INTERRELATIONSHIPS OF NITROGEN PHOSPHORUS, SULFUR, ZINC AND CHLORINE ON THE GROWTH AND COMPOSITION OF FIELD TOMATOES

by

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TOMATO NUTRITION

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ABSTRACT

At the Beka'a, Lebanon in an irrigated field experiment the individual effects and the effects of various possible combinations of five nutrient elements, N, P, S, Zn and Cl on the yield and composition of the tomato plant were investigated. Field tomatoes responded highly to P application and marketable yields were profitably increased up to the 375.8 kg./ha. rate of applied P especially at low levels of S and N. Even though S application tended to increase tomato yields addition of P decreased the requirement for S for higher yields of better quality. Chlorine, however, proved beneficial for tomato yields particularly at high levels of applied P, but the inferior fruit quality induced by Cl application at high rates of P made high levels of Cl application undesirable. Application of N was detrimental to marketable yields especially early in the season and Zn tended to produce a negative effect. Furthermore it was clearly demonstrated that yield response to the nutrient elements under study was highly regulated by the consequent effect of the particular element on fruit set. Data on leaf composition were discussed at length.

The failure to establish a critical level for PO_4-P concentration in tomato leaves collected during the harvest season was attributed to the fluctuations in leaf concentrations brought about by the

differential assimilation of PO_4-P following the cyclic waves of fruit setting and development.

The exceptionally high tomato yields - up to 96.43 m. tons/ha.- were attributed to the favorable soil and climatic conditions of the area as well as to the ample water supply and optimum cultural practices.

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INTRODUCTION

Tomato, Lycopersicon esculentum, is a warm season crop and requires a relatively long growing season to produce profitable yields. In Jordan tomatoes constitute an important commodity for export to neighboring countries because they can be produced out of season with little competition from other areas. Unlike other vegetable crops, it is produced all the year around in the Jordan Valley where the winters are relatively warm due to its low elevation (about 300 meters below sea level).

Because of the increasing importance the tomato crop has assumed in the economy of the country, several varietal trials and some nutritional studies were undertaken at the Deir Alla research station of the Jordan Valley with variable degrees of success. In a few instances P application significantly increased tomato yields whereas other results were inconclusive. Probably the saline nature of the Jordan Valley soils and the use of irrigation water containing some salts had interfered with the performance of tomato plants to some extent and consequently low yields were reported. Hayward and Long (31) obtained a progressive growth depression of the tomato plant by increasing the concentration of $NaCl$ or Na_2SO_4 in culture solutions.

Flower bud formation was also adversely affected.

In tomatoes flower formation has a close relationship to nutritional conditions (14). According to Lambeth (44), the tendency of an element to hasten or delay the time of anthesis was effective only with a favorable balance of supply of the other elements under consideration. As reported by Kraybill (42), Kraus and Kraybill showed maximum fruitfulness to be associated with a condition of balance between N and carbohydrate within the tomato plant. The ratio can be modified by changing the supply of available salts. Apparently, at the Deir Alla research station the relatively small amounts of fertilizers involved probably did not furnish the proper nutrient balance for optimum fruitfulness of tomatoes and consequently resulted in low yields. Furthermore, the relatively reduced hours of illumination and somewhat low winter temperatures of the Jordan Valley might have reduced fruit set and yield as compared with the Beka'a, Lebanon conditions where summer days are longer and summer temperatures higher.

With regards to the reduced response to P application, short days and low temperatures of the winter were probably among the factors. Hence further experimentation with higher rates of P seems necessary for more conclusive results.

The purpose of this investigation was to study the direct effects and interactions of the nutrient elements N, P, S, Zn and Cl on the yield and composition of field grown tomatoes under the conditions of the Beka'a, Lebanon. In order to study these five variables with each at five different levels of application and using a reasonable number of treatment combinations, a central composite, rotatable, incomplete factorial design was adopted.

LITERATURE REVIEW

Nitrogen

Wilcox and Langston (84) reported that Watts found the nutrient requirement for normal growth of tomato seedlings to be higher for N and P than for K when considering N, P and K in a nutrient solution. In a pot culture experiment, Leone and Shive (46) obtained optimum growth of tomato plants at 100 ppm. concentration of N when N and P were varied from 10-250 ppm. and 0.5-50 ppm., respectively. Similarly, Raleigh and Chucka (72) obtained the highest weight of green plant at the 300 ppm. N level and the lowest at the 2400 ppm. level in the nutrient solution. Increasing N alone slightly retarded development without enhancing yields (Tagmaz'jan, 79).

The excessive application of N fertilizers may favor vegetative activity of tomato plants at the expense of fruitfulness. Under greenhouse conditions (Mack, 57) N fertilization in amounts ranging from medium applications (500 lbs. of $NaNO_3$/acre) to very heavy ones did not induce an overvegetative condition in tomato plants. Work (86) failed to bring about a condition of high vegetation and unfruitfulness at heavy applications of nitrates as high as nine tons per acre (as $NaNO_3$).

In a greenhouse study by Wilcox and Langston (84), without P in the fertilizer band, N first depressed yields of tops slightly and then increased the growth as the N rate increased to the highest level. As the rate of P in the band was increased, the effect of N on growth was diminished. Under normal day length (10-12 hrs.) in the greenhouse, Harris (29) found the fastest growth rate at a low N level in the presence of high P and K. High N, P and K increased the growth rate of tomatoes under conditions of additional light.

According to Gilbert and Smith (25) the determination of soil nitrates predicts the N needs of young plants adequately, but analysis of the expressed plant solution is more exact for later growth stages. They obtained uniformly greater yields of tomatoes by maintaining the NO_3-N of the soil quite consistently above 20 ppm. and that of the plant solution above 300 ppm. for the entire season. Results of a two year experiment, by Malcolm (58) indicated a highly significant yield increase from the application of N and K. Application of N at 150 lbs./acre gave a larger increase in yield over the check than double this amount. Similarly, Mamber-Rylska (59) advocated the beneficial effects of N application on tomato yields.

However, increased rates of N did not always result in increased yields. Kattan <u>et al</u>. (41) obtained no effect on tomato yield by sidedressing N at the rate of 100 to 200 lbs./acre on plots that had previously received 500 lbs./acre of 5-10-10 fertilizer in the spring. As reported by Neubert (65) tomato yields increased up to the 160 kg. of N/ha. rate and decreased with higher N applications in the field.

Dunn (12) reported that spring tomatoes receiving 100 ppm. of N in the nutrient culture produced greater yields and a larger number of fruits than those grown at the 50 and 200 ppm. levels. In contrast, Leopold and Guernsey (47) obtained highest yields at a N level of 200 ppm. According to Raleigh and Chucka (72) the 400 and 300 ppm. levels of applied N were associated with the highest number and weight of fruit, respectively. The 2400 ppm. level produced the least of both.

Flower formation in tomatoes is closely related to nutritional conditions. According to Wittwer and Teubner (85) a high N level (440 ppm.) favored earlier and increased flower formation in contrast to a low N level (55 ppm.). On the other hand, Lambeth (44) reported anthesis to occur later at the higher N treatments.

Several workers (12, 20, 83) reported N application to increase N concentration of tomato tops. Malcolm (58) obtained a relatively large increase in N in the tomato leaves when 150 lbs./acre of N was applied compared to the no N treatments, but only a slight increase occurred where the applied N was raised to 300 lbs./acre. According to Leone and Shive (46) increasing N in the culture solutions up to 100 ppm. at any given P level (0.5 to 50 ppm.) increased N contents of the tomato seedlings. Beyond this optimum concentration the increase in N content did not correspond with the increase in N supply. Mori and Abe (63) worked on Marglobe tomato plants in nutrient solutions with four levels of N (50-400 ppm.) and with P, K, Ca, Mg and S in varied or constant proportions to N. They reported that the amount of N absorbed increased with the level of applied N with other elements having no effect on N absorption.

The interrelationships of other nutrient elements on N were given by some investigators. Leone and Shive (46), Lingle (49) and Cannell _et al_. (7) reported increased N content of the tomato plant following P application. In contrast Dunn (12) obtained a decrease in leaf N following increases in P supply for a tomato spring crop. Breon and Gillman (3) provided evidence that excess nitrates are present in the P deficient plants by virtue of accumulation following more rapid absorption rather than as a result of the plants inability to reduce them. Lambeth (44) reported that a high N/P ratio resulted in delayed anthesis whereas a high P/N ratio hastened flowering.

According to Smith (77) Zn significantly raised the concentration of N in tomato leaflets, as its concentration was raised from 0.025 to 2.5 ppm. in a rigidly controlled nutrient solution. Harward _et al_. (30) and Kretschmer _et al_. (43) obtained lower N contents of potato leaves and tomatoes, respectively, as the Cl concentration in the substrates was increased. In an ion uptake study, Meyer _et al_. (62) obtained less N from tomato plants grown in the chloride treatment as compared with the all sulfate treatment. Studies on tomatoes by Hayward and Long (32) indicated that salinity increased the total N content of the plants. According to Raleigh and Chucka (72), varying S in the base solution from 50-800 ppm. increased the N content of tomato vines. The S deficient tomato plants were extremely high in carbohydrate and contained much more nitrate than the plants which received the complete nutrient solution (Nightingale et al., 66). He attributed this accumulation to the comparatively slow reduction of nitrate ions and oxidation of sugars in the minus sulfate plants.

An adequate supply of available N is essential for high yields and better quality of tomato fruits. Nitrogen deficiency or excess has adverse effects on growth, flower formation and fruit set. Consequently yields are reduced and quality of fruit is marred. The available literature contains very little information on the interactions of P, S, Zn and Cl on the absorption of N by the tomato plant.

Phosphorus

According to Kraybill (42) P is just as essential for the production of the nonseed as the seed portion of the tomato fruit. Ermolaeva (17) reported that high rates of P increased resistance to cold, increased starch and chlorophyll in leaves and photosynthetic activity. As reported by Jones and Warren (40), Turner clearly demonstrated that P applied to deficient tomato plants caused greater increases in root growth than top growth. According to Rogalev (75) P nutrition stimulated the formation of fibrovascular bundles and xylem vessels in several crop plants. In tomato stems the width of the vascular ring and the number of the xylem vessels were greatest when normal rates of N and K were applied with a double rate of P.

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In general, it has been shown that the P-nutrition of tomato plants grown on soil is most critical during the early growth stages (Wilcox and Langston, 84). According to Jones and Warren (40) increasing early P uptake was shown to be more important in affecting yields than was increasing total P uptake. Late P absorption was found to have little bearing on yield. Ingram <u>et al</u>. (35) obtained a positive correlation ($r=0.67$) between the soluble phosphate contents of tomato plants and plant rejuvenation late in the season. The coefficient for the correlation of plant P content and total yield was 0.72.

Several workers reported beneficial effects of P fertilization on the growth of tomato plants. In greenhouse experiments Cannell <u>et al</u>. (7) studied the effect of irrigation and four levels of P (2 to 50 g. of $Ca(H_2PO_4)_2.H_2O$ per 12.5 kg. of soil) on vegetative growth and composition of tomato leaves. The smaller plants were associated with the lowest P treatment at all stages of plant growth when compared to other P treatments. As reported by Locascio and Warren (53) growth of tomato plants increased linearly with increasing rates of P (0-488 lbs./acre) up to the highest level applied with a soil temperature of 55°F. At the higher soil temperatures (70 and 85°F) the growth tended to reach a maximum and level off. Wilcox and Langston (84) found that the amount of response to P applied in the band diminished at the higher levels of associated N.

An adequate nutrional level of P is required for quantity and quality of tomato yields (7, 20). Under greenhouse conditions, Pattanaik and Lathwell (68) considered 0.15 to 0.20% as the critical range of P concentration of the tomato shoot. Baker (2) reported earlier ripening and increased tomato yields when commercial phosphoric acid and mono-ammonium phosphate were used in the transplanting solution. As reported by Tiessen (83) a high P content in tomato plants from solutions given shortly after transplanting was correlated with subsequent growth and yield. Fertilizer solutions tended to decrease flower abscission and increase fruit set and early yield.

Application of 4-16-4 fertilizer at 0, 500, 1000 and 2000 lbs./acre under a medium level of irrigation (irrigation practiced when the moisture content of the soil was reduced in the top 6 inches of soil to 17%) showed a linear relationship between the quantity of fertilizer applied and tomato yields up to the second highest application (Thomas and Cotton, 81). However, according to Dunn (12), an increase in the P-supply for a tomato spring crop was followed by a decrease in both number and weight of fruit produced.

Just before fruit set is a critical period of high demand for P. At this time if N is excessive in comparison to the P and carbohydrate supply most of the blossoms will drop or fail to develop and early fruiting will be greatly reduced. Just before fruit set a 1000 lbs./acre application of 20% superphosphate applied in a 2 inch deep furrow as close to the plants as possible will increase fruit set considerably even on some highly phosphatic soils (Emmert, 16).

As reported by several workers (3, 19, 35, 46, 49, 63, 68) the P content of the tomato plant was increased by P application. Phosphorous starvation decreased the percent P in all parts of the plant (MacGillivray, 56). In a nutrient culture experiment, Dunn (12) obtained increased P content in whole leaves, leafblades and petioles of one spring and two autumn crops of tomatoes following application of P. According to Raleigh and Chucka (72), increase in P in the base solution increased P contents of vines, fruits and roots of Marglobe tomato plants grown outdoors with subirrigation.

Lingle and Davis (50) studied the effect of soil temperature and P nutrition on the growth and mineral absorption by tomato seedlings. Greater quantities of P were absorbed at the higher substrate levels in spite of the low temperature. At the higher temperatures a low P nutrient level materially limited growth. Increasing temperature and P level (0-488 lbs./acre) increased the P concentration in the tomato plant (Locascio and Warren, 53).

McLean (61) growing several crop species in cultures of various N levels reported that the concentration of P was generally decreased with greater N content of the medium. According to Dunn (12) and Malcolm (58) an increase in the N supply was followed by a decrease in the P concentration of tomato leaves. As reported by Leone and Shive (46), the highest P concentrations were found, in general, at the lowest N level. Phosphorus absorption then, appeared to decrease with increased N until the optimum N range (50-100 ppm.) was reached.

Beyond this point P accumulation increased with further increase in N concentration. At the rate of 60 mg. of P per 2000 g. of soil the total P uptake by transplanted tomatoes increased in a linear manner from 5 to 12 mg. as the N rate in the band increased from 0-40 mg./2000 g. of soil (Wilcox and Langston, 84). Similarly, Lingle (49) including N with water soluble dry phosphate increased total P concentration in the tissue above that from P alone.

According to Lingle (49) tomato plants fertilized with highly water soluble monoammonium phosphate contained significantly greater concentrations of acetic acid soluble P than did the ammonium phosphate sulfate treated plants. The possibility certainly existed that the sulfate fraction in the ammonium phosphate-sulfate might have provided ion competition for the phosphate and hence tended to depress P-uptake. As reported by Lewis et al. (48) the anions chloride, sulfate and carbonate varied in their effects on the availability of soil and fertilizer P. Chloride ions resulted in the greatest and least P availability in the presence of Ca and Mg, respectively. While in the presence of Na, sulfate gave the least availability.

In an ion uptake study with tomatoes, chloride depressed radioactive phosphate absorption (Meyer et al., 62). When nitrate was the sole N source, increasing the Cl concentration in the nutrient solution resulted in a decrease in percent P while if both ammonium and nitrate were present P was increased in potato leaves (Harward et al., 30). Gausman and Awan (23) working on potatoes, indicated that the amount of P^{32} increased as increments of Cl from $CaCl_2$ were increased to 400 ppm. after which there was an apparent and progressive decrease in the amount of P^{32} absorbed. According to Burleson et al. (5) P uptake was increased with P fertilization and decreased by Zn fertilization under greenhouse conditions. When both Zn and P were applied, the uptake of both by red kidney beans was reduced.

Several workers have advocated the beneficial effects of P fertilization on the growth, yield and early maturity of tomatoes. The essentiality of P for tomato fruit production and its favorable effects on photosynthetic activity, root and top growth and fruit set have been reported. In the literature available, little has been mentioned about the interactions of S, Cl and Zn on P absorption by tomatoes, although information on the interactions of N on P nutrition was available.

Sulfur

Gilbert (24) made a detailed review on S-nutrition. According to him S produces certain formative effects in plants in addition to its function as a building material. As reported by Thomas (80), Thomas and Hill found that S-deficiency lowered the photosynthetic level of alfalfa, tomatoes and sugar beets but did not affect respiration appreciably. In water culture experiments in the greenhouse, increasing the concentration of chloride and sulfate salts reduced the water requirements and increased the weights of tomato roots relative to the weights of the entire plant (Eaton, 13). Hayward and Long (31) obtained progressive growth depressions of tomato plants when sufficient Na_2SO_4 was added to a base nutrient solution to give a range of osmotic concentrations (1.5-6 atm.). Raleigh and Chucka (72) reported that the green weight of Marglobe tomato plants was highest at the 50 ppm. level of S and progressively decreased to the highest level employed (800 ppm.).

