommended	Broadcast	1.72 a	0.40 ab	1.75 b	1.40 ab
½ Recommended	Broadcast	1.29 bc	0.32 ab	1.39 c	1.31 ab
Recommended	Plane	1.16 bc	0.45 ab	1.98 ab	1.40 ab
½ Recommended	Plane	1.05 c	0.31 b	1.74 b	1.16 b

Means followed by the same letter are not significantly different (Duncan's Multiple Range Test, $P > 0.05$).

Table 14. Effect of Fertilizer Rate and Placement of Application on Calcium Concentrations of Shoots (Dry Weight Basis)

Rate of Fertilizer	Placement	Beans	Cabbage	Carrot	Lettuce
		%Ca			
0	--	1.48 ab[1]	1.51 a	2.38 a	0.82 a
Recommended	Band	1.59 ab	0.96 cd	2.10 a	0.62 b
½ Recommended	Band	1.53 ab	1.16 bc	2.27 a	0.66 ab
Recommended	Broadcast	1.36 b	0.81 d	2.45 a	0.47 b
½ Recommended	Broadcast	1.35 b	1.34 ab	2.45 a	0.59 b
Recommended	Plane	1.67 ab	1.08 bcd	2.22 a	0.61 b
½ Recommended	Plane	1.75 a	1.13 bc	2.25 a	0.63 b

[1]Means followed by the same letter are not significantly different (Duncan's Multiple Range Test, $P > 0.05$).

Table 15. Effect of Fertilizer Rate and Placement of Application on Calcium Concentrations of Roots (Dry Weight Basis)

Rate of Fertilizer	Placement	Beans	Cabbage	Carrot	Lettuce
		%Ca			
0	--	0.94 a	1.49 a	0.25 a	0.82 a
Recommended	Band	1.09 a	0.42 b	0.24 a	0.39 b
½ Recommended	Band	1.02 a	0.43 b	0.27 a	0.36 b
Recommended	Broadcast	0.99 a	0.53 b	0.22 a	0.41 b
½ Recommended	Broadcast	0.98 a	0.76 b	0.23 a	0.52 b
Recommended	Plane	0.85 a	0.51 b	0.22 a	0.38 b
½ Recommended	Plane	0.93 a	0.42 b	0.24 a	0.33 b

Means followed by the same letter are not significantly different (Duncan's Multiple Range Test, $P > 0.05$).

Table 16. Effect of Fertilizer Rate and Placement of Application on Concentrations of Magnesium of Shoots (Dry Weight Basis)

Rate of Fertilizer	Placement	Beans	Cabbage	Carrot	Lettuce
		%Mg			
0	--	0.351 ab	0.479 a	0.396 ab	0.269 a
Recommended	Band	0.354 ab	0.336 cd	0.362 b	0.223 abc
½ Recommended	Band	0.348 ab	0.372 bc	0.407 ab	0.243 ab
Recommended	Broadcast	0.297 b	0.296 d	0.450 a	0.161 c
½ Recommended	Broadcast	0.315 b	0.443 ab	0.441 a	0.191 bc
Recommended	Plane	0.351 ab	0.375 bc	0.393 ab	0.205 abc
½ Recommended	Plane	0.413 a	0.400 bc	0.396 ab	0.201 abc

Means followed by the same letter are not significantly different (Duncan's Multiple Range Test, $P > 0.05$).

Table 17. Effect of Fertilizer Rate and Placement of Application on Magnesium Concentrations of Roots (Dry Weight Basis)

Rate of Fertilizer	Placement	Beans	Cabbage	Carrot	Lettuce
		%Mg			
0	--	0.67 a	0.182 a	0.110 ab	0.265 ab
Recommended	Band	0.463 b	0.108 a	0.111 ab	0.271 ab
½ Recommended	Band	0.575 ab	0.080 a	0.126 a	0.252 ab
Recommended	Broadcast	0.535 ab	0.112 a	0.113 ab	0.260 ab
½ Recommended	Broadcast	0.595 ab	0.118 a	0.1020 b	0.334 a
Recommended	Plane	0.413 b	0.105 a	0.111 ab	0.245 b
½ Recommended	Plane	0.490 ab	0.237 a	0.119 ab	0.251 ab

Means followed by the same letter are not significantly different (Duncan's Multiple Range Test, $P > 0.05$).

