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Thompson,

Christopher Dwight

1990

THE EFFECT OF PHOSPHORUS PLACEMENT AND RATE ON PHOSPHORUS UPTAKE, AND GROWTH AND YIELD OF TOMATOES

A Thesis

Presented to

the Faculty of the Department of Agriculture

Western Kentucky University

Bowling Green, Kentucky

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Christopher Dwight Thompson

May 1990

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THE EFFECT OF PHOSPHORUS PLACEMENT
AND RATE ON PHOSPHORUS UPTAKE,
AND GROWTH AND YIELD OF TOMATOES

Date Recommended May 2, 1990

Ray E. Johnson
Director of Thesis

Dr. Linda G. Brown

James P. Worthington

Date Approved May 4, 1990

Elmer Gray
Dean of the Graduate College

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THE EFFECT OF PHOSPHORUS PLACEMENT AND RATE ON PHOSPHORUS UPTAKE, AND GROWTH AND YIELD OF TOMATOES

Christopher Dwight Thompson May 1990 37 pages

Directed by: Ray E. Johnson, James P. Worthington and Linda G. Brown

Department of Agriculture Western Kentucky University

Research was undertaken in the summer of 1989 to determine the effect of phosphorus placement on the yield and quality of field grown tomatoes *Lycopersicon esculentum*. A subsequent study was undertaken in the winter of 1989 to determine the effect of phosphorus rate and placement on the early growth and phosphorus uptake of young tomatoes in the greenhouse.

The purpose of this study was to attempt to find the most efficient placement and rate of supplemental phosphorus when growing tomatoes. It has been shown that placing phosphorus in a concentrated zone in contact with plant roots results in more growth and fruit yield. The current trial involved the application of phosphorus at different rates and use of different methods of application. The methods of application included broadcasting phosphorus, placing phosphorus in a concentrated band, and combinations of the two.

It is of great interest to the tomato producer to know the most efficient rate and placement of fertilizer phosphorus. Availability of phosphorus is necessary for the proper development of the tomato and a good supply is needed for adequate yield and quality. If improved application methods are developed, perhaps higher yields and improved fruit quality can be realized. This could possibly result in higher production for the producer and more satisfaction for consumers.

The results of the field study were not statistically significant. One reason for the lack of any yield response was the greatly reduced yields caused by hail damage and fungal disease.

Suprisingly, the greenhouse study showed that significant growth increase resulted from phosphorus broadcast treatments. One explanation may be the small volume of soil used in this study. The plant roots were distributed throughout the entire soil volume in contrast to the situation with widely spaced field grown tomatoes. Thus, the broadcast treatments achieved more root-fertilizer contact in the greenhouse pot cultures.

INTRODUCTION

Research was undertaken at the Western Kentucky University Farm to study the effects of phosphorus placement and rate on the growth, yield, and quality of tomatoes. The purpose of this research was to study production methods that would potentially aid in making the tomato an alternative crop in southern Kentucky.

Two experiments were included in this study. First a field study was undertaken to determine the effect of phosphorus placement methods on the yield and quality of tomatoes. Also included in the field study were treatments that involved a nitrogen placement variable. The phosphorus and nitrogen were either broadcast or banded at varying rates and included broadcast-band combinations. The rates of these nutrients were recommended rates based on soil test results. The quantities of phosphorus and nitrogen applied were equal in all treatments except the check. Only the relative amounts of these nutrients broadcast and/or band applied varied.

The second experiment was undertaken in the greenhouse during the winter following the spring research. The purpose of this study was to determine the effects of phosphorus placement and rate on early growth and phosphorus uptake of young tomato plants. This study involved broadcasting and banding phosphorus at varying rates and included one broadcast-band application. Both the field research and greenhouse research were conducted on a low phosphorus soil on which a growth response to fertilizer phosphorus would normally be expected.

REVIEW OF LITERATURE

Nitrogen and phosphorus are considered to be extremely important macronutrients in fruit and vegetable production. Both of these nutrients have vital roles in the metabolism of plant cells. These elements are fairly abundant in the environment but not always in available form to plants (12). Nitrogen, in the form of nitrate, is easily leached and denitrified from wet soils and phosphorus can be readily fixed in unavailable forms by certain types of clay minerals and at either low or high soil pH (6). For these reasons nitrogen and phosphorus are often placed in bands to provide for maximum availability to plant roots (12).

Phosphorus is mobilized in all meristematic tissue and highly metabolizing centers inside the plant. Thus, the nutrient readily moves from older to younger tissues (19). Phosphorus is found in most plants at concentrations between 0.1% and 0.4%. Phosphorus is responsible for "energy currency" in plants. The most important energy derived from phosphorus is found in adenosine diphosphate and adenosine triphosphate. These compounds are formed and regenerated when phosphorus is available in sufficient quantities. The process of phosphorylation converts adenosine diphosphate to adenosine triphosphate, which is responsible for most all of the energy that is required to carry out biological processes in plants. A good supply of phosphorus early in a plant's life is important in formation of the earliest developing reproductive parts. Large amounts of phosphorus are found in phytin of seeds and fruit and are deemed essential for seed formation. Additionally, phosphorus is a main component of nucleic acids, coenzymes, nucleotides, phosphoproteins, phospholipids, and sugar phosphates. In addition, phosphorus is an important component of the chloroplast structure (16).

Nitrogen is found in most plants in concentrations between 1% and 5%. Nitrogen is a major constituent of amino acids, and necessary for protein synthesis. Some of these proteins are enzymes which carry out metabolic processes within the plant. The most critical of the proteins in the plant are the nucleoproteins, deoxyribonucleic acid and ribonucleic acid. Deoxyribonucleic acid duplicates genetic information to newly forming cells during meristematic growth. Ribonucleic acid's role is to carry out the instructions which are contained within the deoxyribonucleic acid molecules. Nitrogen is also a major constituent of chlorophyll. One nitrogen atom is contained within each of the four pyrrole rings of the chlorophyll structure. Therefore, it is an essential part of the molecule that absorbs light energy needed for photosynthesis (16).

Early production and marketing is extremely important in vegetable crops due to fluctuating prices. It is very desirable to have an early producing crop to achieve maximum profitability. It takes approximately 65-75 days for tomatoes to mature. This suggests that to have an early crop, such as early- to mid-July in southern Kentucky, the producer should have his tomatoes transplanted by late April or at the latest, early May. As reported by Wittmer (19), most annuals tend to absorb the major portion of their total mineral supply very early in life. This is very typical of phosphorus. Data indicate that when only 20% of total plant growth has occurred, 50% of the total phosphorus required for that plant has been absorbed (19). This presents the tomato producer with a problem. There are typically lower soil temperatures associated with early spring plantings. This decreases the availability of phosphorus due to slowing down the mineralization of soil organic phosphorus and of plant root growth (16).