According to Hayward and Long (31), no evident flower buds had developed up to the time of harvest when a sufficient amount of Na_2SO_4 was added to a base solution to give an osmotic concentration of 4.5 atmospheres. Eaton (13) growing the Stone tomato variety at two concentrations of chloride and sulfate salts (50 and 150 me./l), obtained 28% and 73% reductions in the relative dry weights of fruits at the low and high sulfate levels, respectively. As reported by Raleigh and Chucka (72), the number of fruits increased up to the 200 ppm. S level then started decreasing. The weight of fruit of the Marglobe tomatoes decreased as the level of S increased from 50 to 800 parts per million. Lyon (54) found significant reductions in the mean weight of the Johannisfeuer tomato variety when Na_2SO_4 was added at 80 and 120 me./l. levels. At the higher salt level the fresh weight of fruit was reduced by 40 percent.

According to Kretschmer et al. (43) variation in sulfate content of the substrate had little effect on plant content of sulfate. Increasing the sulfate level from 2-50 me./l. for tomatoes grown in sand culture resulted in an increase of only one me. sulfate in 100 g.

oven-dried tissue. Hayward and Long (31) reported an increase in the accumulation of Na ion as the concentration of Na_2SO_4 increased in the culture solution, but there was less correlation between the accumulation of the sulfate ion and the concentration of sulfate in the solution. According to Seatz et al. (76) application of S (at 4.22 to 25.32 equivalents/2 million lbs. of soil) increased S in corn and tomato plants. They fertilized tomato plants at four different rates of chloride or sulfate and two different rates of both lime and P with no variation in N and K applications. In the chloride series S uptake was decreased with increasing P application.

As reported by Smith (77), the S concentration of tomato leaflets was increased when the concentration of Zn was increased in rigidly controlled nutrient solutions. When nitrate was the sole N source or when both ammonium and nitrate were present, increasing chloride concentration in the nutrient solution decreased the percent S in potato leaves (Harward et al., 30).

Zinc

The value of Zn as a nutrient element and its toxic effects has been recognized for a considerable length of time, although the extensive use of Zn salts for nutrient purposes on crops in the field dates from about 1931 (Camp, 6). Sommer and Lipman (78) proved conclusively that Zn is indispensable to the life and growth of a considerable number of widely different species of higher green plants.

The earlier work of Eltinge and Reed (15) and Reed (73) showed that marked cytological abnormalities occurred in tomatoes in the absence of Zn. In Rutgers tomato seedlings, low Zn (0.0005 ppm.) in the nutrient solution resulted in a reduction of meristimatic activity in root tips and cambium (Carlton, 8). According to Hewitt (33), Reed concluded that Zn deficiency in tomatoes resulted in the accumulation of inorganic phosphate, and a role in the activation of a phosphate-ester enzyme, possibly hexokinase, was suggested. As reported by Larsen (45), Tsui found that the content of four forms of auxin increased with age in normal tomato plants and decreased in the Zn deficient ones. Tsui concluded that Zn is required directly for the synthesis of tryptophan, a precursor for the growth hormone, indolacetic acid. Possingham (71) observed increased levels of amino acids in Zn deficient tomato plants.

There have been reports of increased growth and yields by tomato plants in the field in response to application of Zn. As reported by Pirson (69) Bergh found that of several different crop plants, the tomato was remarkably resistant to Zn excess. It responded even to high dosages with an increase in production. Deficiency of Zn in a controlled culture experiment, resulted in considerably less growth and fruitfulness than was measurable in control tomato plants (Lyon <u>et al.</u>, 55). Similarly, other workers (1, 51, 60) reported increased growth of tomato plants following Zn application.

Several workers reported tomato yields to increase with Zn fertilization. In a field experiment where $ZnSO_4$ was used at the rate of one pound per acre, Lingle et al. (51) reported a significant increase in tomato yields. Lingle et al. (52) applied Zn on tomatoes transplanted into Zn deficient soils at the rate of ten pounds of $ZnSO_4$ per 500 gallons of water per acre. Zinc sulfate effectively increased early and total yields giving 28 tons/acre total yield relative to 6.4 given by the no Zn treatment. Zinc with other micronutrients applied in the form of sulfates to tomato nutrient pots increased the dry matter content of the plants and the average weight of fruit (Abutalybov and Mardanov, 1). Govindan (27) reported that increased doses of Zn up to two ppm. in solution culture increased the number and weight of tomato fruits, whereas three ppm. of Zn was injureous and adversely affected the number and size of fruit. On the other hand, addition of 2.5 ppm. of Zn to cultures having a combination of major nutrient elements improved blossoming and quality of the tomato fruit (size and color), as reported by McHargue and Calfee (60).

Hill (34) applied Zn to tomato plants at concentrations ranging from 0.01 to 0.5 ppm. in the nutrient solution without observing either signs of injury or stimulation. Govindan (26) obtained symptoms of Zn toxicity at 2 and 3 ppm. concentrations when tomato plants were grown in sand culture to which $ZnSO_4$ at concentrations of 0, 0.5, 1, 2 and 3 ppm. was added. Crooke (11) found 15 ppm. concentration of Zn toxic for tomatoes. The yield of tops and roots as a percentage of that of the control plants was 32 and 43, respectively, and branching of the roots was reduced.

According to Lingle et al. (51) Zn from 5 lbs. metallic Zn/acre to 10 lbs./acre increased the Zn content of tomato leaf tissue significantly from 17.2 to 27.7 ppm. Lyon et al. (55) obtained significantly smaller quantities of Zn from leaflets and fruits from tomato plants grown with limited Zn supply, than from the control plants.

Little work have been reported on the interaction of the elements under study on uptake of Zn by tomato plants. As reported by Cannell et al. (7) Zn availability is usually reduced by heavy P applications the extent depending upon the soil, the fertilizer source and the quantity used. Phosphorus fertilization of the Olivenhain soil decreased the concentration of Zn in tomato tissue under greenhouse conditions. In contrast, Jamison (37) obtained little difference with regard to fixation of Zn in the presence and absence of superphosphate on several soils taken from different parts of peninsular Florida.

Chlorine

According to Hewitt (33) no satisfactory evidence for the essential nature of chlorine is forthcoming for higher plants, and Arnon and Whatley recently disposed of the possibility of this element being needed for photosynthesis in *vivo*. As reported by Gaffron and Fager (21), they have shown that sugar beets and chard grown under chloride free conditions photosynthesize normally. In contrast

Gauch (22) reported that Stout <u>et al.</u> have recently shown that the element, Cl, is essential for the growth and reproduction of tomato. In a water culture, Eaton (13) obtained maximum growth of tomatoes at 10 me. of chloride. In sand culture tomatoes made 35% more growth on the basis of green weight with 3 me. of chloride (106.5 ppm.) in the nutrient solution than with a trace of chloride.

The chlorine requirement is not small as compared to other micronutrients, for in the leaves of tomatoes suffering from Cl-deficiency chlorine concentration was in the order of 250 ppm. (Broyer <u>et al.</u>, 4). According to Johnson <u>et al.</u> (38) acute Cl-deficiency and decreased yields were produced with tomatoes in low Cl culture solutions. The lateral roots of Cl-deficient plants were many branched and stubby with club tips. Ozanne <u>et al.</u> (67) cultured tomatoes in purified inorganic solutions. Leaf and top yields were reduced by over 80% when insufficient Cl was supplied. Large decreases in tomato yields were found when leaf Cl concentration fell below 2 ug.-atoms/g. dry weight.

Robbins (74) experimenting with tomatoes, found that fruits produced on plants grown in nutrient solutions of 3.1 atm. osmotic pressure were much smaller than those grown at lower concentrations. Decreasing the Cl level resulted in significantly greater weight and number of marketable fruits (Kretschmer <u>et al.</u>, 43). In a base nutrient solution where NaCl was added to give osmotic concentrations of 1.5 to 6 atm., Hayward and Long (31) obtained a greater degree of succulence in the high chloride solutions. Flower bud formation was retarded and anthesis was delayed. Eaton (13) growing the Stone tomato variety at two concentrations of chloride salt (50 and 150 me./l.) obtained 19% and 96% reductions in the relative dry weights of fruits at the low and high Cl levels, respectively.

According to Kretschmer et al. (43) absorption of Cl by plants is a linear function of the Cl content of the substrate, independent of its type. Hayward and Long (31) reported an increased accumulation of Cl in the tops of tomato plants when the concentration of Cl was increased in the culture solution. As reported by Seatz et al. (76) plant Cl rose with the increase in Cl application, but was little affected by the sulfate level. In the chloride series the Cl concentration of the tomato plant was depressed by liming and in the sulfate series by increasing the P application.

MATERIALS AND METHODS

Experimental Design

A central composite, rotatable, incomplete factorial design as described by Hader *et al.* (28) was used to study the effects of the five variables, N, P, S, Zn and Cl, as related to yield and composition of field tomatoes. Each element was varied at five different levels (Table 1) coded as -2, -1, 0, +1 and +2 with the coded 0 representing a medium rate of fertilizer application for the crop. The coded -2 and +2 rates represented possible deficiency and possible excess levels, respectively.

Table 1. Rates of application of N, P, S, Zn and Cl for tomatoes.

Level	Coded rate	N, P and Cl		S		Zn	
		lb. per acre	kg. per ha.	lb. per acre	kg. per ha.	lb. per acre	kg. per ha.
1	-2	10.0	11.36	15.0	18.37	2.50	2.84
2	-1	27.2	30.90	40.8	46.36	6.80	7.72
3	0	73.8	83.85	110.7	125.80	18.45	20.96
4	+1	200.0	227.25	300.0	340.88	50.00	56.81
5	+2	544.0	618.12	816.0	927.17	136.00	154.53

The carriers of the elements under study were NH_4NO_3 for N, $Ca(H_2PO_4)_2$ for P, $CaSO_4 \cdot 2H_2O$ for S, $CaCl_2 \cdot 6H_2O$ for Cl and $ZnSO_4 \cdot 7H_2O$

or $Zn(NO_3)_2$ for Zn. The carriers were mixed in the proportions to correspond with the required rates (table 1).

A total of 27 treatment combinations was required (appendix table 5). To get an overall estimate of the experimental error, one of the treatments was repeated six times. The design was replicated twice.

Statistical methods of Cochran and Cox (9) were adopted for statistical analysis of the data obtained.

Field Procedures

This study was conducted at the American University Farm in the Beka'a, Lebanon. Just before planting the soil was prepared by opening furrows and the mixed fertilizers were distributed in the furrows by hand and covered with a layer of soil about 15 cms. thick by splitting the ridges. The resulting new ridges were thoroughly packed with a packer. On the 25th of May transplants of a local variety were set in the field in rows one meter apart with plants 1.25 meters apart within the row, thus allowing for six plants per treatment. Throughout a period of about one month the seedlings that did not survive were replaced at various dates in an attempt to get a perfect stand. For the first three weeks the transplants were pocket-irrigated when needed. Thereafter furrow-irrigation was practiced at weekly intervals until mid October. Weeds were adequately controlled.

Possible damage from cutworm attacks in the seedling stage was avoided by applying Heptachlor in a band on the soil surface around the stem of the seedlings at planting time. Gusathion was applied at the rate of one part per thousand on the 27th of July and the 8th of August against Leafhoppers, the possible vectors for transmitting an unidentified virus disease that showed up in the plots.

The vegetative performance of the tomato plants was observed in the field on July 11. Data on yield, number of fruits, and fruit cracking were collected over a period of three months starting August 29 and ending November 25th, two days before the first killing frost. Data were taken from the middle four plants of each treatment. Diseased and stray stunted plants were discarded and data related to total and marketable yields, number of fruits, size of fruit and percent of cracking were computed on the basis of the average per good plant.

Three leaf samples were collected: on July 18, August 22 and September 24. The youngest mature leaf was sampled. For uniform sampling, it was found convenient to sample the fourth leaf from the apex of any leader of the plant. The two replicates of each treatment were composited for chemical analysis.

Analytical Procedures

The composite sample was washed in tap water, rinsed three times with distilled water and left overnight to air-dry. Leaf blades of the individual leaflets of the compound leaves were trimmed and oven dried at 68°C. in a ventilated oven for 48 hours. The samples were ground in a micro Wiley mill to pass a 40-mesh screen and were stored in covered glass jars. A two percent acetic acid solution was used to obtain extracts of the leaf tissue. Perchloric-nitric digests of the August 22 sample were carried out as outlined by Jackson (36).

Water-soluble-nitrate in the presence of excess chloride was determined by the method outlined by Johnson and Ulrich (39). Total nitrogen on the second harvest was determined by the modified Kjeldahl procedure (Jackson, 36).

Phosphorous was determined on the three acetic acid extracts and on the nitric-perchloric digest by the chlorostannous-reduced molybdophosphoric blue color method in hydrochloric acid system as described by Jackson (36). Where the extracts were colored, a two ml. aliquot was digested with two drops of 30% H_2O_2 on a steam bath. The color was developed on the residue and the absorbancy readings were taken on a Klett-Summerson colorimeter using a red filter.

Sulfur was determined only on the acetic acid extracts and nitric-perchloric digests of the August 22 samples. The acetic acid extracts were decolorized by the addition of ten drops of 30% H_2O_2 to a two ml. aliquot of the extract and digesting on a steam bath to dryness. The residue was dissolved in 0.03 N HCl, and the S therein was determined turbidimetrically according to the method of Chesnin and Yien as outlined by Jackson (36).

The method of Platte and Marey (70) was used for zinc determination on the nitric-perchloric digests.

Chlorine was determined on the clear filtrates of the water extracts passed over activated carbon by titration with standard $AgNO_3$ solution using potassium chromate as the indicator (Johnson and Ulrich, 39).

Sodium and K on the acetic acid extracts and Ca and Mg on the nitric-perchloric digests were determined using a Beckman D.U. emission spectrophotometer with acetylene flame. Gas pressure and wave length settings and other adjustments were those of Jackson (36).

RESULTS AND DISCUSSION

Interrelationships of the nutrient elements N, P, S, Zn and Cl on total and marketable yield, number of fruits, size of fruits, the incidence of cracking and the composition of the leaves in field tomatoes were investigated in a field experiment in the central Beka'a, Lebanon. A central composite, rotatable, incomplete factorial design as described by Cochran and Cox (9) was used to study the five variables at five levels for each. This design allows calculation of the quadratic regression equations for the characteristics measured. The magnitude of the individual regression coefficients indicates the relative effect of the variables and allows determination of their statistical significance. A negative sign for the regression coefficient for an interaction term indicates that an increase in the level of one element decreased the requirement for the other whereas a positive regression coefficient means an increase in the requirement for one element as the level of the other is increased. In this manuscript, these relationships will be referred to as negative and positive effects, respectively.

Soil and Water Analysis

Data on soil analysis showed that the soil was calcareous with 15% $CaCO_3$ and a pH of 8.1 (table 2). The soil content of organic matter was 1.22% (low) and the total N content (0.061%) was low. The ammonium acetate extractable K, Ca and Na were 1.95, 40.00 and 0.58 me./100 g. of soil, respectively. The bicarbonate soluble P (Olsen method) was 18 ppm. which was considered a medium level. The quality of the irrigation water used was considered good from a salinity standpoint. However, a small amount of S and Cl were being added with the water (table 2).

Table 2. Chemical analysis of the surface soil for the experimental plots and of the irrigation water.

Soil Analysis			Water Analysis	
pH		8.1	Sodium	0.282 me./l.
Calcium carbonate, %		15	Calcium	0.705 "
Organic matter, % (Wet oxidation)		1.22	Magnesium	0.833 "
Total nitrogen, % (0.05 X O.M.)		0.061	Potassium	0.056 "
Phosphorus, ppm. (bicarbonate soluble)		18	Sulfur	0.125 "
Ammonium Acetate Soluble, me./100g.	K	1.95	Chlorine	0.318 "
	Ca	40.00		
	Na	0.58	Electrical conductivity	0.155 m.mho/cm.

Effect of Nitrogen

An adequate supply of available nitrogen is essential for high yields of good quality tomato fruit through its beneficial effect on foliage (Thompson and Kelly, 82). Under the conditions of this investigation, however, N application retarded vegetative growth and reduced fruit set and the least growth was observed at the highest N-rate (appendix table 5). This could partly explain the adverse effect of N application on tomato yields (p=0.95) (table 3), since good growth of foliage is necessary for food manufacture which goes into fruit production. The recorded marketable yields ranged from 50.29 to 93.58 tons per hectare and were only slightly less than the corresponding total yields (appendix table 5). The correlation coefficient for actual marketable yields and yields calculated from the regression equation was 0.90 indicating a close fit of the quadratic equation with the observed results. That N application did not always result in increased tomato yields has been pointed out. In the field, Neubert (65) obtained decreased yields at N applications higher than 160 kg. of N per hectare.