This reduction may have been caused by a dilution effect (Table 13).

Cabbage shoots: Potassium concentrations in cabbage shoots were not affected when fertilizer was applied at one-half rate regardless of placement or when fertilizer was broadcast at the recommended rate. Potassium concentrations increased significantly as the rate of either banded or planed fertilizer was increased.

Cabbage roots: Potassium concentrations were slightly higher when the recommended rate of fertilizer was used regardless of placement. Concentrations from the check were slightly greater than the treatments with one-half of the fertilizer application.

Lettuce shoots: There was no difference in potassium concentration among treatments. The high concentration shown by the check may have been caused by a high uptake of potassium compared with its very low fresh weight yield shown in Table 12.

Lettuce roots: As described in lettuce shoots and probably for the same reason, the check showed again the highest K concentration. No detectable effect of rate and placement on potassium concentration of lettuce roots was observed.

Carrot shoots: The potassium concentration in carrot shoots increased as the rate of K increased. When fertilizer was applied at the recommended rate regardless of placement and in a plane at one-half rate the concentrations were consistently higher (level 0.05) than the rest of treatments.

The check showed the lowest concentration.

Carrot roots: The concentration of K in carrot shoots, grown in fertilized pots were appreciably higher than when broadcast at one-half rate or where no fertilizer was used (Table 13).

Calcium concentrations in shoots and roots

Bean shoots and roots: As shown in Tables 14 and 15 bean shoots and roots calcium levels were not affected by either rate or placement of fertilizer.

Cabbage shoots: All fertilizer treatments significantly reduced the concentration of Ca in cabbage shoots. Treatments that received the highest rate of fertilizer resulted in the least amount of calcium in the shoots. The dry weight percent of Ca in the plant tissue was decreased from 1.5 to 0.8 by increased rates of fertilizer applied broadcast.

Cabbage roots: The Ca concentration in the check was consistently higher (level 0.05) than those of the fertilized pots. There were no difference among the fertilized treatments (Table 15).

Lettuce shoots and roots: The results of calcium concentrations in both shoots and roots clearly show a decrease in calcium content in the fertilized pots as compared with the checks. There were no consistent differences among the fertilized treatments in the calcium concentrations of either shoots or roots.

Carrot shoots and roots: Data of calcium concentration in shoots and roots (Tables 14 and 15) showed no significant

effect of the treatments on either shoot or root calcium concentration.

Magnesium concentrations in shoots and roots

Bean shoots: There were no differences in magnesium concentrations among treatments (Table 16).

Bean roots: The Mg content was lower in shoots of plants grown in pots to which fertilizer was applied than in the unfertilized pots. However, only banded and planed both at the recommended rate, were significantly lower (Table 17).

Cabbage shoots: The Mg concentration in cabbage shoots decreased as the rate of fertilizer increased. Percent Mg decreased from 0.48 in the check to 0.33 and 0.30 percent in pots fertilized at the recommended rate in band and broadcast treatments respectively.

Cabbage roots: The Mg concentration of cabbage roots was not affected by rate or placement of fertilizer.

Lettuce shoots: The magnesium concentration of lettuce shoots was definitely higher in the plants from the unfertilized pots. However this difference was significant only compared with the broadcast placement at both rates.

Lettuce roots: As shown by data presented in Table 17 lettuce root Mg levels were not affected by treatments.

Carrot shoots and roots: The Mg concentration in carrot shoots and roots was not affected by rate or placement of fertilizer (Tables 16 and 17).