It is suggested by Sleight et al. (13) that phosphorus is more chemically available to crops when placed in a band to increase root-fertilizer contact and decrease soil-fertilizer contact. Hence, less fixation is caused by heavy metal oxides, acidic soils, and by phosphate ions attaching to clay mineral surfaces. Because phosphorus is essentially immobile in the soil, it should be placed in an area that is readily accessible to plant roots. This becomes even more important when soil phosphorus levels are low (6).

The placement of fertilizers in a band produces equal and sometimes greater yields compared to broadcast fertilization. The main objectionable feature to band fertilization is that it is most commonly done at planting and results in inconvenience. Banding, however, has been investigated and used more in recent years due to the advantage that plants have in taking up banded fertilizers (6).

Evidence exists showing that row application of nitrogen can benefit plants. However, it is not desirable to apply large quantities of nitrogen in a band directly in contact with the plant roots because of possible injury from a salt effect. More favorable results have come from applying the bulk of nitrogen by top- or side-dressing and applying a low rate in the row as a starter fertilizer (16).

Miller and Ohlrogge (11) conducted a study of nitrogen's effect on phosphorus uptake by corn. They found that low levels of nitrogen increased phosphorus uptake when placed in the band with the phosphorus. This placement gave a 100% increase in the weight of phosphorus per plant at all levels of phosphorus availability in the soil. When nitrogen was separated from the phosphorus band, an increase in plant phosphorus content of only 50% was noted at low soil phosphorus levels and of 25 to 30% at higher phosphorus levels. Part of this was explained by an increase in root growth, thus resulting in more absorbing root surfaces in the band area. This accounted for slight growth increases when nitrogen was placed near the phosphorus band and greater increases when nitrogen was mixed with the phosphorus band. Results also indicated that nitrogen increased the root system's ability to utilize phosphorus from the band. It was theorized that this resulted from an increase in phosphorus availability through chemical effects as well as the increase in root surface area within the band.

A followup study was conducted by Duncan and Ohlrogge (5). They also found that root weights significantly increased when nitrogen and phosphate were present together in the soil volume. However, it was also discovered that in the presence of nitrogen and phosphate, the roots were much finer and silkier in appearance and that the number of roots increased. The result was a much greater difference between treated and untreated soils on the amount of plant root surface area than the difference in root weight suggested. This was explained by fine root hairs accounting for only a minimal amount of the dried root weight but contributing a large portion of the root surface area. When the nutrients were broadcast throughout the soil, nitrogen had little effect on phosphorus uptake. When only a small portion of the soil was fertilized, more roots developed in the fertilized zone, which resulted in nitrogen having an increasing effect on phosphorus uptake. Later research done by Leikam et al. (10) showed similar results. They reported that dual knife applications of nitrogen and phosphorus together consistently increased grain yields and leaf tissue phosphorus concentration in winter wheat. They suggested the possibility of a synergistic effect between nitrogen and phosphorus when placed in a band.

Similar results have been obtained in nitrogen-phosphorus interrelationships in horticultural crops. Nitrogen placed in starter solutions and in bands with phosphorus accelerates phosphorus uptake and utilization by several horticultural crops (19).

It was noted by Weston and Zandstra (17) that nitrogen and phosphorus are very important nutrients in the production of tomato transplants. A study was conducted on the nutritional effects of nitrogen and phosphorus and transplant age effects on tomato growth and yield. Phosphorus levels of 15, 30, and 60 mg l^{-1} were used. Nitrogen was applied in an aqueous solution weekly to the flats containing the three phosphorus levels. The nitrogen levels consisted of 100, 200, and 400 mg l^{-1}. Transplant flats were started on April 22, April 29, May 6, and May 13. The seedlings from these flats were transplanted on May 30. From measurements taken five weeks after sowing, it was found that high levels of nitrogen increased tomato seedling height, leaf area, and shoot and root weights. Moderate to high levels of phosphorus increased seedling height and leaf area versus the low phosphorus level. The optimal fertilization level for the production of the largest tomato transplants was 400 mg l^{-1} nitrogen and 30 mg l^{-1} phosphorus. Tomato sets were transplanted in soil that had the nutrients brought up to levels recommended for tomatoes. All seedlings overcame the initial differences in size by the first fruit set. Conclusions from this study show that tomato transplants grown in cells four to five weeks and fertilized with high levels of nitrogen and moderate levels of phosphorus produce the best tomato seedlings. The combination of this growth period with these nutrient levels enable the plant to more quickly recover from transplant shock, thereby enabling them to produce the highest early and total fruit yields (17).

Increasing the availability of phosphorus throughout the growing season has been studied extensively in tomato production. Hipp (9) reported that the broadcasting of 100 kg ha^{-1} phosphorus on a soil relatively high in available phosphorus resulted in only a slight increase of 1,000 kg ha^{-1} in tomato yield. Whereas, the banding of 100 kg ha^{-1} phosphorus resulted in an increased yield of nearly 5,000 kg ha^{-1} in tomato weights. On another soil, which was low in phosphorus availability, similar results occurred. The broadcast application of 49 kg ha^{-1} of phosphorus gave little yield response. The band application of 49 kg ha^{-1} phosphorus markedly increased yields. Plant tissue phosphorus concentrations were taken at 20 and 44 days after planting. The plants grown on soils with concentrated phosphorus bands had phosphorus concentrations of .26% and .36%, respectively. Plants grown on soil with broadcast applied phosphorus had phosphorus concentrations of only .14% and .28%, respectively. The relative difference in phosphorus concentration between these two treatments is much more evident at 20 days. This indicates the importance of fertilizer placement for early phosphorus uptake by tomatoes. Thus, the need for an abundant supply of phosphorus early in the plant's growth cycle is essential.

Fontes and Wilcox (7) found similar results. In this study, phosphorus was concentrated in the root zone of tomato seedlings. An increase in shoot dry weight and phosphorus accumulation in plant material incurred with increasing phosphorus concentration in the soil solution from .62 to 19.50 micromoles l^{-1}.

It has been noted that phosphorus availability is greatly dependent upon the moisture content and temperature of the soil (15). In southwestern Nigeria where soil moisture and temperature fluctuate, a combination application of 30 kg ha^{-1} phosphorus banded directly underneath the plant and 90 kg ha^{-1} phosphorus broadcast was optimal for increasing tomato yields. Yields obtained from this method of fertilization resulted in 25 metric tons ha^{-1} of fruit weight (14). Wilcox (18) similarly showed that a combination of banding and broadcasting phosphorus gave the same response as banding all phosphorus.