The N-P (p=0.65) and N-S (p=0.50) interactions tended to produce negative effects on yield (table 3), suggesting a greater response to N application at the lower levels of applied P and S. Examination of the positive (p=0.67) N-Cl interaction (figure 1) indicated that an increase in the rate of either N or Cl increased the requirement for the other. Increasing N application at the

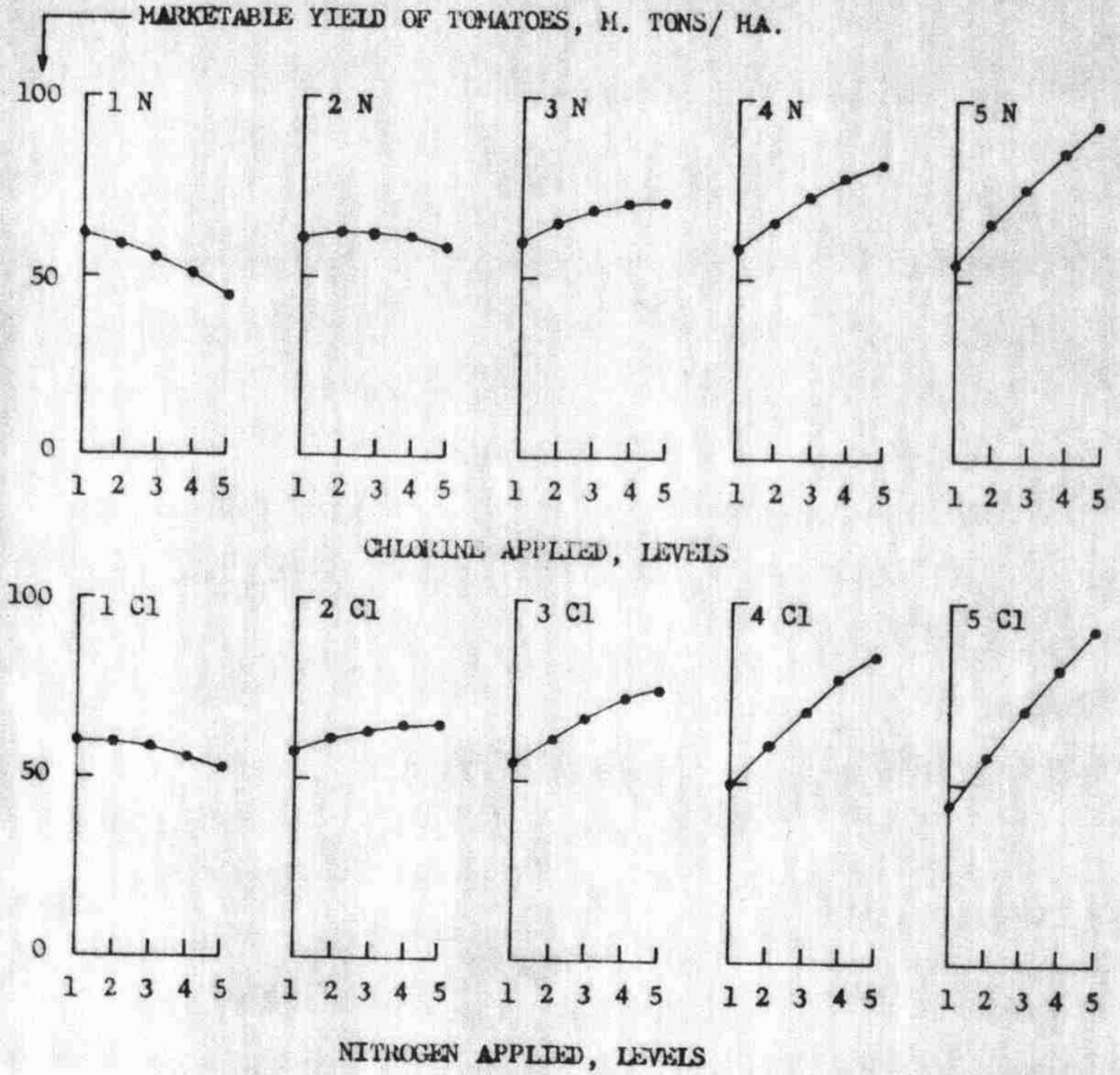

Fig. 1. Marketable yield of tomatoes as affected by levels of applied Cl at constant levels of applied N (above) and by levels of applied N at constant levels of applied Cl (below). Levels of P, S and Zn were held constant at the middle level (3) of five levels of application.

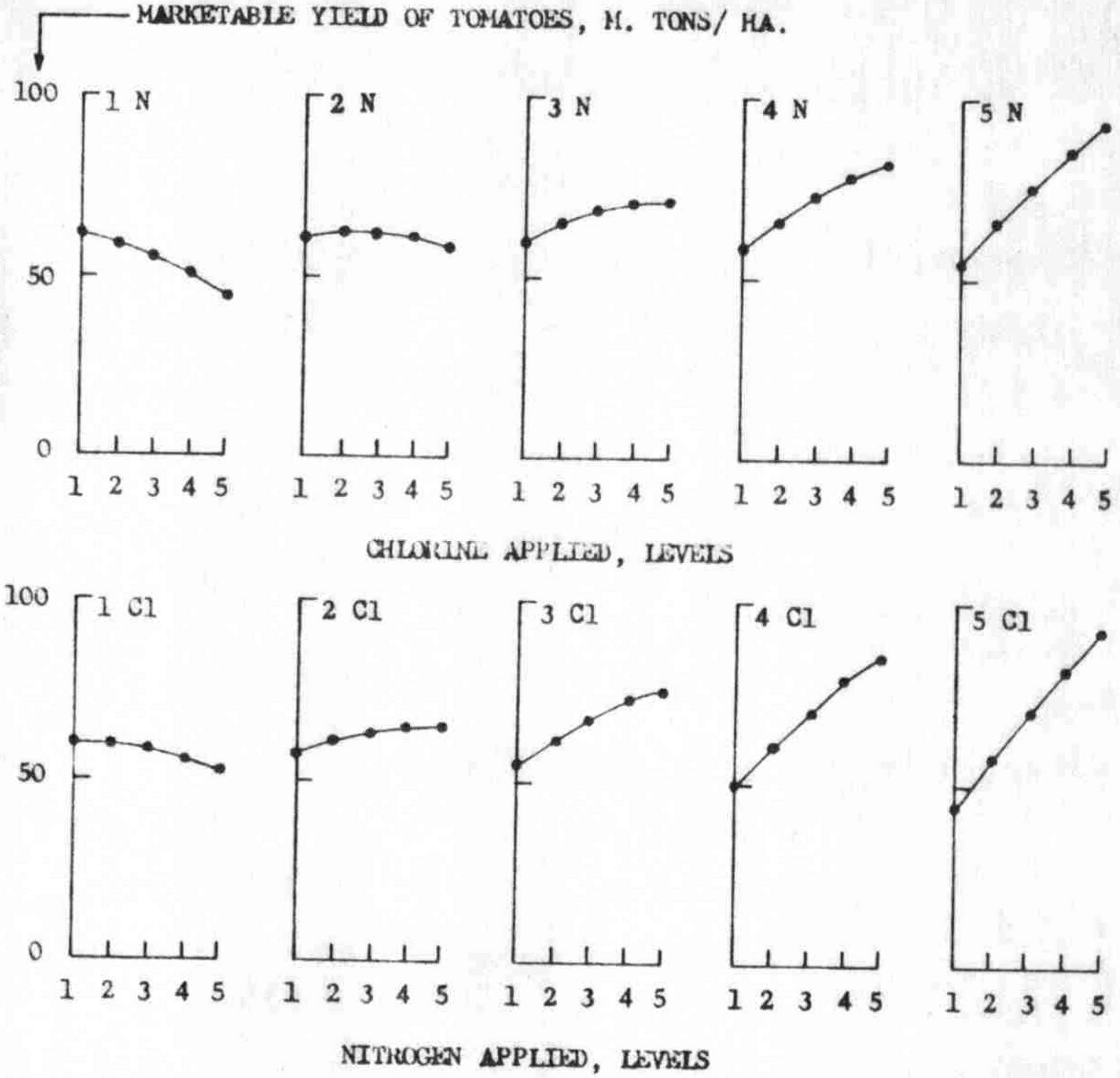

Fig. 1. Marketable yield of tomatoes as affected by levels of applied Cl at constant levels of applied N (above) and by levels of applied N at constant levels of applied Cl (below). Levels of P, S and Zn were held constant at the middle level (3) of five levels of application.

lowest level of applied Cl was associated with a slight decrease in yield. As the level of Cl was raised, application of N tended to cause an increase in yield. On the other hand, varying Cl at constant levels of N decreased yield at the lowest level of N application. The decrease was slight at the second level of N, whereafter a progressive increase was observed. The highest yield was obtained at the fifth level combination of both elements.

The number of fruits was adversely affected by N fertilization ($p=0.96$) (table 3). This was in general agreement with the findings of Raleigh and Chucka (72) who obtained the highest number of fruits at 400 ppm. of N and the least at the 2400 ppm. level. The reduced number of fruits herein, is most probably due to reduced fruit set at higher levels of N application. In support of this view, Lambeth (44) reported delayed anthesis at high N treatments. However, this is not surprising as the application of N in this experiment produced smaller leaf area (appendix table 5). As reported by Leopold and Guernsey (47), Leopold and Scott considered the amount of leaf area on the plant an essential factor in fruit set and by supplying more carbohydrates a larger leaf area might be expected to help overcome the effects of an excessive N supply. Regardless of the nutrient and moisture supply the fruit development eventually checks or stops vegetative growth (Murneek, 64). Hence, the food supply is expected to be more ample for fruit production at low levels of N which produced the greatest vegetative growth early in the season.

Table 3. Regression coefficients (b) and the probability of a true effect (p) for total and marketable yields of tomatoes, size of fruits, number of fruits and proportion of cracked fruits.

Equation variables	Yield, m.tons/ha. total		Yield, m.tons/ha. marketable		Size of fruits, g.		Number of fruits/plant		Cracked fruits, %	
	b	p	b	p	b	p	b	p	b	p
Mean	+68.47	---	+66.40	---	+175.51	---	+48.53	---	+42.26	---
N	-5.40	.95	-5.20	.95	+4.15	.97	- 4.46	.96	+3.12	.94
P	+7.03	.98	+6.67	.98	-3.14	.92	+5.96	.99	-3.49	.96
S	+1.44	.48	+1.30	.44	-3.57	.95	+1.88	.70	-1.72	.76
Zn	-1.81	.58	-2.23	.66	-3.45	.94	-0.88	.38	+0.34	.18
Cl	+2.80	.76	+2.82	.76	+2.40	.84	+0.96	.42	+1.09	.58
NN	-0.64	.23	-0.68	.25	+0.13	.07	-0.16	.08	+2.31	.90
PP	-2.79	.80	-2.91	.81	-3.17	.94	-0.78	.38	-1.44	.73
SS	+3.22	.85	+2.94	.82	-0.19	.10	+2.59	.86	-1.89	.84
ZnZn	+4.18	.92	+3.93	.91	-2.60	.90	+4.09	.96	-1.31	.69
ClCl	-0.79	.29	-0.75	.28	+0.20	.10	-0.16	.08	-1.43	.73
NP	-2.77	.67	-2.62	.65	-6.51	.99	-0.19	.07	-4.40	.96
NS	-2.16	.56	-1.81	.50	-3.69	.91	-0.94	.34	-0.53	.24
NZn	-0.25	.07	-0.27	.08	-2.16	.72	-0.31	.11	+1.83	.70
NCl	+3.37	.75	+2.77	.67	-5.33	.97	+4.44	.93	-2.44	.82
PS	-5.09	.90	-5.22	.90	-1.13	.45	-3.19	.83	+3.12	.90
PZn	-0.90	.24	-0.93	.25	-2.29	.75	+0.44	.16	-0.13	.06
PCl	+1.34	.36	+1.65	.45	-2.52	.79	+2.44	.73	+1.58	.64
SZn	+2.45	.62	+2.29	.59	-2.38	.76	+3.19	.83	+1.97	.74
SCl	-0.54	.14	-0.07	.02	+2.67	.81	-1.56	.54	+0.64	.27
ZnCl	+1.00	.27	+0.97	.26	+1.71	.63	+0.31	.11	+1.42	.60

Fruit number was highly reduced by N application (p=0.96) (table 3). Among the quadratic terms the N-Cl interaction was high (p=0.93) and positive (figure 2). Application of N decreased the number of fruits at low levels of applied Cl. As the level of Cl was raised the adverse effect of N application was reduced progressively and at the highest level of Cl, N application tended to increase fruit number. Similarly Cl-application tended to reduce fruit number at the lowest levels of N. As the level of N was increased Cl caused a greater increase in number of fruits. The highest number was observed at the lowest level combination of both (figure 2) nutrients. Thus it seems reasonable to attribute the observed adverse effects of N on tomato yields to the reduced fruit set associated with N fertilization.

The data for fruit size (appendix table 5) indicated a size range of 143.5 to 193.8 g. per fruit with a high correlation coefficient (r=0.92) for the observed and calculated size values. The positive response to N application was high (p=0.97). Raleigh and Chucka (72) obtained similar results up to 300 ppm. of N. Excessive N application (2400 ppm.) produced the lowest weight of fruit. Examination of the negative interactions related to fruit size (table 3) revealed greater response to N at low levels of P, S, Zn and Cl. The effect of N and P on fruit size was greatly affected by the negative N-P interaction (p=0.99) (figure 3). At low levels of P, application of N increased fruit size. A further increase in the P supply tended to mask the beneficial effect of N gradually and at the highest levels

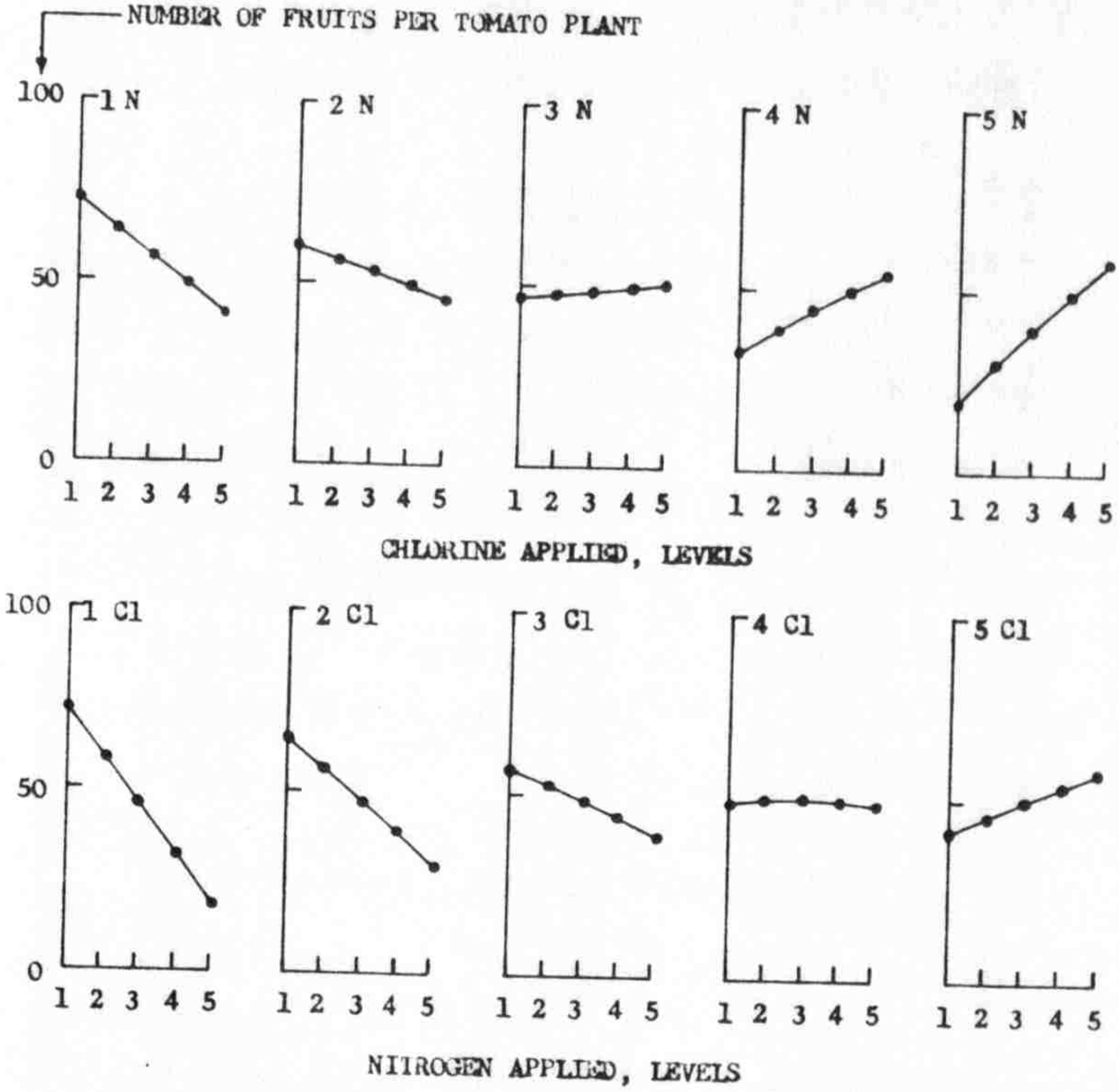

Fig. 2. Number of fruits per good tomato plant as affected by levels of applied Cl at constant levels of applied N (above) and by levels of applied N at constant levels of applied Cl (below). Levels of P, S and Zn were held constant at the middle level (3) of five levels of application.