Phosphorus Uptake

Total phosphorus uptake by both shoots plus roots of each of the vegetable crops are given in Table 18. The uptake is reported as milligrams of phosphorus per pot.

Beans: The uptake of P increased as the rates of fertilizer increased. The highest uptake resulted when the recommended rate was applied in a plane, followed by the same rate applied in a band. However at the moderate rate of application, P uptake at the band placement was the best and was a significantly higher than the rest of the one-half fertilized pots. Broadcast was lowest at both rates. All treatments significantly increased P uptake compared with the check (Table 18). The highest uptake occurred with both the recommended rate applied in a plane and the same rate applied in a band because these treatments were outstanding in dry matter yields and in P content (Tables 8, 9, 10, and 11).

Cabbage: As shown in Table 18 the P uptake was increased by all levels of applied fertilizer. The recommended rate of fertilizer applied in a plane produced the highest P uptake; the same amount of fertilizer applied in a band produced the second largest uptake. Planed fertilizer at high and moderate rates produced significantly higher P uptake than broadcast compared at the same rates of fertilizer application. Broadcast at one-half rate, was significantly lower than planed and banded at the same one-half rate of fertilizer application. Phosphorus uptake was lowest in the check pots.

Table 18. Total Phosphorus Uptake as Influenced by Fertilizer Rate and Placement

Rate of Fertilizer	Placement	Beans	Cabbage	Carrots	Lettuce
		mg/pot P			
0	--	38.4 e[1]	24.7 d	19.4 c	2.4
Recommended	Band	74.9 ab	72.9 ab	79.5 a	49.9
½ Recommended	Band	68.5 abc	64.4 b	71.4 a	37.2
Recommended	Broadcast	66.2 bc	66.7 b	74.0 a	52.4
½ Recommended	Broadcast	56.1 d	47.5 c	56.2 b	24.2
Recommended	Plane	76.9 a	87.0 a	76.8 a	55.3
½ Recommended	Plane	64.1 cd	67.5 b	58.1 b	42.3

[1]Means followed by the same letter are not significantly different (Duncan's MR test, $p > 0.05$).

It appeared that the phosphorus uptake by cabbage plants was more a function of the dry weight of both shoots and roots than of the phosphorus content since phosphorus content showed less change than dry shoot and root weights (Tables 8, 9, 10 and 11).

Carrots: The amount of P taken up by carrot plants increased with each additional increment of fertilizer application. Band application of the fertilizer resulted in greater P uptake at both recommended and one-half rate than the other fertilizer placement when comparing at the same rates of fertilizer application. Broadcast at high and moderate rates produced the lowest P uptake among the fertilized pots. The no fertilized treatment showed the lowest P uptake (Table 18).

As can be seen from the Tables 8, 9, 10 and 11 carrot root and shoot weights are the most important factors that influenced the total uptake of P.

Lettuce: All levels of fertilizer application caused an increased phosphorus uptake. The uptake was increased from 2.43 mg/pot produced by the check to a maximum of 55.35 g/pot that was produced by plane placement at the recommended rate. The second best uptake was obtained when the fertilizer was broadcast at the recommended rate. However at the moderate rate the broadcast application performed poorly and produced the lowest P uptake among the fertilized treatments. All fertilized treatments produced significantly higher P uptake than the non-fertilized pots (Table 18).

In this case the P uptake was especially a function of shoot and root weights (Tables 8 and 9), and secondly, a function of P concentration (Tables 10 and 11).

Potassium Uptake

Potassium uptake is reported as milligrams of K per pot (Table 19).

Beans: The uptake of K by bean plants increased as the rates of fertilizer increased. Band placement resulted in greater K uptake at both rates, however this difference was significant only if compared with broadcast at the one-half rate. All fertilized treatments resulted in higher K uptake than the checks (Table 19).