Besford (1) studied the uptake of phosphorus by tomatoes after eight weeks of growth. Also, the effect that nitrogen had on the phosphorus absorption by the plants was investigated. Plants were grown in a peat-sand mixture that contained an adequate level of phosphate, 1.25 kg superphosphate per cubic meter. After eight weeks of growing in this medium, the plants were transferred to pots supplemented with 2.34 kg superphosphate per cubic meter or nil levels of added phosphorus. Following the transfer, a liquid feed containing either 50 micrograms or 300 micrograms of nitrogen was given to the plants. It was discovered that the transfer of plants from a high phosphorus growing medium to a deficient phosphorus medium resulted in rapid phosphorus deficiency symptoms. Plants suffering from phosphorus deficiency had typical symptoms of small size, thin stems, and dull blue-green leaves with purpling. Severe deficiency resulted in chlorotic areas which quickly became necrotic. Plants receiving an adequate supply of phosphorus accumulated a majority of it in the lower parts of the plant. Plants which were denied adequate phosphorus accumulated the element in the fruit. Phosphorus deficient plants translocated 75% of the element from the leaves to meristematic tissue and the fruit. Thus, growing tissues from phosphorus deficient plants were greatly dependent on phosphorus already within the plants. Gibson and Pill (8) also found that fast growing tissue, including fruit, were the dominant phosphorus sinks in tomatoes.

The nitrogen treatments from Besford's study (1) did not have an effect on the distribution of phosphorus throughout the plant. However, an increase in nitrogen resulted in an increase of phosphorus uptake. An increase of nitrogen in plants grown in the phosphorus deficient medium resulted in an increase in retranslocation of phosphorus within the plant. Likewise, deficiency symptoms occurred earlier in plants with the high rate of nitrogen and the low rate of phoshorus. This agrees with the result that higher nitrogen fed plants need more phosphorus to prevent deficiency symptoms. In general, when tomato plants have a high supply of nitrogen, the uptake and need of phosphorus is increased (1).

Besford also examined the effect that these treatments had on flower development and fruit formation (2). In this experiment, an intermediate phosphorus level of .78 kg per cubic meter was included. Flowers reached anthesis earlier when phosphorus was supplied at deficient rates. Plants receiving adequate phosphorus delayed anthesis eight days. However, the final number of flowers developing was significantly lower when phosphorus was deficient and fruit setting was severely reduced. The rate of nitrogen applied had little effect on either flower development or fruit setting. Even though the low phosphorus rates resulted in earlier flower development, the fruit set and development were so damaged that the phosphorus deficient treatments produced approximately 16% of the weight of fruit developed on plants grown with adequate phosphorus.

Fruit set on the plants receiving no phosphorus was so low that yields were not measured. Instead, a more precise study was done on yield differences between the treatments containing .78 and 2.34 kg superphosphate per cubic meter. Yields were reduced by approximately 16% on plants receiving the intermediate phosphorus level. Low rates of nitrogen resulted in yield reductions of about 36%. The combination of intermediate phosphorus and low nitrogen levels resulted in a yield reduction of 43% (2).

Conclusions from Besford's (1, 2) studies indicate that optimal vegetative growth and maximum yield occurred when leaf tissue phosphorus was .4% in mature leaves. This was accomplished by supplementing the growing medium with 2.34 kg superphosphate per cubic meter.

Blatt and McRae (3) found that, in a high phosphate soil, the highest yield of marketable fruit was attained with phosphorus banded at 8.7 kg ha^{-1} with nitrogen and potassium broadcast at 80 and 132 kg ha^{-1}, respectively. When phosphorus was broadcast with the same levels of nitrogen and potassium, it was reported that the phosphorus application would have to be raised to 35 kg ha^{-1} to achieve approximately the same yield. Similar results were achieved on a low phosphate soil. Here, 35 kg ha^{-1} phosphorus was banded, with nitrogen and potassium broadcast at the previously mentioned rates, to achieve maximum marketable yield versus 70 kg ha^{-1} phosphorus broadcast with the same levels of nitrogen and potassium. One treatment also involved banding of all nutrients. Maximum yields for the all-banded and all-broadcast treatments were 24 and 17% lower for marketable fruit yield, respectively, than for phosphorus banded with nitrogen and potassium broadcast.

The Blatt and McRae study was conducted over a three year period. The results over this period were very consistent. This was attributed to the timely use of irrigation to insure that nutrient uptake and availability were not negatively affected by moisture stress. In all three years, plants seemed to recover from transplant shock sooner and were more vigorous throughout the growing season when phosphorus was banded with nitrogen and potassium broadcasted. This could, in part, explain the distinctive advantage of the banded phosphorus treatment with nitrogen and potassium broadcast. This treatment also consistently resulted in the production of larger fruit than the all-banded or all-broadcast methods (3).

These results prominently indicate the importance of banding phosphorus fertilizer regardless of the soil phosphorus status. Banding phosphorus close to and just below the developing root system without causing root damage assures that the plant will have an earlier contact with a more concentrated, highly soluble source of phosphorus than if phosphorus is broadcast. High rates of band placement nitrogen, potassium and phosphorus results in a depressed rate of growth, thus lower tomato yields. This is presumably caused by a toxicity effect on the root system (3). In most instances this toxicity is attributed to increased salt concentrations. In direct relation to this problem, nitrogen and potassium salts have much higher salt indices and are much more damaging to plants than phosphorus salts. The salting effect is more of a problem in coarse-textured soils. Furthermore, salt damage is more likely to occur from low-analysis fertilizer materials, which have higher salt indices (16).

These studies indicate that phosphorus placed in the row and nitrogen placed in the row are advantageous in increasing plant growth. It is shown in several instances that much of the increased plant growth occurs early in the plant's life. The use of these fertilizing practices could be very beneficial to the vegetable farmer in producing early and high yields to achieve maximum profitability.

MATERIALS AND METHODS

Field Research

Tomatoes, Lycopersicon esculentum, variety 'Mountain Pride' were transplanted on the Western Kentucky University Farm in Bowling Green, Kentucky, on May 10, 1989. The tomatoes were grown on a Pembroke silt loam soil, fine-silty, mixed, mesic, Mollic Paleudalf. A randomized complete block design with four replications and six treatments was used.

The soil that the plants were grown on contained 38 kg P ha^{-1}. Treatments consisted of 1) 0 P added, 2) 24.4 kg P ha^{-1} banded with 73.2 kg P ha^{-1} broadcast, 3) 48.8 kg P ha^{-1} P banded with 48.8 kg P ha^{-1} broadcast, 4) 24.4 kg P ha^{-1} and 28 kg N ha^{-1} banded with 73.2 kg P ha^{-1} broadcast, 5) 48.8 kg P ha^{-1} and 28 kg N ha^{-1} banded with 48.8 kg P ha^{-1} broadcast and 6) 97.6 kg P ha^{-1} broadcast. The treatments that had N banded in the row received 112 kg N ha^{-1} broadcast; all other treatments received 140 kg N ha^{-1} broadcast. The plot area received supplemental water as needed via drip irrigation at an approximate rate of 19,000 l per application, thoroughly wetting the soil approximately .5 m around each plant.