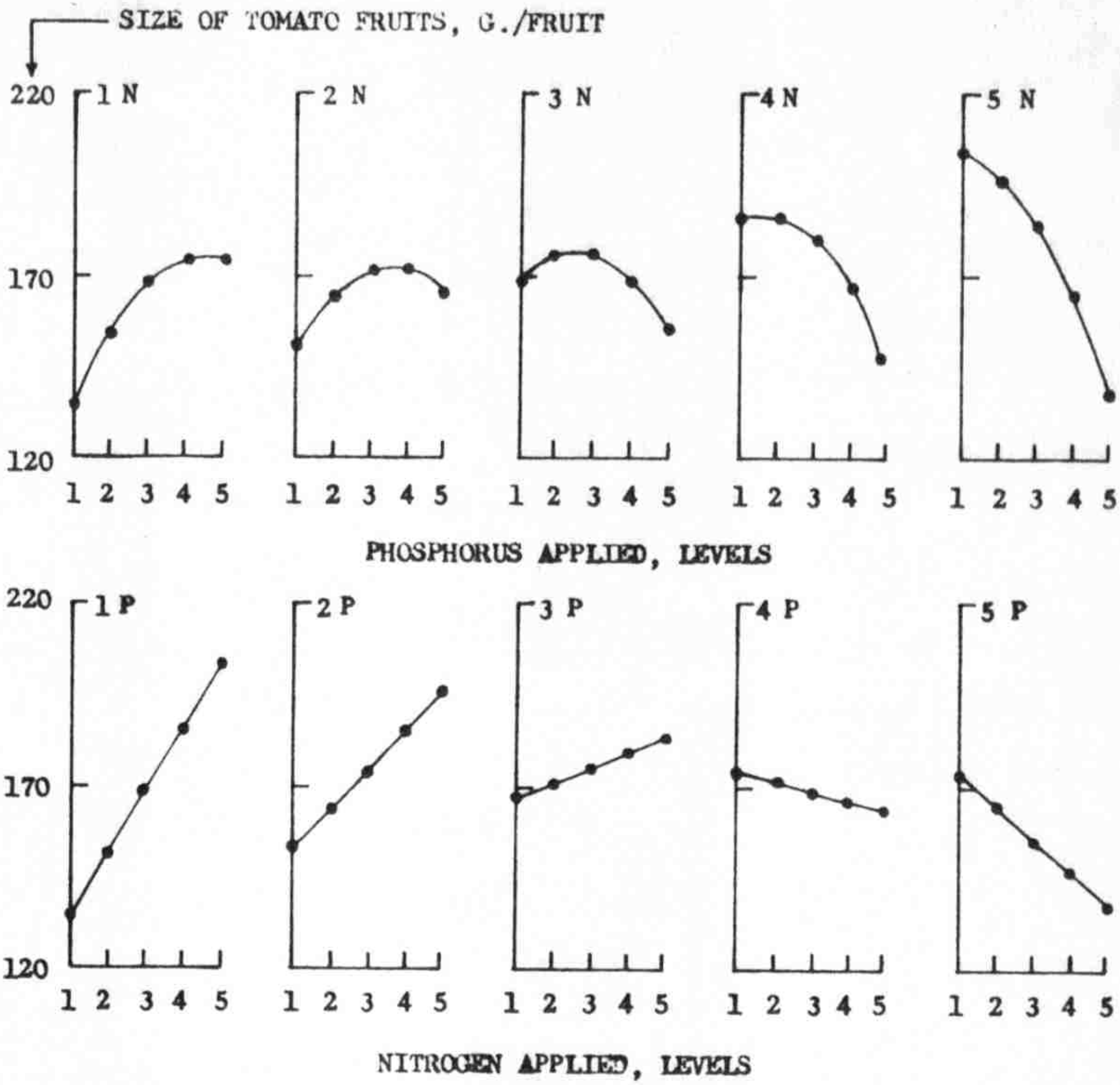

Fig. 3. Size of tomato fruits as affected by levels of applied P at constant levels of applied N (above) and by levels of applied N at constant levels of applied P (below). Levels of S, Zn and Cl were held constant at the middle level (3) of five levels of application.

of P application of N affected fruit size adversely. At low levels of N, P tended to increase fruit size while at the highest N levels, P application was associated with a progressive decrease in fruit size. The highest size of fruit was obtained at the highest and lowest rate combination of N and P, respectively.

Similarly, the N-Cl interaction produced a highly negative effect (p=0.97) (table 3). At constant levels of Cl (figure 4), addition of N was associated with greater fruit size at the lowest levels of applied Cl. As the level of Cl was raised the effect of N was decreased and addition of N tended to decrease size of fruit at the highest Cl levels. Varying Cl at fixed levels of N followed a similar pattern.

The incidence of fruit cracking was increased by N application (p=0.94) (table 3). This phenomenon was probably related to the smaller number of fruits and greater fruit size associated with N-fertilization. Similarly Frazier (18) cited the reduction in size of tomato fruit caused by further leaf removal from tomatoes already trained to one stem as a partial explanation for the observed reduction in the occurrence of cracking. In contrast, he did not get appreciable effects on cracking by adding large amounts of N, P and K to the soil. Results of several years experiments by Crandall and Odland (10) showed high application of N to produce larger seed cavities of the tomato fruit and consequently thinner outer walls resulting in a less firm fruit. This probably had contributed to fruit susceptibility to cracking.

Amongst the interactions N-Zn (p=0.70) (table 3) tended to

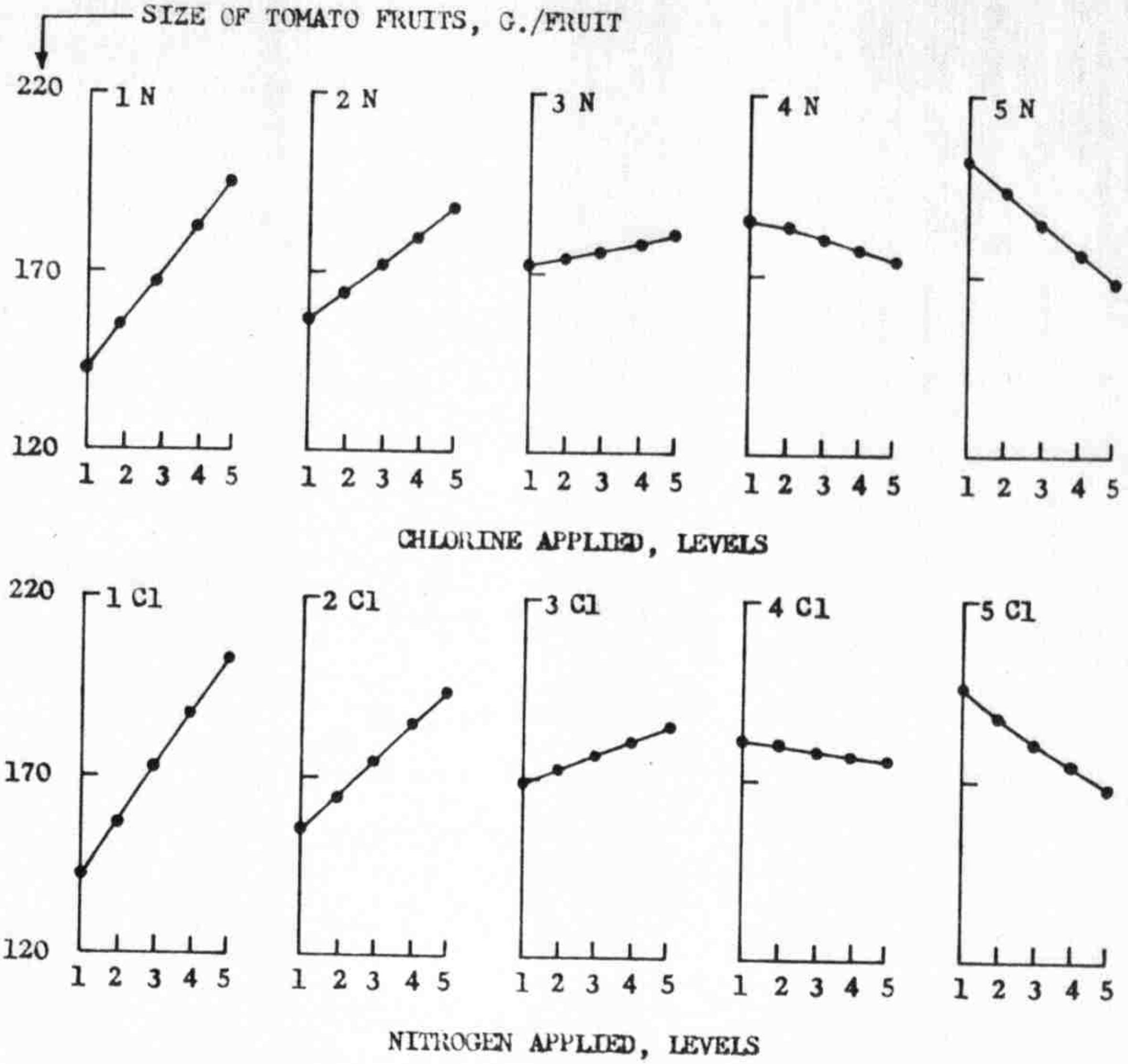

Fig. 4. Size of tomato fruits as affected by levels of applied Cl at constant levels of applied N (above) and by levels of applied N at constant levels of applied Cl (below). Levels of P, S and Zn were held constant at the middle level (3) of five levels of application.

exert a positive effect indicating an increased incidence of cracking by addition of either element as the level of the other was increased. The N-P ($p=0.96$) and N-Cl ($p=0.82$) interrelationships produced negative effects. Examination of the N-P interaction (figure 5) indicated a large increase in percentage cracking with addition of N at the lowest levels of applied P. At higher levels of P, N application tended to have less effect on cracking with a slight reduction in cracking at the highest P level. At constant levels of N, P increased cracking at the lowest level of applied N. As the level of N was raised application of P resulted in greater reductions in fruit cracking. The highest level of cracking occurred at the highest and lowest level combination of N and P, respectively.

Data on total N concentration of tomato leaves (appendix table 6) showed a range of 2.57 to 4.44 percent. In general agreement with the findings of several workers (13, 58), N application increased the N concentration of tomatoes ($p=0.87$) (table 4). The negative N-Zn interaction ($p=0.77$) showed a tendency for applied N to increase the N concentration of tomato leaves at the lower levels of Zn.

On the average N fertilization increased the concentration of water soluble NO_3-N in tomato leaves ($p=0.94$) (table 4). The N-S ($p=0.41$) and N-Cl ($p=0.50$) interactions were of small positive magnitude. Studying the negative N-Zn interaction ($p=0.97$) (figure 6) indicated decreased marketable yields with increasing N application at all levels of applied Zn. At low levels of Zn, N increased the

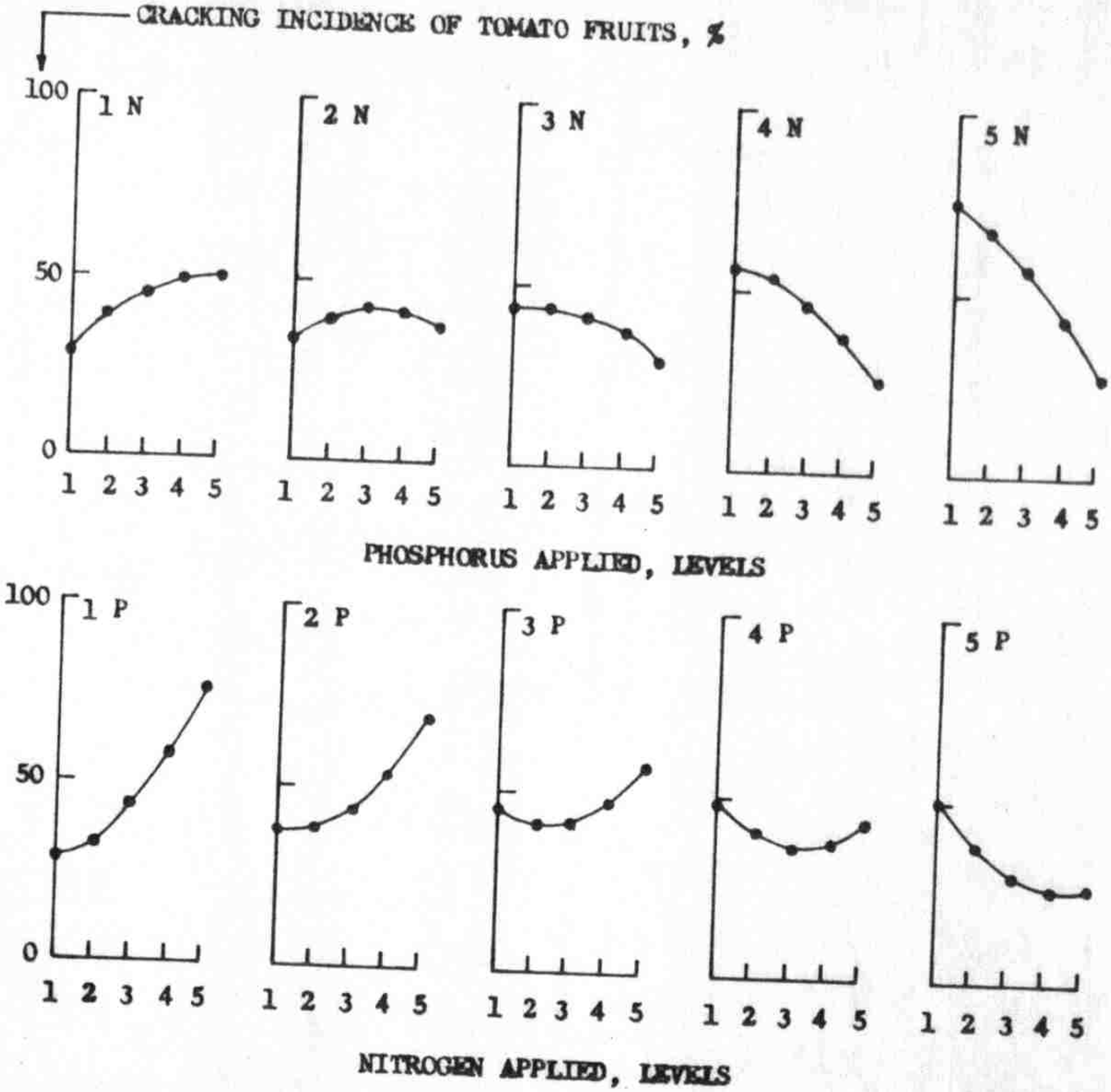

Fig. 5. Cracking of tomato fruits as affected by levels of applied P at constant levels of applied N (above) and by levels of applied N at constant levels of applied P (below). Levels of S, Zn and Cl were held constant at the middle level (3) of five levels of application.

Table 4. Regression coefficients (b) and the probability of a true effect (p) for N, P, S, Zn and Cl concentrations of the youngest mature tomato leaves as affected by various combinations of levels of these elements.