Cabbage: The K uptake was increased by all rates of fertilizer application. Plane application of the fertilizer resulted in significantly greater K uptake when the recommended amount of fertilizer was applied. At one half the fertilizer level band application was more effective. Uptake of K by plants grown with broadcast applications are considerably less when compared to band and plane applications, however, this difference was significant only at the recommended rate. The uptake of K in all the fertilized pots was significantly higher than the check.

Lettuce: The data in Table 19 reveals that K uptake by lettuce plants was definitely influenced by rates and placement of fertilizer application. Plane placement resulted in

Table 19. Total Potassium Uptake as Influenced by Fertilizer Rate and Placement

Rate of Fertilizer	Placement	Beans	Cabbage	Carrot	Lettuce
		mg/pot K			
0	--	99.8 c[1]	61.1 d	44.9 e	20.2 d
Recommended	Band	230.1 a	176.4 b	210.8 a	161.7 a
½ Recommended	Band	215.4 a	151.9 bc	165.4 b	113.1 b
Recommended	Broadcast	219.4 a	137.5 c	178.9 b	143.6 ab
½ Recommended	Broadcast	160.3 b	115.6 c	105.4 d	67.6 c
Recommended	Plane	225.0 a	225.9 a	194.5 ab	177.1 a
½ Recommended	Plane	192.4 ab	132.8 c	135.9 c	142.8 ab

[1]Means followed by the same letter are not significantly different (Duncan's MR test, $p > 0.05$).

greater K uptake at both rates. Band placement at the recommended rate resulted in significantly greater K uptake than the same band placement at the moderate rate of fertilizer application. Broadcast resulted in the lowest K uptake at both rates. All fertilized treatments significantly increased K uptake as compared with the check.

Carrots: Data in Table 19 shows a definite influence of rate and placement of fertilizer on K uptake by carrot plants. Band placement at both rates was more efficient than the other placement methods compared at the same rates. At one-half rate of fertilizer application each placement was significantly different from the other placements. Broadcast fertilizers always produced the lowest uptake when compared with the other placement methods. The check showed significantly lower K uptake than the rest of the pots.

The inspection of the bean shoot and root weights and potassium concentration, reveals that the K uptake by bean plants was a function of both plant weight and K concentration in plant parts in approximately equal proportions. On the other hand as can be seen from Tables 8, 9, 12 and 13 it is evident that K uptake by cabbage, carrots and lettuce was primarily a function of their shoot and root weights.

Changes in Soil P and K Resulting From Broadcast Fertilization

Soil samples taken in September '82 prior to fertilizer application contained 18 kg/ha of Bray 1 extractable P and 85, 1296 and 192 kg/ha of exchangeable K, Ca, and Mg, respectively. After harvesting, samples from the broadcast and check pots were analyzed for available Bray 1 P and exchangeable K, Ca and Mg.

Soil phosphorus: Effects of fertilizer application on soil phosphorus test are presented in Table 20. The "build up" of the soil P level was apparent from the rates of fertilizer applied in all the experiments.

In the cabbage and carrot pots the soil test value resulting from additions of fertilizer, increased with each rate of fertilizer application. Each level was significantly different from the other levels.

In the bean and lettuce pots each addition of fertilizer increased the soil P level consistently, however, this increase was significant only when comparing the one-half recommended rate with the recommended rate.

Soil phosphorus in the checks decreased from 18 kg/ha prior to cropping to 12 kg/ha for beans and cabbage pots and to 14 kg for carrot pots. Soil P in lettuce pots did not change at the end of the experiment. It would appear that the difference in response could be due to the differences in P uptake from the check pots (Table 18), this comparison reveals that the uptake of lettuce was meager whereas the

Table 20. Soil Phosphorus Level After Harvesting as Influenced by Fertilizer Rate[1]