Each plot area was 4.55 m by 3.03 m and included .0013946 ha. Within this area each treatment consisted of two 4.55 m rows that were 1.5 m apart. Plants were placed 45.7 cm apart to give 10 plants per row. The spacing between each treatment was 1.8 m to protect against fertilizer movement from one treatment to another. A border row surrounded the plant area. All plants were staked and tied as needed throughout the growing season using nylon and grass string using the San Diego system of trellising (12).

Weed control was maintained using several methods. First, napromide [N,N-diethyl-2-(1-napthalenoxy)-proprionamide] was preplant incorporated at a rate of 2.24 kg ha^{-1}. Later hoeing, hand weeding, and mechanical tilling followed as needed. Insect control was achieved by spraying carbonyl (1-napthyl methyl carbamate) at a rate of 2.75 g l^{-1} applied as needed. Zinc ethylene bisdithiocarbamate was applied at a rate of 9 g l^{-1} in an attempt to keep fungal damage to a minimum. Fungal disease damage was very severe and the fungicide was applied at the most frequent rate recommended.

Leaf tissue samples were taken twice during the course of the season. The samples included the entire leaf, which includes leaflets and stems. The samples were taken from ten plants within each treatment. The first samples were taken on July 14. At this time the tomatoes were in full blossom and the first fruits were beginning to set. The second samples were taken on July 26. This was after the first fruit harvest. Fruit samples were taken on August 14. The fruit samples consisted of two tomatoes taken from the marketable grades of each treatment. These tissue samples were used to determine phosphorus content using tissue analysis methods described by Cottenie (4). Only the July 26 leaf samples were also analyzed for total nitrogen content by using the Kjeldahl nitrogen analysis (4).

Fruit was harvested at two to five day intervals. The irregularity in harvest dates was due to fungicide applications label restrictions. The fruit was harvested upon early color change regardless of size or quality. The fruit was divided into two grades, marketable tomatoes and cull tomatoes. Marketable tomatoes were those which were at least 5 cm in diameter with only slight flaws in color or shape. Cull tomatoes were those which were either too small in diameter or had excessive flaws. Fruit harvest began on July 26 and continued until September 14. The lateness in the harvest period was due to the severity of the fungal damage.

Greenhouse Research

'Mountain Pride' tomato seedlings were planted into 18 cm plastic pots that contained 3.18 kg of soil per pot. Surface soil from the field research area which had received no phosphorus fertilizer was used in this study. Each pot received 140.0 kg N ha^{-1}. This study was conducted in a completely random design.

Treatments included: 1) 0 P added, 2) 24.4 kg P ha^{-1} broadcast throughout the soil, 3) 24.4 kg P ha^{-1} banded, 4) 48.8 kg P ha^{-1} broadcast throughout the soil, 5) 48.8 kg P ha^{-1} banded, 6) 48.8 kg P ha^{-1} broadcast throughout the soil with 48.8 kg P ha^{-1} banded, and 7) 97.6 kg P ha^{-1} broadcast throughout the soil. The band treatments were placed 5 cm beneath the surface of the soil.

The plants were thinned to four plants per pot and were harvested by clipping them just above the adventitious root. Harvest took place 56 days after the seedlings had been transplanted. The plants were oven dried and weighed and tissue samples were tested for phosphorus using methods described by Cottenie (4).

RESULTS AND DISCUSSION

Field Research

Total and marketable yields are shown in Table 1. Phosphorus and nitrogen placement had no significant effect on total weights of tomatoes. This was also the case when independently comparing the treatments with each other (Appendix, Table 1). There also were no significant differences between the total marketable weights of tomatoes. However, when independently comparing the treatments, it was found that the broadcast phosphorus treatment produced a significantly higher amount of marketable fruit than did phosphorus banded treatments (Appendix, Table 2).

Marketable tomato yields relatively followed the same trend during the growing season until the August 28 harvest. At this time, the broadcast treatment produced higher yields. By the end of the harvest season the phosphorus and nitrogen band treatments showed a trend to increase yields also (Figure 1).

Table 1 shows the percent marketable yield of total yield. There was a highly significant difference in the percent of total production of tomatoes which graded marketable between treatments (Appendix, Table 3). Independent comparisons show that the check treatment produced a highly significantly lower percentage of marketable fruit when compared against all other treatments. Other comparisons show that treatments with nitrogen placed in the row produced a highly significantly higher percent marketable fruit than did the other treatments.

Table 1. Effect of phosphorus placement and rate and nitrogen placement ontotal and marketable tomato fruit weights and on percent marketable fruit weights of total fruit weights.

	Treatment*					
	P0	P1	P2	P1N	P2N	PB
Total Yield (kg ha^{-1})	34,227	33,512	30,103	32,596	33,505	39,371
Marketable Yield (kg ha^{-1})	9,330	9,975	9,925	11,159	11,102	11,637
% Marketable Yield	27	30	33	34	33	30

*P0 - no phosphorus added

*P1 - 24.4 kg P ha^{-1} banded, 73.2 kg P ha^{-1} broadcast

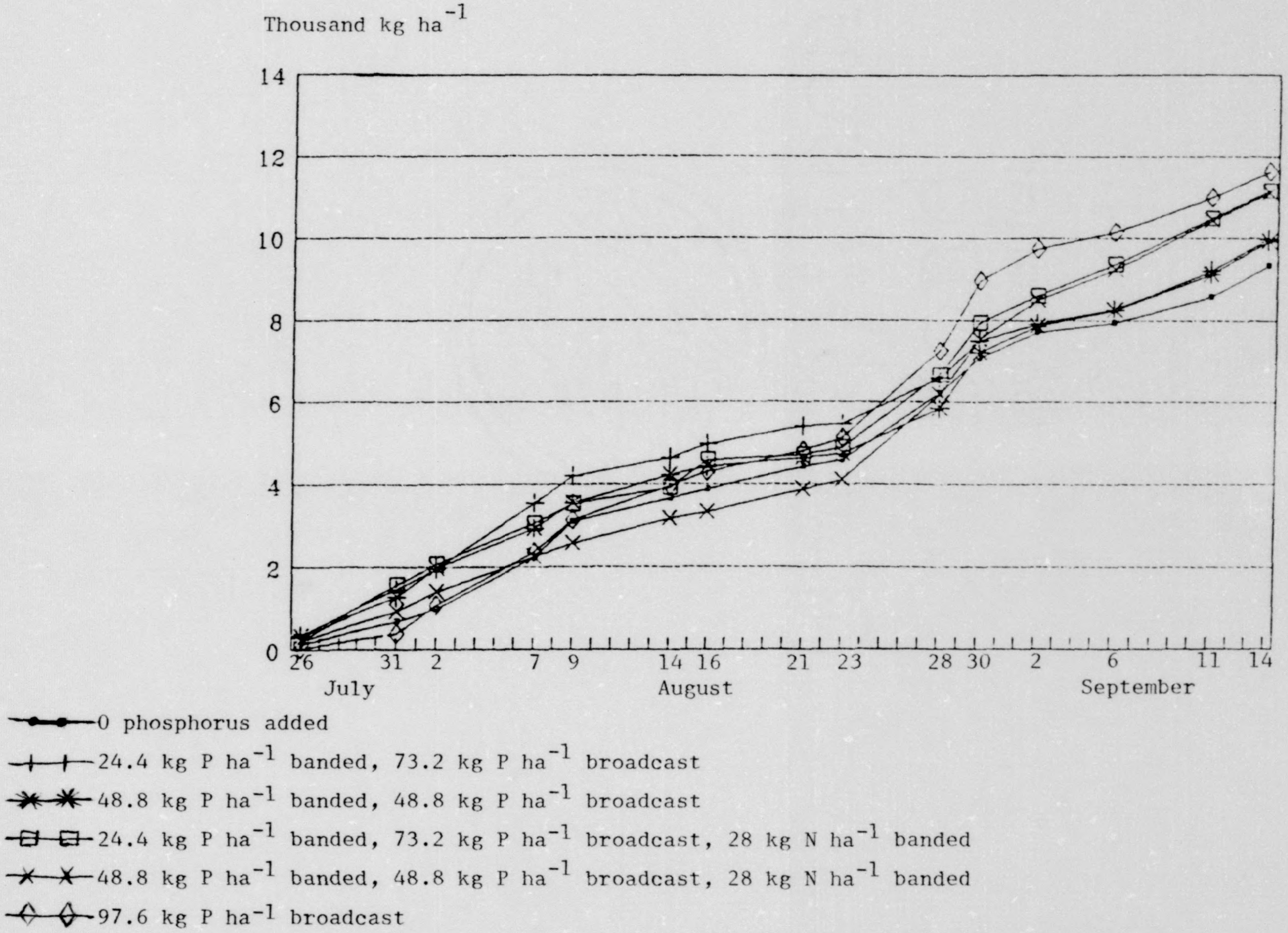
*P2 - 48.8 kg P ha^{-1} banded, 48.8 kg P ha^{-1} broadcast