Equation	Nitrogen				Phosphorus				Sulfur				Zinc		Chlorine	
Variables	Total, % 2nd sample		NO_3-N, ppm. (average)		Total, % 2nd sample		HAc Soluble, % (average)		Total, % 2nd sample		HAc Soluble, % 2nd sample		ppm. 2nd sample		% average	
	b	p	b	p	b	p	b	p	b	p	b	p	b	p	b	p
Mean	+2.998	---	+373.8	---	+.2368	---	+.2033	---	+.9376	---	+.5940	---	+51.43	---	+1.429	---
N	+0.175	.87	+41.9	.94	+.0039	.40	-.0019	.38	-.1207	.99	-.1559	.99	-3.32	.99	-.077	.96
P	+0.027	.18	+14.8	.57	+.0005	.06	+.0060	.85	+.0037	.09	+.0012	.04	-3.61	.99	-.026	.61
S	-0.151	.81	+ 4.5	.18	-.0108	.82	-.0024	.48	+.0819	.97	+.0995	.99	+1.60	.99	+.020	.51
Zn	-0.033	.23	-59.0	.98	-.0018	.18	+.0008	.16	+.0232	.57	+.0203	.69	+0.85	.94	+.021	.53
Cl	-0.039	.28	-36.5	.91	+.0014	.14	+.0052	.80	+.0040	.01	-.0064	.25	-3.17	.99	+.094	.98
NN	+0.154	.85	+46.1	.97	+.0089	.78	-.0032	.64	-.0389	.82	+.0010	.04	-2.99	.99	-.045	.87
PP	-0.009	.07	+37.6	.94	+.0017	.18	-.0025	.54	-.0488	.90	+.0107	.32	+1.50	.99	+.008	.22
SS	+0.133	.80	+48.1	.97	-.0012	.13	-.0035	.67	+.0061	.17	+.0388	.94	-0.39	.71	-.010	.28
Zn Zn	+0.055	.43	+15.7	.63	-.0056	.59	-.0030	.61	+.0237	.62	+.0788	.99	+1.19	.99	+.012	.34
Cl Cl	+0.108	.72	+13.0	.55	+.0044	.49	+.0005	.11	+.0058	.16	+.0063	.27	-2.11	.99	+.059	.94
NP	+0.026	.15	-11.2	.36	-.0028	.24	+.0014	.22	+.0158	.32	+.0474	.92	-0.09	.14	+.018	.37
NS	+0.064	.40	+12.6	.41	+.0042	.34	+.0033	.53	-.0079	.16	+.0027	.08	+0.26	.41	-.044	.74
NZn	-0.166	.77	-62.8	.97	-.0107	.74	-.0035	.55	-.0030	.06	+.0404	.88	-0.32	.50	-.064	.88
NCl	-0.011	.04	+15.2	.50	-.0110	.74	-.0081	.88	-.0090	.18	-.0253	.70	+0.23	.36	-.050	.80
PS	-0.164	.77	+ 7.2	.24	-.0094	.68	-.0046	.66	-.0138	.28	+.0022	.07	+0.98	.92	-.019	.39
PZn	+0.051	.30	-12.4	.40	+.0057	.46	+.0049	.69	+.0026	.06	-.0383	.86	-6.82	.99	-.044	.74
PCl	+0.124	.65	+ 4.6	.14	+.0159	.88	+.0010	.16	-.0126	.27	-.0751	.98	+3.83	.99	-.030	.59
SZn	-0.069	.40	- 5.7	.18	+.0001	.01	+.0030	.49	-.0352	.66	-.0566	.95	-4.07	.99	+.069	.90
SCl	-0.026	.15	+14.3	.46	-.0102	.72	+.0026	.42	+.0078	.16	+.0237	.67	+0.26	.41	-.028	.56
Zn Cl	+0.044	.26	-11.1	.36	+.0044	.36	+.0009	.14	-.0284	.57	-.0231	.66	+0.71	.83	+.002	.01

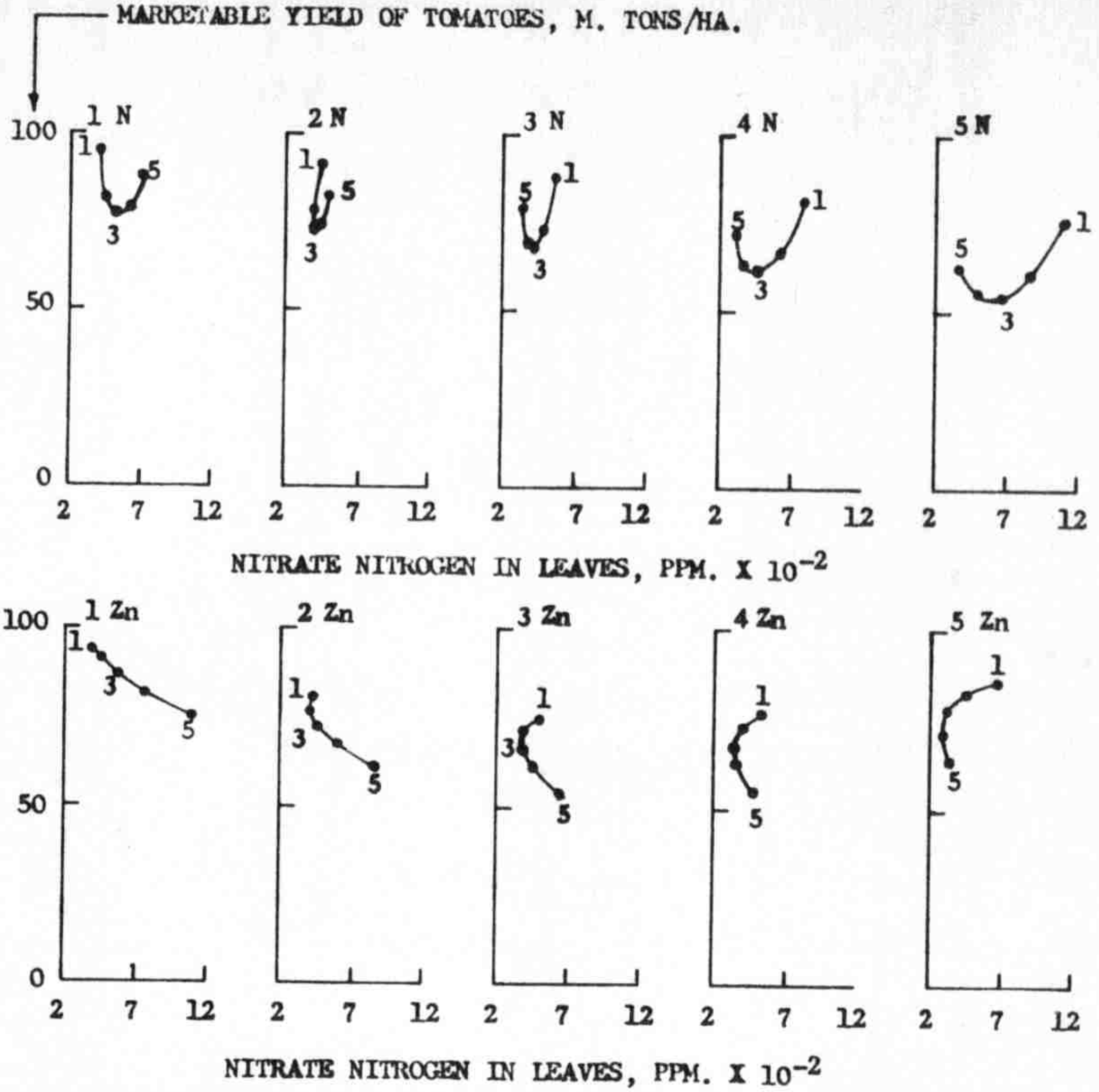

Fig. 6. Relationship between marketable yield of tomatoes, m. tons/ha., and nitrate nitrogen of the youngest mature leaves (dry basis) as affected by addition of different levels of N and Zn with P, S and Cl held at the middle level (3) of five levels of application. Numbers at points refer to the levels of Zn (above) and N (below) added.

leaf content of NO_3-N but as the level of applied Zn was raised the effect of N diminished gradually and even tended to decrease NO_3-N concentration at the highest levels of Zn. Zn application, however, showed no apparent critical level relative to the marketable yields of tomatoes. At the lowest level of applied N Zn tended to increase NO_3-N concentration. At high levels of N application a reduction in NO_3-N concentrations was caused by increasing Zn application. The highest marketable yields were obtained at the lowest level combination of both nutrients at a fairly low concentration of NO_3-N in the tomato leaves (figure 6).

The water soluble NO_3-N content of the youngest mature tomato leaves decreased as the season advanced (figure 7). The decrease was more pronounced on the August 22 leaf sample, possibly because of the more exhaustive nature of fruit development during the interim between July 18 and August 22 (figure 8).

Examination of the seasonal fruit production (figure 8) as affected by N application indicated a wave pattern of production. Early in the season the low N treatments proved superior and as the season advanced general fruit production decreased gradually for the first month of harvesting except for the highest N rate. Thereafter production increased till mid October where a sharp and continuous drop in fruit production was observed. Differences among treatments tended to diminish towards the end of the season. Murneek (64) conclusively proved the regulatory effect of fruit development on

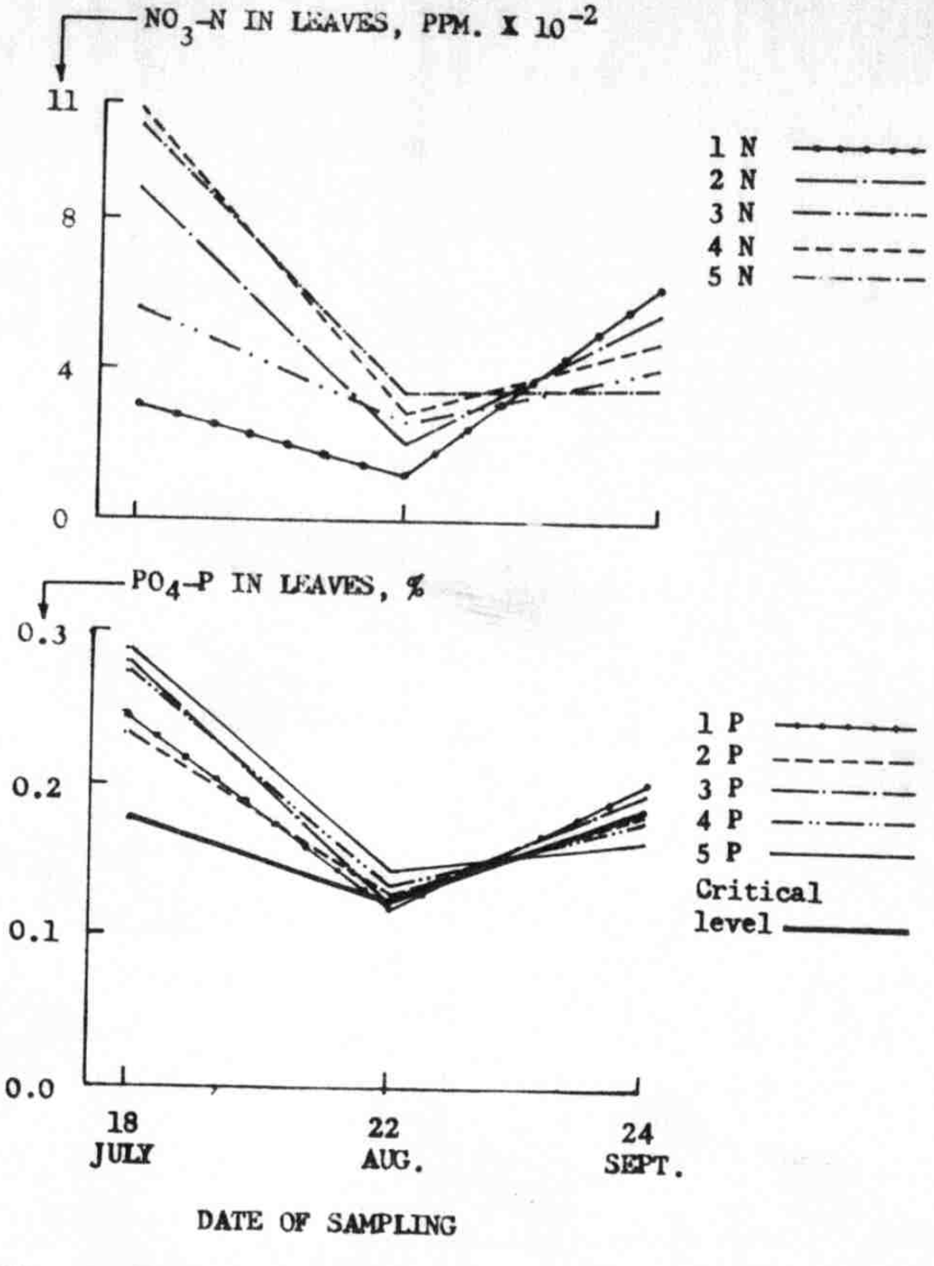

Fig. 7. Observed seasonal change in average nitrate nitrogen concentration (ppm., dry basis) (above) and average phosphate phosphorus concentration (per cent, dry basis) (below) of the youngest mature tomato leaves.

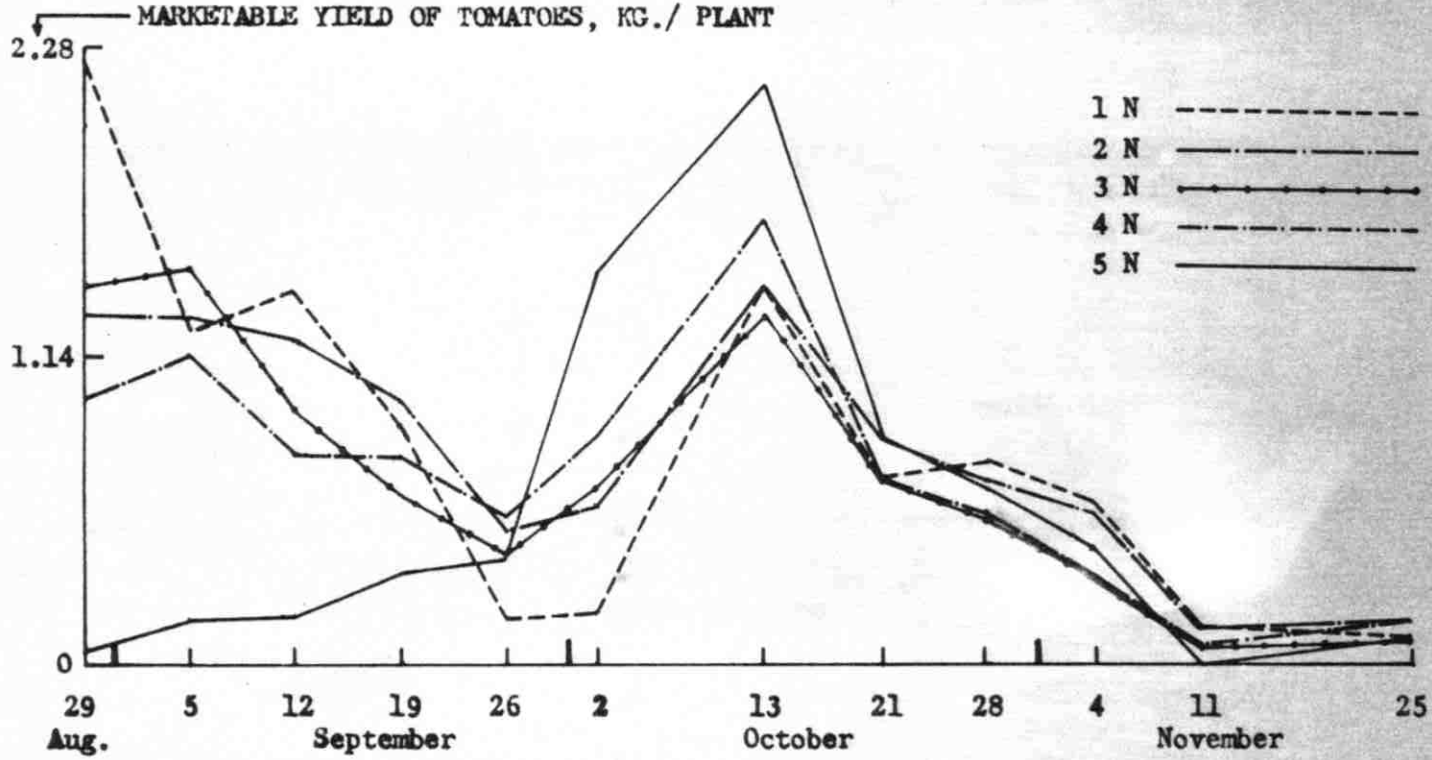

Fig. 8. Observed seasonal change in fruit production of marketable tomatoes as affected by five levels of N application. Marketable yields were calculated from actual data on the basis of the average per good plant.

vegetative growth of tomatoes. Removal of fruits was found to stimulate vegetative growth and further fruit setting. The application of N decreased the early yields due to decreased and delayed fruit set. As the season advanced this trend was reversed and N application increased yields during most of October. However at the September 24 leaf sampling date the NO_3-N in the leaves was least at the highest N application levels. Since this period was just prior to a period of high fruit yield (figure 8) it can be presumed that heavy fruit formation was going on and that assimilation of N was high during this period. Therefore it would appear that leaf analysis of tomato plants is considerably subject to the particular stage of fruit setting or bearing. A very similar trend was found with the concentrations of acetic acid soluble PO_4-P as related to P application rates. Thus determination of critical levels for N and P during fruit bearing would be subject to considerable variations.