Rate of Fertilizer	Beans	Cabbage	Carrot	Lettuce
	kg/ha P			
0	13.2 b[2]	14.5 c	15.4 c	20.3 b
½ Recommended	20.9 b	23.0 b	22.6 b	24.3 b
Recommended	35.8 a	33.6 a	36.0 a	35.4 a

[1]Fertilizer was applied broadcast

[2]Means followed by the same letter are not significant

Table 21. Soil Potassium Level After Harvesting as Influenced by Fertilizer Rate[1]

Rate of Fertilizer	Beans	Cabbage	Carrot	Lettuce
0	118 b[2]	72 c	86 c	110 b
½ Recommended	141 b	93 b	113 b	165 a
Recommended	183 a	146 a	143 a	167 a

[1]Fertilizer was applied broadcast

[2]Means followed by the same letter are not significant

uptake was considerably higher in beans, cabbage and carrot.

When one-half the recommended rate of fertilizer containing phosphorus (32 kg/ha P) was applied the soil P level increased slightly in all the experiments. Whereas when the recommended rate of fertilizer was applied (64 kg/ha P), the P level increased slightly more than one-fourth the amount of P added by the fertilizer. This change in soil P is higher than the values obtained by Rouse (1968), whose data revealed that 5 to 6 kg/ha was requried to raise the extractable P 1 kg/ha in a sandy loam soil. However similar increases to those reported in this investigation were reported by Peck et al (1971) working with medium textured Alfisols.

Soil Potassium: The effect of fertilizer on the concentration of potassium in the soil after harvesting is shown in Table 21. It is readily seen in the data from the four experiments that the level of exchangeable K was increased significantly by each rate of fertilizer application.

The effect of cropping on the level of exchangeable potassium may be noted by comparing the initial exchangeable K (85 kg/ha K) with the check levels of potassium (Table 21). Three experiments showed equal or higher exchangeable values than the initial K level; only in the cabbage experiment was the level of K in the check lower than before planting. The total K uptake by cabbage shoots and roots when no fertilizer was applied (Table 19) was 49 kg/ha which is a greater value than the decrease in exchangeable K during the cropping period (13 kg/ha). This suggests that in the check pots of

all the experiments considerable amounts of non-exchangeable K was released during the growing time.

When one-half the recommended rate of fertilizer containing K was applied (83 kg/ha K), soil exchangeable K (Table 21) was increased by 56, 8, 28 and 80 kg/ha for beans, cabbage, carrot and lettuce plots, respectively, and the plant uptakes (Table 19) were 130, 93, 82 and 54 kg/ha in the same order. This indicates that in all pots variable amounts of non-exchangeable K were released during the season.

When the recommended rate was applied (166 kg/ha K), soil exchangeable K was increased by 98, 61, 58 and 82 kg/ha and shoots and roots (Table 19) contained 178, 112, 144 and 115 kg/ha K for beans, cabbage, carrot and lettuce.

SUMMARY AND CONCLUSIONS

The effects of rate and placement of phosphorus and potassium fertilizer application on yield and composition of snap beans, cabbage, carrot and lettuce were studied in field and greenhouse experiments.

The field study was established on a Washtenaw silt loam soil high in phosphorus and potassium. The soil used for the greenhouse experiment was a phosphorus and potassium deficient Marlette fine sandy loam.

For both field and greenhouse experiments and for each of the four crops, two rates of fertilization and three methods of fertilizer placement were used. The fertilizer rates were: one hundred percent and fifty percent of the recommendation based on soil analysis. Fertilizer placements used were: band--the fertilizer was applied in a narrow band below the seeds; broadcast--the fertilizer was thoroughly mixed into soil; plane--the fertilizer was uniformly applied in a wide strip and covered with 8-10 cm of soil.

The results from this investigation are summarized as follows:

Field Experiments

Yields: For snap beans and carrot yields, one-half of the fertilizer rate applied in a plane was the most effective

method. This same rate applied in a band was the most effective treatment for cabbage.