*P1N - 24.4 kg P ha^{-1} banded, 73.2 kg P ha^{-1} broadcast, 28 kg N ha^{-1} banded

*P2N - 48.8 kg P ha^{-1} banded, 48.8 kg P ha^{-1} broadcast, 28 kg N ha^{-1} banded

*PB - 97.6 kg P ha^{-1} broadcast

Figure 1. Effect of phosphorus placement and rate and nitrogen placement on cumulative marketable tomato fruit weights.



A study conducted in the summer of 1988 on the Western Kentucky University Farm using 'Mountain Pride' variety tomatoes resulted in a marketable yield of 65,118 kg ha^{-1} compared to the high yield of 11,637 kg ha^{-1} found in this study (Table 1). The 1988 study showed the percentage marketable yield to be 77 percent compared to a high of 34 percent in this study.*

At least some of the drastic reduction in marketable yield and in percent marketable yield are explained by undesirable environmental conditions occurring during the growing season. On May 27 it was noticed that the new plant growth appeared to be knarled and twisted. This is believed to be the result of an overapplication of napromide [N,N-diethyle-2-(1 naphthalenoxy)-proprionamide]. These symptoms remained throughout the growing season. On June 18 a severe wind and hail storm was responsible for defoliating approximately 40 percent of the leaves from the plants. The storm also caused considerable damage by breaking stems and damaging some of the plant's main stems. Very soon after this damage occurred, symptoms of early blight, Alternaria solani, began to appear. By July 14 blight damage was so severe that all of the plant's lower leaves were dead, which resulted in approximately 30 percent defoliation of the plants (Illustration 1). Overall, the fruit size was also drastically reduced. The previously mentioned plant damage is the only explanation.

Table 2 shows the percent total nitrogen found in leaf tissue samples taken on July 26. There were no significant differences between treatments (Appendix, Table 7). The range of percent nitrogen found in the tissue samples was broad and followed no pattern when comparing treatments. This is unexplainable.

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*Unpublished data, 1988, Western Kentucky University Department of Agriculture.

Illustration 1. Symptoms of *Alternaria solani* on tomato plants.

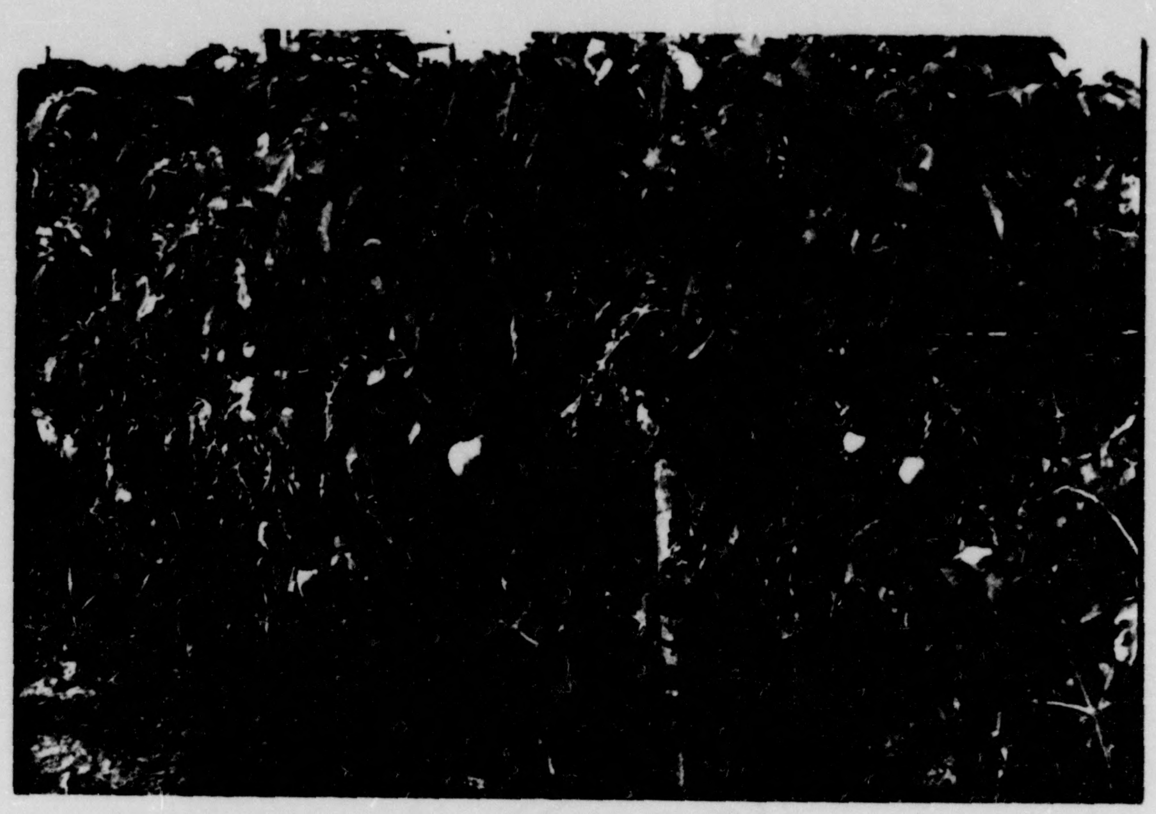

Table 2. Effect of phosphorus placement and rate and nitrogen placement on percent phosphorus in tomato leaf and fruit tissue (three sampling dates) and on percent nitrogen in leaf tissue (one sampling date).