The tendency of N to increase the total P concentration of tomato leaves was slight ($p=0.40$) (table 4). The negative N-Cl and N-Zn interactions ($p=0.74$) indicated a greater tendency of N to increase total P at low levels of applied Cl and Zn. In contrast, to the increase in total P, N application had a small tendency ($p=0.38$) to decrease the average leaf content of acetic acid soluble PO_4-P (table 4). Among the quadratic terms the negative N-Zn ($p=0.55$) and positive N-S ($p=0.53$) interactions were small. Examination of the negative N-Cl relationship ($p=0.88$) (figure 9) indicated a

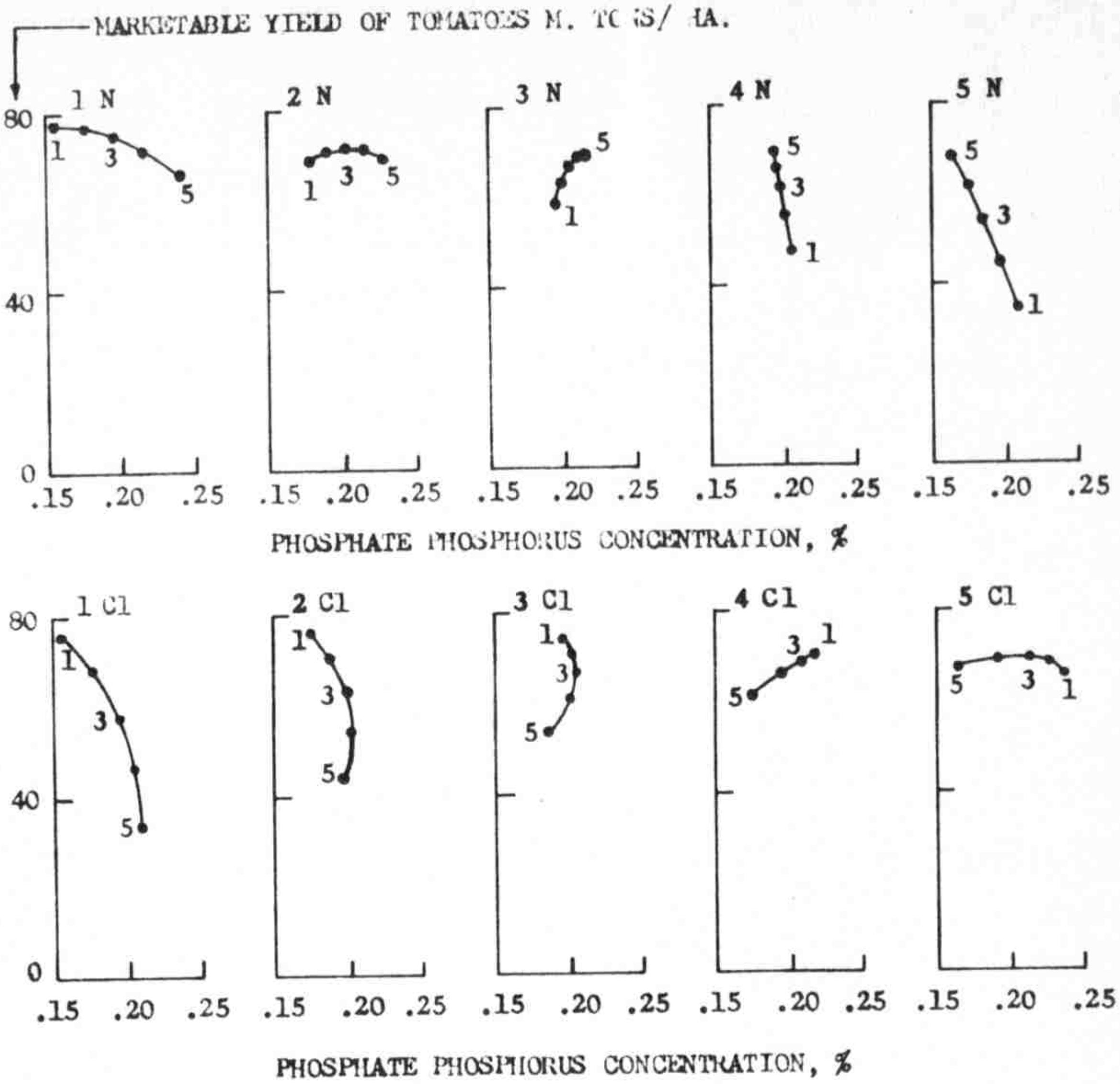

Fig. 9. Relationship between marketable yield of tomatoes, m. tons/ha., and phosphate phosphorus concentration of the youngest mature leaves (dry basis) as affected by addition of different levels of N and Cl with P, S and Zn held at the middle level (3) of five levels of application. Numbers at points refer to the levels of Cl (above) and N (below) added.

tendency for N application to increase the PO_4-P concentration at low levels of applied Cl. At the highest Cl levels the PO_4-P concentration was greatly reduced by N application. At low levels of N, addition of Cl tended to reduce marketable yield. At higher levels of N, Cl application progressively increased tomato yields. Chlorine increased the concentration of PO_4-P at low levels of N but as the N level was increased the effect of Cl became less and less pronounced and produced adverse effects at the highest N levels. The highest yield was obtained at the lowest combination of levels of N and Cl at a comparatively low concentration of acetic acid soluble PO_4-P in the tomato leaves.

Application of N significantly decreased the total and acetic acid soluble SO_4-S of tomato leaves ($p=0.99$) (table 4). The positive N-P ($p=0.92$) and N-Zn ($p=0.88$) interactions indicated that N application increased acetic acid soluble SO_4-S content at high levels of applied P and Zn. In contrast, N tended ($p=0.70$) to decrease SO_4-S at the high levels of associated Cl.

Addition of N significantly ($p=0.99$) reduced the concentration of Zn in the leaves of the tomato plant (table 4).

On the average N decreased the Cl concentration in tomato leaves ($p=0.96$) (table 4). The interactions N-Cl ($p=0.80$) and N-S ($p=0.74$) tended to exert negative effects. Careful examination of the negative N-Zn interaction (figure 10) showed N application to decrease the marketable yield at all fixed levels of Zn. In general

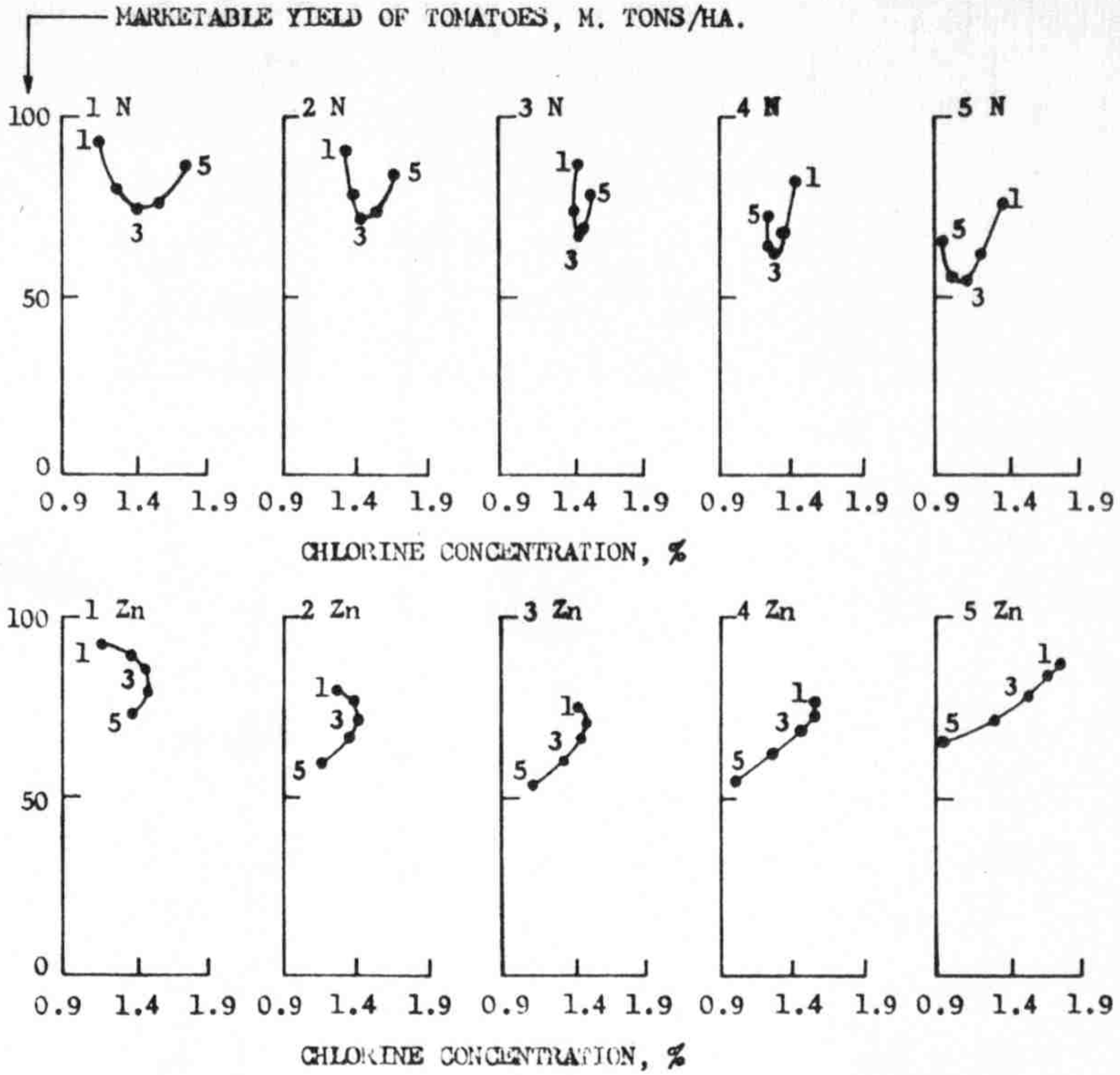

Fig. 10. Relationship between marketable yield of tomatoes, m. tons/ha., and water soluble chlorine concentration of the youngest mature tomato leaves (dry basis) as affected by addition of different levels of N and Zn with P, S and Cl held at the middle level (3) of five levels of application. Numbers at points refer to the levels of Zn (above) and N (below) added.

Cl tended to be increased at the lowest Zn level. At the higher levels of Zn, addition of N adversely affected Cl content of the leaves. Zinc application increased Cl concentration at low levels of applied N. As the level of N was raised the favorable response to Zn decreased gradually and became adverse at the highest levels of applied N.

With regards to cations, N tended to increase the leaf concentration of K ($p=0.77$) and decrease the Ca ($p=0.69$) concentration. Similar results were reported by Dunn (12). The effect of N on the Na and Mg concentrations was negligible (appendix table 9).

Consequently, under the conditions of this experiment, N application had the tendency of reducing vegetative growth early in the season thus reducing fruit set and marketable yields of field tomatoes. Low levels of applied P and S and high levels of associated Cl were conducive to increased yields following N application. Application of N was associated with increased incidence of fruit cracking which was apparently related to the greater fruit size and smaller fruit numbers brought about by N fertilization. Nitrogen, however, increased the concentration of N and greatly reduced the leaf concentrations of S, Zn and Cl.

Effect of Phosphorus

Application of P, as reported by other workers (7, 53) stimulated vegetative growth of tomato plants (appendix table 5). The positive N-P interaction (appendix table 9), contrary to the findings of Wilcox and Langston (84), revealed greater growth response to P at high levels of associated N.

Fertilization with P increased marketable yields of tomatoes (p=0.98) (table 3) which was in general agreement with the findings of Fuller, et al. (20). Among the quadratic terms the negative N-P interaction (p=0.65) indicated greater response to P at low levels of associated N. Response to P and S was considerably affected by the negative P-S interaction (p=0.90). Phosphorus application (figure 11) increased marketable yields of tomatoes at the lower levels of associated S. Raising the level of S tended to neutralize the observed beneficial effect of P and consequently P tended to decrease yield at the highest applied level of S. Similarly, varying S at fixed levels of P increased marketable yield at the lowest P levels and tended to cause greater reductions at the highest levels of P employed. The highest yield was obtained at the highest rate of P applied at the lowest fixed level of S. This would indicate that the S present in ordinary superphosphate fertilizers might be detrimental to the yields of certain crops such as tomatoes. Further investigation of this problem is necessary.

Phosphorus significantly (p=0.99) increased the number of fruits per plant (table 3), as reported by Kraybill (42). Among the quadratic terms the positive P-Cl relationship (p=0.73) indicated a greater response to P at higher levels of Cl. Consideration of the negative P-S interaction (p=0.83) for fruit number indicated

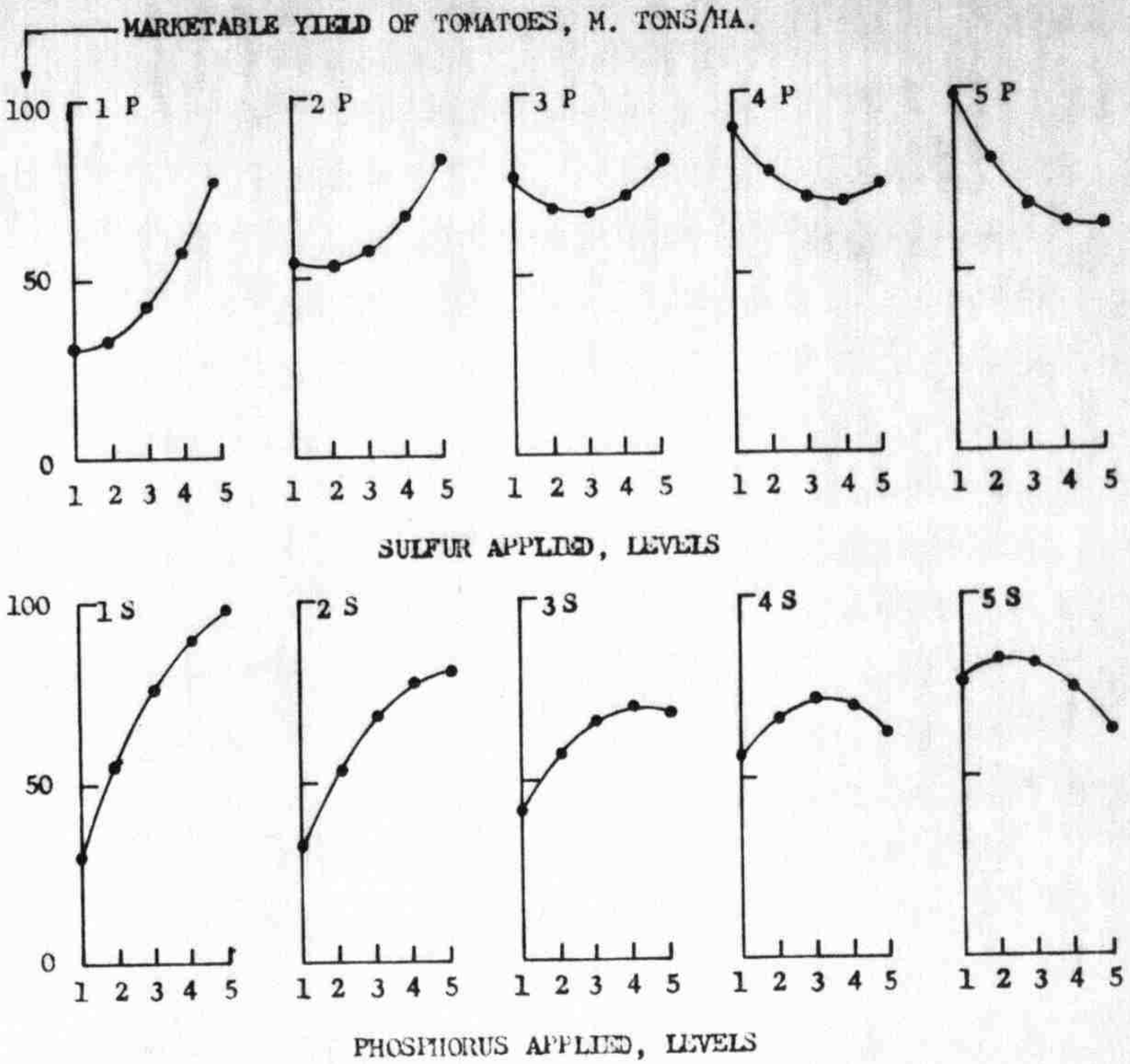

Fig. 11. Marketable yield of tomatoes as affected by levels of applied S at constant levels of applied P (above) and by levels of applied P at constant levels of S (below). Levels of N, Zn and Cl were held constant at the middle level (3) of five levels of application.

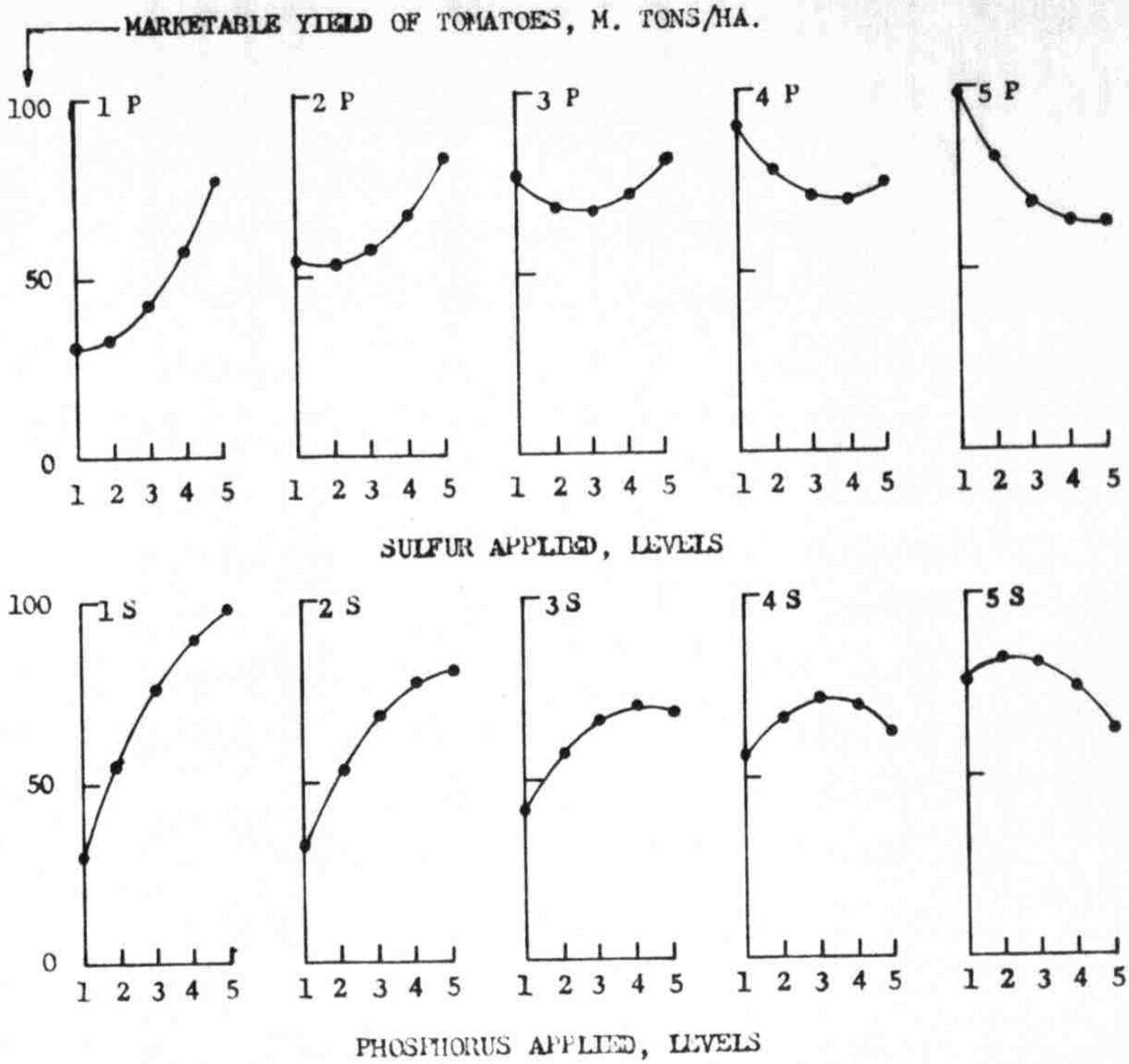

Fig. 11. Marketable yield of tomatoes as affected by levels of applied S at constant levels of applied P (above) and by levels of applied P at constant levels of S (below). Levels of N, Zn and Cl were held constant at the middle level (3) of five levels of application.

that the effect of P and S on number of fruits was about identical to the effect on marketable yields.