Nutrient concentrations: The concentration of phosphorus in leaves was neither significantly or consistently affected by the rate or placement of fertilizer.

Rates of fertilizer application increased slightly but consistently the concentration of K in beans and cabbage leaves. No consistent differences in K concentrations were observed in lettuce leaves.

When fertilizer was banded the K content of bean and cabbage leaves tended to be higher. No concentration differences were observed in lettuce leaves due to placement of fertilizer.

Calcium concentration in bean leaves was slightly reduced as fertilization increased. Calcium concentrations of cabbage and lettuce leaves were not affected by rates or placement of fertilizer.

Fertilizer rate and placement had no effect on bean and cabbage leaf magnesium concentration. Fertilization decreased the concentration of magnesium in lettuce leaves.

Greenhouse Experiments

Top yields:

Plane placement of the fertilizer at the recommended rate resulted in greatest yields of cabbage, lettuce and carrots, whereas the best yield of snap beans was produced by the recommended rate applied in a band. In beans,

cabbage and carrot the band placement at one-half rate produced only slightly lower yields than the best treatment. In lettuce the next two best yields were obtained from the pots on which the recommended rate was applied in a band or broadcast.

Root Yields

In beans and cabbage, plane placement of the fertilizer resulted in greater root weights when applied at the recommended and the suboptimum rates. With both crops the root weights produced by the one-half and recommended fertilizer rates were not significantly different when plane placed.

Band placement of the fertilizer resulted in greater carrot and lettuce root weights when applied at both the recommended and moderate rates. These two treatments produced the largest root weights of both carrot and lettuce.

Phosphorus concentrations:

The moderate rate of fertilizer application increased the concentration of carrot and cabbage shoots, no further increases were evident with the higher rate of fertilizer.

Concentrations of P in bean and lettuce shoots increased with each rate of fertilizer application.

Phosphorus concentrations in the roots of the four vegetables tended to increase with increasing rates of fertilizer application. Band application at the recommended rate produced the highest P concentrations in bean, lettuce

and cabbage roots. In carrot roots the largest P concentration was produced by broadcast at the recommended rate.

Potassium concentration:

The potassium concentration in carrot, cabbage and bean shoots increased as the rate of fertilizer increased. In all the crops the broadcast placement produced equal or lower K concentrations than plane and band at both rates. In lettuce shoots, and probably due to a concentration effect, the highest K concentration was shown by plants from the check pot.

Increasing rates of K showed a trend toward higher K concentrations in carrot roots. Band and plane placements resulted in greater K concentration than broadcast at both recommended and one-half rates. Generally high rates of fertilizer increased the concentration of K in bean roots. At the moderate rate no effect was found. Fertilizer rate and placement had no definitive effect on K concentration in lettuce and cabbage roots.

Calcium concentration:

Carrot and bean shoot and root calcium levels were not affected by either rate or placement of fertilizer. Fertilization reduced the concentration of Ca in cabbage and lettuce shoots and roots.

Magnesium concentration:

The Mg concentration in cabbage and lettuce shoots decreased as the rate of fertilizer increased. Generally, no

significant effects of the treatments were observed on root Mg concentration of cabbage, lettuce and carrots. The Mg concentration of bean roots decreased as the rate of fertilizer increased. This decrease tended to be greater when fertilizer was banded or planed than when broadcast.

Phosphorus and Potassium uptake

In the four crops studied the P and K uptake was increased by all rates of fertilizer application. Banded and planed fertilizer at high and moderate rates produced consistently higher P and K uptake than broadcast fertilizer compared at the same rate of fertilizer application.

Effects of fertilization on available soil P and K

When one-half the recommended rate of fertilizer was applied the soil P level increased slightly in all the experiments. When the recommended rate was applied, the P level increased slightly more than one-fourth the amount of P added by the fertilizer. Generally soil phosphorus in the checks decreased after cropping.

The level of exchangeable K was increased significantly by each rate of fertilizer application.

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