	Treatment*					
	P0	P1	P2	P1N	P2N	PB
July 14 leaf P	.485	.493	.510	.485	.523	.490
July 26 leaf P	.360	.380	.365	.315	.403	.353
August 14 fruit P	.358	.343	.335	.313	.483	.433
July 26 leaf N	4.23	4.30	4.08	3.73	4.40	3.93

*P0 - no phosphorus added

*P1 - 24.4 kg P ha^{-1} banded, 73.2 kg P ha^{-1} broadcast

*P2 - 48.8 kg P ha^{-1} banded, 48.8 kg P ha^{-1} broadcast

*P1N - 24.4 kg P ha^{-1} banded, 73.2 kg P ha^{-1} broadcast, 28 kg N ha^{-1} banded

*P2N - 48.8 kg P ha^{-1} banded, 48.8 kg P ha^{-1} broadcast, 28 kg N ha^{-1} banded

*PB - 97.6 kg P ha^{-1} broadcast

Table 2 also shows the percent phosphorus in leaf tissue samples taken on July 14 and July 26 and in fruit samples taken on August 14. There were no significant differences found between the treatments on either the first or second sample date (Appendix, Tables 4 and 5). However, when the treatments were independently compared, it was discovered that the treatment with the high rate of phosphorus placed in the row with nitrogen had a significantly higher amount of leaf tissue phosphorus than did the low rate of phosphorus placed in the row with nitrogen treatment. There were no significant differences found between treatments in the fruit tissue samples (Appendix, Table 6). There was a trend in the tissue sampling as a whole. The treatment containing the high rate of phosphorus with nitrogen in the row consistently had the highest amount of tissue phosphorus in all of the samples. This is in agreement with Miller and Ohlrogge (11) that nitrogen increases phosphorus uptake when placed in the row with phosphorus.

Greenhouse Research

The average harvest weights for four 56-day old tomato plants are shown in Figure 2. There were significant differences among the various treatments (Appendix, Table 8). The differences as determined by Duncan's Multiple Range Test are shown in Table 3. The plants receiving zero phosphorus had an obvious deficiency, thus weighing significantly less than all other treatments. These plants also showed deficiency symptoms of phosphorus throughout the entire growth period, e.g. blueish color, purple veination. It is believed that the plants receiving only 24.4 kg P ha^{-1}, whether banded or broadcast, weighed less because of a lack of phosphorus also. Although the other treatments were not statistically different, there appears to be a trend toward increased weights with all

Figure 2. Effect of phosphorus placement and rate on the weight of whole above ground plant material.

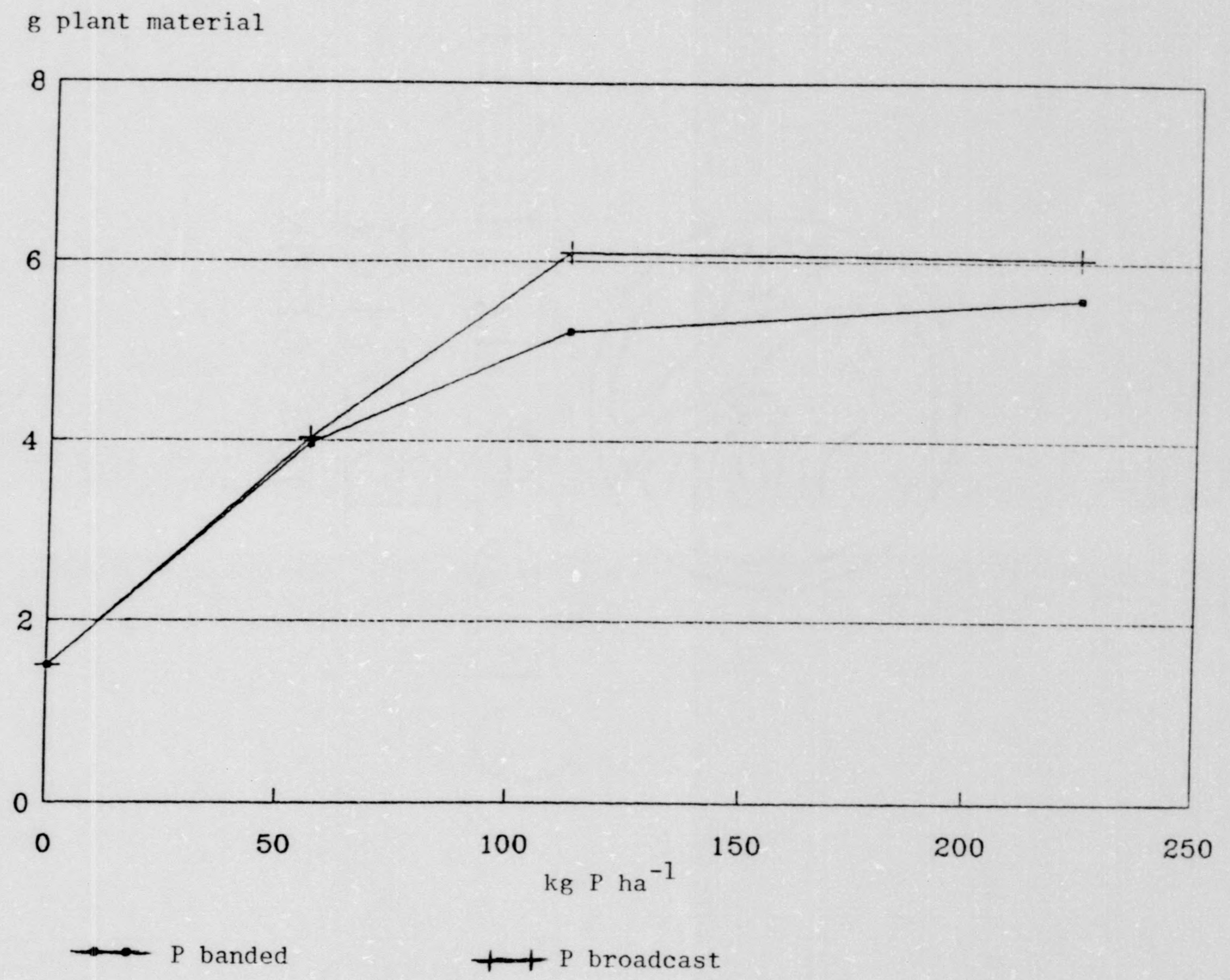

Table 3. Effect of phosphorus placement and rate on tomato plant weights and percent phosphorus concentration.