Consequently, P application increased yields of field tomatoes as it increased fruit set, regardless of the observed adverse effect on fruit size (p=0.92) (table 3). This decreasing effect on fruit size was, apparently, accentuated by the negative effects of the N-P (p=0.99), P-Cl (p=0.79), P-Zn (p=0.75) and P-S (p=0.45) interactions which indicated greater reductions in fruit size following P application at high levels of N, Cl, Zn and S.

Cracking incidence was effectively decreased by P application (p=0.96) (table 3). The probability exists that the reduced fruit size associated with greater fruit set following P application is closely related. Of the quadratic interactions P-Cl (p=0.64) tended to be positive, whereas the positive P-S (p=0.90) interaction indicated less incidence of cracking due to addition of P at low levels of applied S. In contrast the negative N-P interaction (p=0.96) indicated that P reduced cracking at the highest levels of associated N.

The tendency of P application to increase the total N content of tomato leaves was negligible (p=0.18) (table 4). The positive P-Cl (p=0.65) and negative P-S (p=0.77) interactions indicated a tendency of applied P to increase total N at high and low levels of Cl and S, respectively. On the other hand P application tended to increase the average leaf content of water soluble NO_3-N (p=0.57).

Data on P concentration of tomato leaves indicated a range of 0.180 to 0.340 and 0.127 to 0.227 percent for total P and average of acetic acid soluble PO_4-P, respectively (appendix table 6). Even though P increased the average seasonal concentration of acetic acid soluble PO_4-P in tomato leaves ($p=0.85$), the overall linear effect of P application on total concentration of P in the leaves at the second harvest was negligible (table 4). Many workers (3, 19, 35) reported increased P content of the tomato plant following application of P. Among the quadratic terms the P-Zn interactions tended to be of small positive magnitude (table 4). On the other hand Burleson et al. (5) obtained reduced uptake of Zn and P by red kidney beans when both were applied together. The negative P-S relationships indicated a tendency of P to increase the total P and PO_4-P concentrations at low levels of associated S. The possibility certainly exists that sulfate might have provided ion competition for phosphates and hence tended to depress P uptake (49). Studying the P-Cl interaction ($p=0.88$) (figure 12) for total P indicated an increase in marketable yield with P application at all levels of applied Cl. Phosphorus tended to decrease P content at low levels of Cl. As the level of Cl was raised the adverse effect became less pronounced and at the highest levels of Cl P application favored P uptake. Chlorine, however, had an almost identical effect on total P concentration. Effect of Cl on marketable yield was negligible at the lowest level of P and as the level of applied P was increased

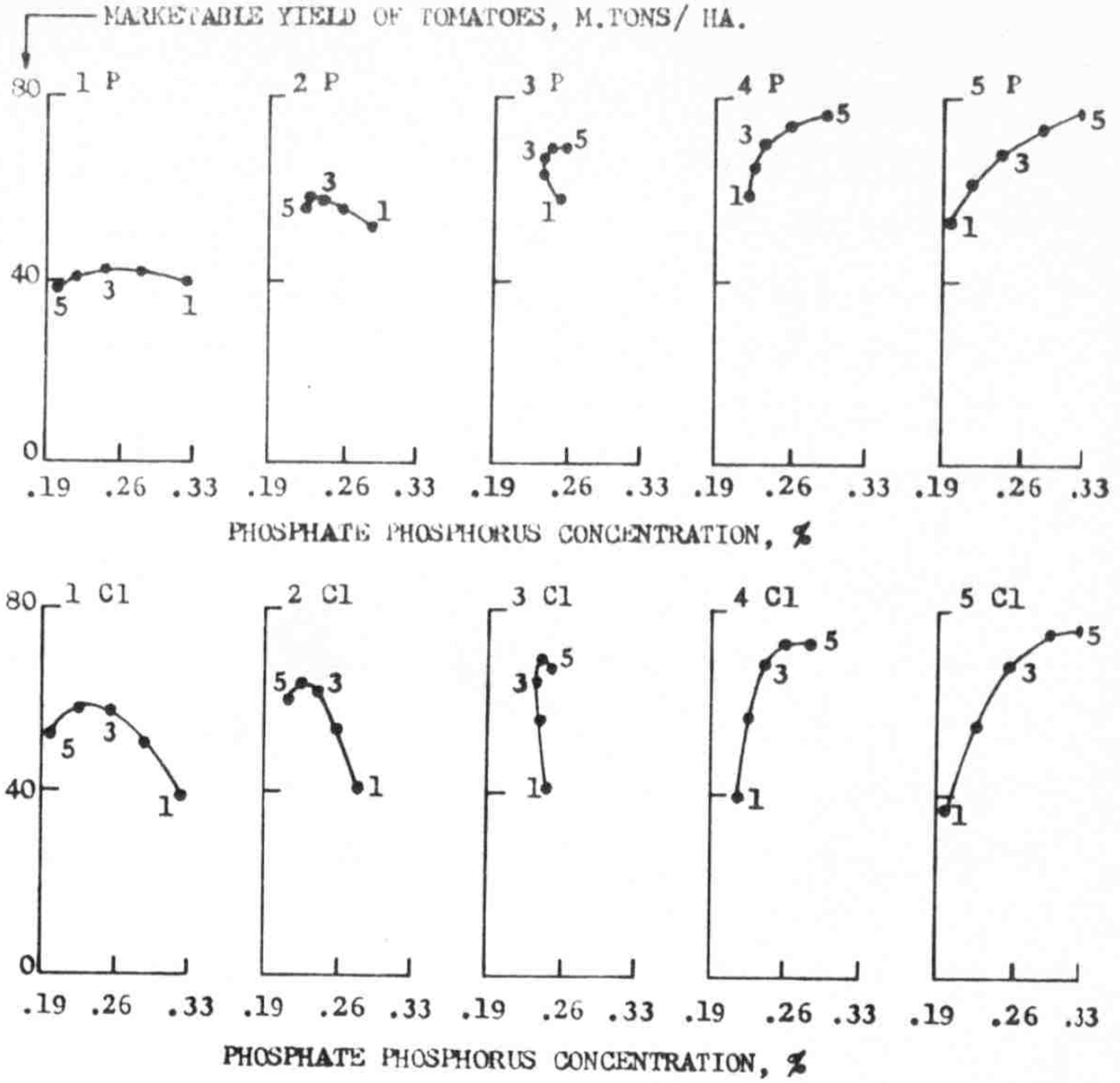

Fig. 12. Relationship between marketable yield of tomatoes, m. tons/ha., and total phosphate phosphorus concentration of the youngest mature tomato leaves (dry basis) as affected by addition of different levels of P and Cl with N, S and Zn held at the middle level (3) of five levels of application. Numbers at points refer to the levels of Cl (above) and P (below) added.

addition of Cl resulted in greater increases in yield.

The acetic acid soluble PO_4-P concentration of tomato leaves decreased with the season (figure 7) up to the time of the first heavy production of fruit. The lowest concentration was reported in the August 22 sample which is possibly related to the greater stress of fruit production previous to this sampling date. After the first wave of heavy fruit production the PO_4-P concentration was increased with time but the highest PO_4-P concentration occurred with the lowest P application rate and the lowest PO_4-P was found at the highest application rate of P. The yields following this period were particularly high possibly indicating that a high rate of assimilation of P was occurring thus resulting in less soluble PO_4-P in the leaves of the subsequently high yielding plants compared to low yielding plants. This illustrates the difficulty of trying to establish a critical level of P in the leaves since the successive waves of fruit production change the leaf content over the season.

The linear effect of P on total and acetic acid soluble SO_4-S was negligible (table 4). Examination of the quadratic terms related to acetic acid soluble SO_4-S indicated a greater SO_4 concentration when P was applied at low levels of Cl ($p=0.98$) and Zn ($p=0.86$) and at high levels of applied N ($p=0.92$).

Phosphorus application decreased the leaf content of Zn significantly ($p=0.99$) (table 4). Among the quadratic terms the positive P-Cl ($p=0.99$) and P-S ($p=0.92$) interactions indicated larger decreases in Zn concentrations following P application at low levels of associated Cl and S. The negative P-Zn interaction (p=0.99) (figure 13) indicated that phosphorus fertilization slightly increased Zn concentration at the lowest level of Zn but at high levels of applied Zn P addition resulted in reduction in the Zn concentration. Zinc, however, increased the Zn content of tomato leaves at the lowest levels of applied P but tended to have less effect progressively, as the level of P was raised. With regards to marketable yields no definite critical or toxic level of Zn was apparent.

Phosphorus tended to decrease the average Cl concentration of tomato leaves (p=0.61) (table 4). The negative P-Zn (p=0.74) and P-Cl (p=0.59) interactions indicated a more pronounced adverse effect of P application on Cl concentration at the high levels of Zn and Cl.

The addition of P tended to increase the Mg (p=0.78) and Ca (p=0.69) concentrations of the youngest mature tomato leaves. The effect of P on the Na concentration was of small positive magnitude (appendix table 9).

That P application greatly stimulated vegetative growth, fruit set and high yields of field tomatoes has been established. However low levels of N and S and high levels of Cl were needed for highest yield responses. Among the beneficial effects of P the observed reduction in cracking incidence was of prime importance because fruit which is void of cracks is more desirable. This was probably due to the decreasing effect of P on size of the tomato fruit.

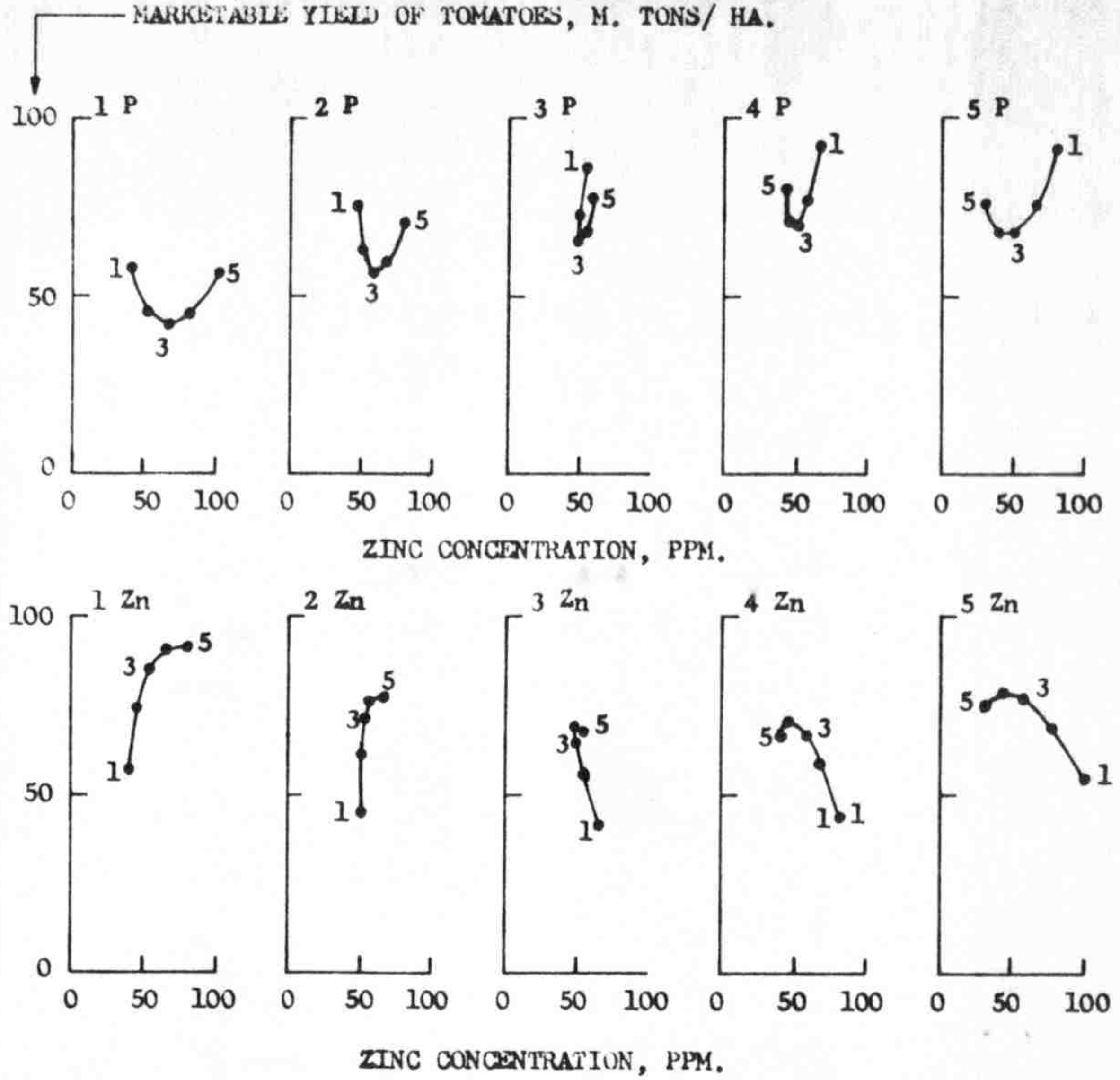

Fig. 13. Relationship between marketable yield of tomatoes, m. tons/ha., and zinc concentration of the youngest mature tomato leaves (dry basis) as affected by addition of different levels of P and Zn with N, S and Cl held at the middle level (3) of five levels of application. Numbers at points refer to the levels of Zn (above) and P (below) added.

With regards to leaf composition P increased the average seasonal concentration of acetic acid soluble PO_4-P and had a tendency to increase the Mg and Ca concentrations of the youngest mature tomato leaves. On the other hand, with increasing application of P the Zn concentration was decreased significantly whereas the effect on the concentration of the other nutrient elements was negligible.

Effect of Sulfur

Observations on vegetative growth of field tomatoes (appendix table 9) revealed a tendency of S to enhance early growth of foliage, probably because it affected the photosynthetic rate of the tomato plant (80). In water culture increasing the concentration of the sulfate salts increased the weights of tomato roots relative to the weights of the entire plant (Eaton, 13). Consequently, S application had a small overall tendency of increasing the marketable yields of tomatoes ($p=0.44$) (table 3). Among the quadratic terms the N-S ($p=0.50$) and S-Zn ($p=0.59$) interactions had a small tendency of producing negative and positive effects, respectively. The negative P-S relationship indicated a greater yield response to S application at the lower levels of applied P ($p=0.90$).

Sulfur application tended to increase the number of fruits per plant ($p=0.70$). Raleigh and Chucka (72) reported similar results up to 200 ppm. of applied S. At low levels of P and Zn, S tended to increase and decrease fruit number, respectively, as indicated by the negative P-S ($p=0.83$) and positive S-Zn ($p=0.83$) interactions (table 3). With regards to fruit size, as reported by other workers (13, 54, 72), the addition of S had a considerably adverse effect (p=0.95). The negative interactions of S with N, Zn and P indicated a tendency of S to cause more reduction in fruit size at the high levels of these elements (table 3). In contrast the positive S-Cl relationship (p=0.80) revealed an increasing effect of S application on fruit size at high levels of Cl. Hence it is highly feasible that the tendency of S to increase tomato yields was closely related to improved fruit set and a more complete foliage canopy since fruit size was adversely affected.

Among the beneficial effects of S application was a tendency to reduce the incidence of fruit cracking (p=0.76) (table 3). This is probably related, indirectly, to the associated reduction in fruit size as a smaller fruit is less apt to crack. The positive P-S (p=0.90) and S-Zn (p=0.74) relationships showed a tendency of less fruit cracking following S application at low levels of applied P and Zn.

Total N concentration of the youngest mature tomato leaves was decreased by S application (p=0.81) (table 4). The P-S interrelationship (p=0.77) was negative suggesting more reduction in N concentration when S was applied at high levels of P.