Placement and Rate	g Plant Tissue per Four Plants	% P
0 P	1.50a	.28bc
24.4 kg P ha^{-1} banded	3.97b	.16a
24.4 kg P ha^{-1} broadcast	4.03b	.25abc
48.8 kg P ha^{-1} banded	5.22bc	.23ab
48.8 kg P ha^{-1} broadcast	6.10c	.36c
48.8 kg P ha^{-1} banded, 48.8 kg P ha^{-1} broadcast	5.59c	.25abc
97.6 kg P ha^{-1} broadcast	6.04c	.27abc

Means in any column followed by the same letter are not significantly different at the .05 level of probability.

broadcast treatments. It is believed that this results from the phosphorus being broadcast throughout such a small volume of soil which in essence results in a band. Sleight et al. (13) indicated that the optimum availability of phosphorus was obtained by mixing the fertilizer with the portion of the soil where the highest concentration of roots was located. This was the case with the broadcast treatments in this study as roots were found throughout the soil volume. These data indicate, as shown in Figure 2, the classic example of the increase in plant growth when a limiting nutrient is applied to a deficient soil.

Sleight et al. (13) also indicate that the fertilizer should not be concentrated to such an extent that root-fertilizer contact can become limited by the number of roots that can remain in the fertilized zone. This is in agreement with the percent phosphorus concentration data shown in Table 3. There were significant differences found between treatments (Appendix, Table 9). Duncan's Multiple Range Test shows significant differences between banding and broadcasting phosphorus at different rates (Table 3). These data indicate that 48.8 kg P ha^{-1} broadcast is optimal for both plant growth and nutrient uptake. It is theorized that when 48.8 kg P ha^{-1} was banded that the phosphorus was limited by the number of roots that could remain in the band. Such high concentration occurring when zero phosphorus was added was unexpected and is not explained.

CONCLUSIONS

Results indicate that tomato plants need an adequate supply of phosphorus for optimum growth and fruit production. The greenhouse research clearly indicates a favorable response from tomatoes that receive supplemental phosphorus when grown in a phosphorus deficient soil. Because of severely reduced yields, the results from the field research are inconclusive.

Without the damage that was incurred by the hail storm and fungal disease, it is believed that more favorable results would have been found from the field research. Perhaps further field studies could be conducted over a number of locations or years to avoid such environmental factors.

The greenhouse study results showed increased growth of tomatoes with increased phosphorus rates as expected. But results from placement were not found as anticipated. It is believed that the band that the phosphorus was placed in was too small. This limited the area in which the roots could grow and still be in contact with concentrated amounts of supplemental phosphorus. Taking into consideration the small volume of soil used, it was concluded that the broadcast treatments had more phosphorus contacting more roots. The broadcast treatments in the greenhouse could now be possibly viewed as a dispersed band placement of phosphorus.

It is believed that further investigation is warranted in finding the most efficient method of supplementing phosphorus to tomatoes. The greenhouse study suggests that broadcast application appears to be the most favorable. This treatment could be duplicated in the field by placing phosphorus in a band and then mixing it in the soil volume which would have the most dense root distribution. Placing phosphorus in this broad concentrated zone may furthermore improve root-fertilizer contact. This type of placement may result in the application of less supplemental phosphorus for adequate tomato production.

APPENDIX

Table 1. Analysis of variance for total weights of fruit produced.

Source	D.F.	S.S.	M.S.	F
Total	23	9,674.25		
Blocks	3	4,945.99	1,648.67	7.76**
Treatment	5	1,543.29	308.66	$1.45^{n.s.}$
*P0 vs. others	(1)	21.46	21.46	$.10^{n.s.}$
*P1N, P2N vs. P1, P2, PB	(1)	10.29	10.29	$.05^{n.s.}$
*P1N vs. P2N	(1)	45.13	45.13	$.21^{n.s.}$
*P1, P2 vs. PB	(1)	6.80	6.80	$.03^{n.s.}$
*P1 vs. P2	(1)	2.26	2.26	$.01^{n.s.}$
Error	15	3,184.97	212.33	

** - significant at the .01 level
* - significant at the .05 level
n.s. - not significant
*P0 - no phosphorus added
*P1 - 24.4 kg P ha^{-1} banded, 73.2 kg P ha^{-1} broadcast
*P2 - 48.8 kg P ha^{-1} banded, 48.8 kg P ha^{-1} broadcast
*P1N - 24.4 kg P ha^{-1} banded, 73.2 kg P ha^{-1} broadcast, 28 kg N ha^{-1} banded
*P2N - 48.8 kg P ha^{-1} banded, 48.8 kg P ha^{-1} broadcast, 28 kg N ha^{-1} banded
*PB - 97.6 kg P ha^{-1} broadcast

Table 2. Analysis of variance for total weights of marketable fruit.

Source	D.F.	S.S.	M.S.	F
Total	23	2,158.56		
Block	3	1,541.67	513.89	21.16**
Treatment	5	252.58	50.16	$2.07^{n.s.}$
*P0 vs. Others	(1)	96.75	96.75	$3.98^{n.s.}$
*P1N, P2N vs. P1, P2, PB	(1)	1.01	1.01	$.04^{n.s.}$
*P1N vs. P2N	(1)	7.03	7.03	$.29^{n.s.}$
*P1, P2 vs. PB	(1)	135.38	135.38	5.57*
*P1 vs. P2	(1)	10.13	10.13	$.42^{n.s.}$
Error	15	364.31	24.29	

** - significant at the .01 level
* - significant at the .05 level
n.s. - not significant
*P0 - no phosphorus added
*P1 - 24.4 kg P ha^{-1} banded, 73.2 kg P ha^{-1} broadcast
*P2 - 48.8 kg P ha^{-1} banded, 48.8 kg P ha^{-1} broadcast
*P1N - 24.4 kg P ha^{-1} banded, 73.2 kg P ha^{-1} broadcast, 28 kg N ha^{-1} banded
*P2N - 48.8 kg P ha^{-1} banded, 48.8 kg P ha^{-1} broadcast, 28 kg N ha^{-1} banded
*PB - 97.6 kg P ha^{-1} broadcast

Table 3. Analysis of variance for percent marketable fruit weights of total fruit weights.

Source	D.F.	S.S.	M.S.	F
Total	23	299.63		
Block	3	191.79	63.93	28.29**
Treatment	5	73.88	14.78	6.53**
*P0 vs. others	(1)	46.88	46.88	20.74**
*P1N, P2N vs. P2, P1, PB	(1)	20.83	20.83	9.22*
*P1N vs. P2N	(1)	0	0	0 n.s.
*P1, P2 vs. PB	(1)	.04	.04	.02 n.s.
*P1 vs. P2	(1)	6.13	6.13	2.70 n.s.
Error	15	33.96	2.26	

** - significant at the .01 level
* - significant at the .05 level
n.s. - not significant
*P0 - no phosphorus added
*P1 - 24.4 kg P ha^{-1} banded, 73.2 kg P ha^{-1} broadcast
*P2 - 48.8 kg P ha^{-1} banded, 48.8 kg P ha^{-1} broadcast
*P1N - 24.4 kg P ha^{-1} banded, 73.2 kg P ha^{-1} broadcast, 28 kg N ha^{-1} banded
*P2N - 48.8 kg P ha^{-1} banded, 48.8 kg P ha^{-1} broadcast, 28 kg N ha^{-1} banded
*PB - 97.6 kg P ha^{-1} broadcast

Table 4. Analysis of variance for leaf tissue phosphorus levels of field grown tomatoes (July 14).

Source	D.F.	S.S.	M.S.	F
Total	23	.020		
Block	3	.020	.006	$2.22^{n.s.}$
Treatment	5	.005	.001	$.34^{n.s.}$
*P0 vs. others	(1)	.00075	.00075	$.25^{n.s.}$
*P1N, P2N vs. P1, P2, PB	(1)	.068	.0068	$2.25^{n.s.}$
*P1N vs. P2N	(1)	.0028	.0028	$.94^{n.s.}$
*P1, P2 vs. PB	(1)	.0003	.0003	$.11^{n.s.}$
*P1 vs. P2	(1)	.0006	.0006	$.20^{n.s.}$
Error	15	.041	.003	

** - significant at the .01 level
* - significant at the .05 level
n.s. - not significant
*P0 - no phosphorus added
*P1 - 24.4 kg P ha^{-1} banded, 73.2 kg P ha^{-1} broadcast
*P2 - 48.8 kg P ha^{-1} banded, 48.8 kg P ha^{-1} broadcast
*P1N - 24.4 kg P ha^{-1} banded, 73.2 kg P ha^{-1} broadcast, 28 kg P ha^{-1} banded
*P2N - 48.8 kg P ha^{-1} banded, 48.8 kg P ha^{-1} broadcast, 28 kg P ha^{-1} banded
*PB - 97.6 kg P ha^{-1} broadcast

Table 5. Analysis of variance for leaf tissue phosphorus levels of field grown tomatoes (July 26).

Source	D.F.	S.S.	M.S.	F
Total	23	.073		
Block	3	.012	.004	1.33$^{n.s.}$
Treatment	5	.017	.003	1.00$^{n.s.}$
*P0 vs. others	(1)	.00003	.00003	.01$^{n.s.}$
*P1N, P2N vs. P1, P2, PB	(1)	.00024	.00024	.08$^{n.s.}$
*P1N vs. P2N	(1)	.01531	.01531	5.10*
*P1, P2 vs. PB	(1)	.00107	.00107	.36$^{n.s.}$
*P1 vs. P2	(1)	.00045	.00045	.15$^{n.s.}$
Error	15	.044	.003	

** - significant at the .01 level
* - significant at the .05 level
n.s. - not significant
*P0 - no phosphorus added
*P1 - 24.4 kg P ha^{-1} banded, 73.2 kg P ha^{-1} broadcast
*P2 - 48.8 kg P ha^{-1} banded, 48.8 kg P ha^{-1} broadcast
*P1N - 24.4 kg P ha^{-1} banded, 73.2 kg P ha^{-1} broadcast, 28 kg N ha^{-1} banded
*P2N - 48.8 kg P ha^{-1} banded, 48.8 kg P ha^{-1} broadcast, 28 kg N ha^{-1} banded
*PB - 97.6 kg P ha^{-1} broadcast

Table 6. Analysis of variance for fruit tissue phosphorus levels of field grown tomatoes (August 14).

Source	D.F.	S.S.	M.S.	F
Total	23	.435		
Block	3	.028	.0093	$.44^{n.s.}$
Treatment	5	.087	.017	$.82^{n.s.}$
*P0 vs. others	(1)	.426	.0018	$.09^{n.s.}$
*P1N, P2N vs. P1, P2, PB	(1)	.074	.074	$3.52^{n.s.}$
*P1N, vs. P2N	(1)	.0578	.0578	$2.75^{n.s.}$
*P1, P2 vs. PB	(1)	.0234	.0234	$1.12^{n.s.}$
*P1 vs. P2	(1)	.0006	.0006	$.03^{n.s.}$
Error	15	.320	.021	

** - significant at the .01 level
* - significant at the .05 level
n.s. - not significant
*P0 - no phosphorus added
*P1 - 24.4 kg P ha^{-1} banded, 73.2 kg P ha^{-1} broadcast
*P2 - 48.8 kg P ha^{-1} banded, 48.8 kg P ha^{-1} broadcast
*P1N - 24.4 kg P ha^{-1} banded, 73.2 kg P ha^{-1} broadcast, 28 kg N ha^{-1} banded
*P2N - 48.8 kg P ha^{-1} banded, 48.8 kg P ha^{-1} broadcast, 28 kg N ha^{-1} banded
*PB - 97.6 kg P ha^{-1} broadcast

Table 7. Analysis of variance for percent total nitrogen in leaf tissue samples (July 26).

Source	D.F.	S.S.	M.S.	F
Total	23	7.32		
Block	3	.94	.31	$.92^{n.s.}$
Treatment	5	1.27	.25	$.74^{n.s.}$
*P0 vs. others	(1)	.07	.07	$.21^{n.s.}$
*P1N, P2N vs. P1, P2, PB	(1)	.01	.01	$.03^{n.s.}$
*P1N vs. P2N	(1)	.91	.91	$2.68^{n.s.}$
*P1, P2 vs. PB	(1)	.18	.18	$.53^{n.s.}$
*P1 vs P2	(1)	.10	.10	$.29^{n.s.}$
Error	15	5.11	.34	

** - significant at the .01 level
* - significant at the .05 level
n.s. - not significant
*P0 - no phosphorus added
*P1 - 24.4 kg P ha^{-1} banded, 73.2 kg P ha^{-1} broadcast
*P2 - 48.8 kg P ha^{-1} banded, 48.8 kg P ha^{-1} broadcast
*P1N - 24.4 kg P ha^{-1} banded, 73.2 kg P ha^{-1} broadcast, 28 kg N ha^{-1} banded
*P2N - 48.8 kg P ha^{-1} banded, 48.8 kg P ha^{-1} broadcast, 28 kg N ha^{-1} banded
*PB - 97.6 kg P ha^{-1} broadcast

Table 8. Analysis of variance for whole above ground plant tissue weights of greenhouse grown tomatoes.

Source	D.F.	S.S.	M.S.	F
Total	27	79.37		
Treatment	6	63.97	10.66	14.54**
Error	21	15.70	.73	

** - significant at the .01 level

Table 9. Analysis of variance for whole above ground plant tissue phosphorus levels of greenhouse grown tomatoes.

Source	D.F.	S.S.	M.S.	F
Total	27	.202		
Treatment	6	.089	.015	2.74*
Error	21	.113	.005	

* - significant at the .05 level

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