Sulfur application reduced the total P content of tomato leaves (p=0.82) (table 4). The negative S-Cl (p=0.72) and P-S (p=0.69) interactions indicated a tendency for S to be more effective in increasing the P concentration at low levels of applied Cl and P. On the average S application had a slight tendency to reduce the acetic acid soluble PO_4-P (p=0.48). Among the quadratic terms N-S (p=0.53) and S-Zn (p=0.49) tended to be positive in effect. This indicated an increase in concentration of PO_4-P with application of S at higher levels of N and Zn.

Data on the S concentration of tomato leaves indicated a range of 0.569 to 1.191 and 0.248 to 1.142 percent for total and acetic acid soluble SO_4-S, respectively (appendix table 6). Total and SO_4-S increased significantly following S application (table 4). High levels of applied Zn tended to interfere with the increasing effect of S application on S content as indicated by the negative S-Zn interaction (p=0.66). With regards to SO_4-S, the negative S-Zn interaction (p=0.95) indicated a reduction in the concentration of SO_4-S by applying Zn at high levels of S. However, S had a tendency to increase SO_4-S contents at high levels of applied Cl (p=0.67).

Application of S significantly increased the uptake of Zn by the tomato plant (p=0.99) (table 4). The negative S-Zn relationship (p=0.99) suggested reduced response to Zn application at high levels of S whereas the positive P-S interaction (p=0.92) indicated more Zn uptake following S application at higher levels of applied P.

There was a tendency for S to enhance the average content of water soluble Cl (p=0.51) (table 4). Application of S at low levels of associated N (p=0.74) and at high levels of applied Zn (p=0.90) tended to increase Cl concentration of the youngest mature tomato leaves.

In general the effect of S on the Na, K, Ca and Mg concentrations of tomato leaves was very small (appendix table 9).

In summary there was a small overall beneficial effect of S application on growth, yield and fruit set of tomatoes and there was a tendency to decrease the percent cracking of tomato fruits. Concerning the leaf composition, application of S decreased the concentration of total N and P and significantly increased total S, SO_4-S and Zn concentrations in the tomato leaves. The effect on elements other than these, was very small.

Effect of Zinc

In agreement with the findings of several workers (1, 5, 60), Zn application tended to increase the vegetative growth of the tomato plants (appendix table 9). Nevertheless, Zn tended to decrease the marketable yield of tomatoes ($p=0.66$) contrary to the results reported by Lingle *et al.* (5). The positive S-Zn interaction ($p=0.59$) indicated a tendency of better yield responses to Zn application at high levels of associated S (table 3).

There was a small tendency for application of Zn to reduce fruit number per plant ($p=0.38$) (table 3). Govindan (27) reported reduced number and weight of tomato fruits at a 3 ppm. level of Zn in the solution culture. The S-Zn interaction, however, indicated a tendency of Zn to increase number of fruits at high levels of S ($p=0.83$).

On the other hand, Zn application reduced the size of tomato fruits considerably (p=0.94). Among the quadratic terms the negative S-Zn (p=0.76), P-Zn (p=0.75) and N-Zn (p=0.72) interactions indicated a tendency of Zn to induce greater reductions in fruit size at high levels of applied S, P or N. Similarly Zn application tended to decrease size at low levels of Cl as revealed by the positive Zn-Cl interaction (p=0.63). Hence, it can be concluded that the tendency for Zn to decrease tomato yields was associated with reduction in fruit size since the adverse effect on fruit set was negligible.

The positive overall linear effect of Zn on fruit cracking was negligible (p=0.18) (table 3). However, at low levels of S (p=0.74), N (p=0.70) and Cl (p=0.60) Zn tended to decrease the incidence of fruit cracking.

Zinc application had a very slight tendency to decrease leaf contents of total N (p=0.23) (table 4). Of the quadratic terms, the negative N-Zn interaction (p=0.77) indicated a tendency for Zn to decrease the concentration of total N at the higher applied levels of N. In contrast the adverse effect of Zn application on the average content of water soluble NO_3-N was significant (p=0.98) and the negative N-Zn relationship indicated more severe reductions at high levels of applied N.

The adverse effect of Zn on total P content of tomato leaves was negligible (table 4). But Zn application had a tendency to decrease total P (p=0.74) at high levels of associated N. On the other hand Zn tended to increase the average content of acetic acid soluble PO_4-P at the higher levels of associated P (p=0.69) and S (p=0.49) but at high levels of N it tended to decrease the PO_4-P concentration (p=0.55).

Application of Zn resulted in a small tendency to increase the total S and acetic acid soluble SO_4-S concentrations of tomato leaves (table 4). The negative S-Zn (p=0.95), P-Zn (p=0.86) and Zn-Cl (p=0.66) interactions indicated higher SO_4-S contents following Zn application at low levels of S, P and Cl. At high levels of associated N, Zn application increased SO_4-S contents as indicated by the positive N-Zn interaction (p=0.88).

Data on Zn concentration in tomato leaves indicated a range of 31.9 to 79.1 ppm. (appendix table 6). Zinc concentration, as reported by Lyon *et al*. (55), was increased following Zn application (p=0.94). The negative P-Zn interaction (p=0.99) indicated that P application greatly reduced the Zn concentration at high levels of applied Zn. Cannell *et al*. (7) who worked on tomatoes, reported similar results. Similarly, Zn was more effective in increasing Zn concentration of tomato leaves at low levels of applied S as indicated by the negative S-Zn interaction (p=0.99). The positive Zn-Cl relationship (p=0.83) revealed a greater response to Zn application at high levels of associated Cl.

Zinc fertilization had a tendency (p=0.53) to increase the average concentration of water soluble Cl of tomato leaves (table 4).

At low levels of N (p=0.88) (figure 10) and P (p=0.74) Zn had a tendency for increasing Cl uptake. The positive S-Zn interaction (p=0.90) suggested higher levels of applied S for greater Cl concentrations following Zn application.

The effect of Zn on leaf contents of Ca and Na was negligible whereas Zn had a tendency to increase the concentration of Mg (p=0.79) and the average of acetic acid soluble Na (p=0.81) and to decrease the average of acetic acid soluble K (p=0.81) (appendix table 9).

Even though Zn had a small tendency to increase vegetative growth of tomatoes in the field, it tended to decrease yields possibly because of the adverse effects of applied Zn on size of fruit and fruit set. Zinc application significantly increased Zn concentration and tended to decrease the average seasonal concentration of acetic acid soluble K. However, application of Zn tended to increase the concentration of Mg and the average seasonal concentration of Na in the tomato leaves. Leaf concentrations of N, P, S and Ca were negligibly affected by Zn application.

Effect of Chlorine

Even though Cl tended to increase the marketable yields of tomatoes (p=0.76) (table 3), there was a small tendency for Cl application to reduce the vegetative growth of field tomatoes (appendix table 9). Among the quadratic terms the positive N-Cl interaction (p=0.67) for marketable yield indicated a tendency for the application of Cl to increase the yield at high levels of applied N. Similarly, the tendency for Cl to increase the number of fruits was small ($p=0.42$) (table 3). The positive N-Cl interaction ($p=0.93$) indicated an increase in number of fruits following Cl application at high levels of associated N (figure 2). The P-Cl interrelationship ($p=0.73$) indicated a tendency for Cl application to increase fruit number at high levels of applied P. With regards to size of fruit, Cl exerted a considerable enhancing effect ($p=0.84$). Among the quadratic terms, the negative N-Cl interaction ($p=0.97$) indicated a greater increase in fruit size by Cl application at low levels of N (figure 4). On the other hand Cl application had the tendency of increasing size to a greater extent at low levels of applied P ($p=0.79$) and higher levels of S ($p=0.81$) and Zn ($p=0.63$). Thus the tendency of Cl to increase yields is mainly due to the increased fruit size rather than to fruit set.

Chlorine application tended to increase the incidence of cracking ($p=0.58$) (table 3). The negative N-Cl interaction ($p=0.82$) indicated more fruit cracking at low levels of N following Cl application. In contrast the positive P-Cl ($p=0.64$) and Zn-Cl ($p=0.60$) interactions showed a tendency of Cl to induce cracking at high levels of applied P and Zn.

The tendency of Cl to reduce total N concentration of tomato leaves was negligible ($p=0.28$) (table 4). Of the quadratic interactions the positive P-Cl interaction ($p=0.65$) indicated that application of Cl tended to increase N concentration at high levels of applied P. The average leaf concentration of water soluble NO_3-N was reduced (p=0.91) by application of Cl (table 4).

Application of Cl tended to increase the total concentration of P at low levels of associated N (p=0.74) and S (p=0.72) and at high levels of applied P (p=0.88) (figure 12) (table 4). On the average application of Cl tended to increase the acetic acid soluble PO_4-P concentration in tomato leaves (p=0.80). The negative N-Cl interaction indicated greater PO_4-P concentration following application of Cl at low levels of applied N (p=0.88) (figure 9).

The effect of Cl application on total and acetic acid soluble SO_4-S of tomato leaves was negligible (table 4). The negative P-Cl relationship (p=0.98) indicated increased SO_4-S contents following application of Cl at low levels of associated P. At low levels of N (p=0.70) and Zn (p=0.66) and high levels of S (p=0.67), Cl tended to increase the leaf concentrations of SO_4-S.

However, Cl significantly reduced the concentration of total Zn in tomato leaves (p=0.99) (table 4). The positive P-Cl (p=0.99) and Zn-Cl (p=0.83) interactions indicated that Zn concentration was reduced by Cl application at low levels of P and Zn.

Data on the average leaf content of water soluble Cl indicated a range of 1.07 - 2.01 percent (appendix table 7). Chlorine application significantly increased the Cl content of tomato leaves (p=0.98) (table 4). Among the quadratic terms, the negative N-Cl (p=0.80), P-Cl (p=0.59) and S-Cl (p=0.56) interactions indicated a tendency for N, P and S application to increase the concentration of Cl at low levels of applied Cl.

Effect of Cl application on the leaf concentration of the cations, Na, K, Ca and Mg was negligible (appendix table 9).

In conclusion, Cl tended to increase marketable yields of tomatoes in spite of the small observed adverse effect on vegetative performance of the plant in the field, mainly because it favored the development of larger tomato fruits. Fruit set was little affected.

Chlorine application significantly increased the concentration of water soluble Cl in the leaves. In contrast Zn and NO_3-N concentrations were significantly reduced. The effect of Cl on the concentrations of N, P, S and the cations, Na, K, Ca and Mg in the youngest mature tomato leaves, was negligible.

SUMMARY AND CONCLUSIONS

In an irrigated field experiment in the Beka'a, Lebanon in which the application rates of N, P, S, Zn and Cl were the variables it was found that application of P significantly increased the marketable yields of tomatoes (figure 14) especially at low levels of S (figure 11) and N. This was attributed to the highly beneficial effects of applied P on the vegetative performance of the tomato plant early in the season (appendix table 9) and the consequent improved fruit set particularly at low levels of associated S. Also, P as applied considerably improved fruit quality by reducing the incidence of cracking.

The quadratic regression equation was used to determine the best possible combination of the elements under study for maximum yield and economic returns. The best levels of the varied elements, other than P, were first estimated and then the optimum amount of applied P was computed.

The detrimental effect of N application on tomato yields and fruit set, especially early in the season, makes the presence of high N levels undesirable. Furthermore the application of P reduced the need for N to produce higher yields, though higher levels of N were needed for better quality at high rates of P (figure 5) since the tendency for producing a smaller fruit certainly existed (figure 3). Nevertheless the exceptionally high yields of tomatoes following P application at low levels of N are of greater importance.

Even though S had a small tendency to increase yields, P application reduced the need for S (figure 11). Likewise the positive P-S relationship for cracking suggested that application of P at low levels of S reduced this undesirable characteristic.

The tendency of Zn to reduce tomato yields suggested its maintenance at low levels. Consideration of the positive S-Zn and N-Zn interactions for cracking indicated low requirement for these elements for less incidence of cracking.

However, application of Cl tended to increase tomato yields especially at high levels of N (figure 1) and P. The N-Cl interaction for fruit number (figure 2) indicated that the presence of both nutrients at similar levels is favorable for fruit set. Similarly the lowest level combination of N and Cl was conducive to smaller sized fruits (figure 4) of better quality. On the other hand, P had a small tendency to increase the requirement for Cl for higher yields (figure 12) and number of fruits. Nevertheless this does not justify the presence of high Cl at high levels of applied P since the tendency for getting inferior cracked fruit is far greater (table 3).

Taking the aforementioned points into consideration and by the trial and error method using the regression equation for the necessary calculations, the best combination of the fertilizer elements was found to be the following:

- 2N or 11.36 kg./ha.
- 2S or 17.04 kg./ha.
- 2Zn or 2.84 kg./ha.
- ICl or 30.91 kg./ha.

Solving the regression equation for the combination of - 2N, - 2S, - 2Zn and - ICI at the different levels of P, within the range tested, gave a wide range of marketable tomato yields which were plotted against the amount of P applied (figure 14). The return above the cost of fertilizers considering the value of marketable yield, was also presented (figure 14). The estimated wholesale value of the crop (at 10 p.l./kg.) was reduced ten percent to take care of the extra costs expended for picking and marketing as the yield increased. The low levels of applied P produced the lowest tomato yields. Even though the highest rate of P employed (618.12 kg./ha.) produced the highest marketable yield (141.51m. tons/ha.), the last increments in yield were not large. The + 1.5 coded level (375.8 kg./ha.) was considered to be about the most practical rate of P application under the conditions of this investigation since the last increment of fertilizer would provide about two Lebanese pounds for each pound invested for fertilizer (figure 14) thus providing a margin of financial safety with regard to weather and other hazards.

Considering 375.8 kg./ha. as the recommended rate of P

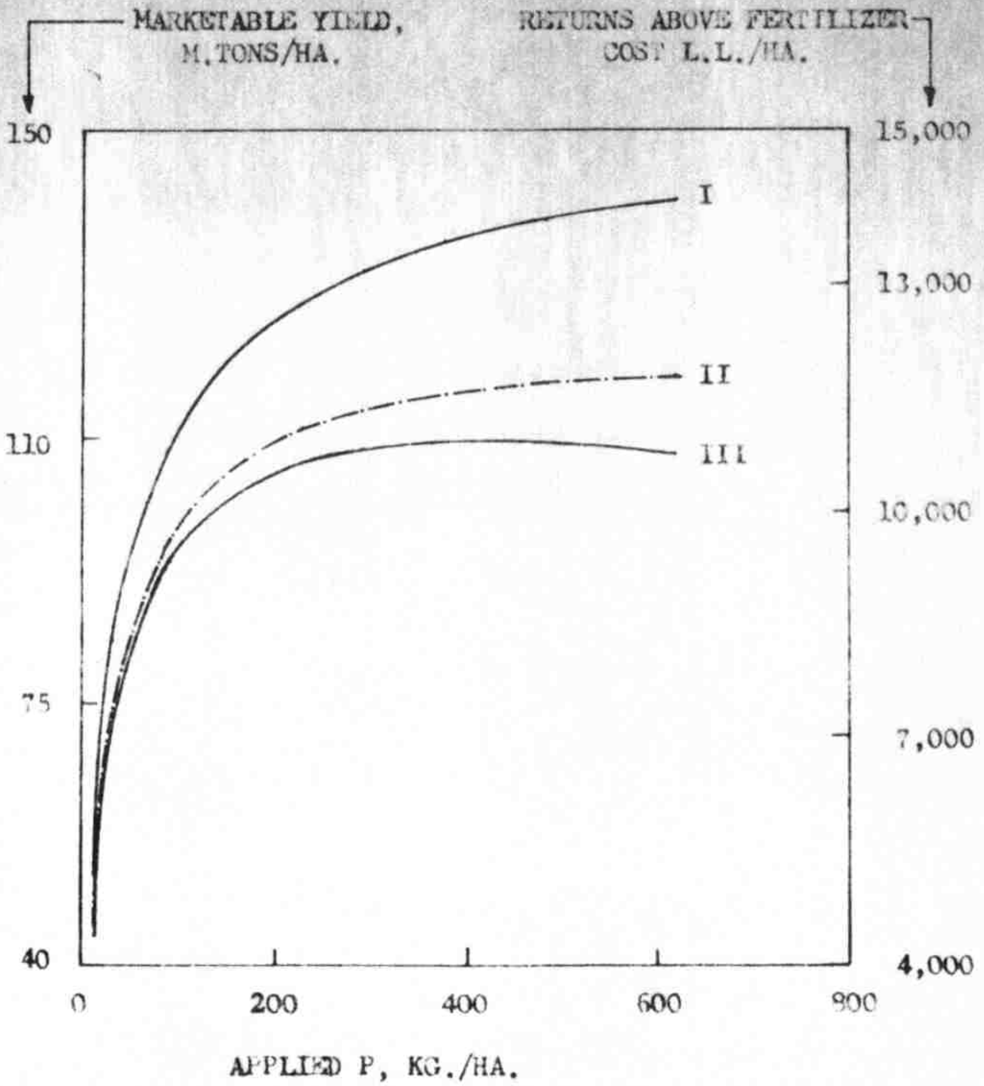

Fig. 14. Yield of marketable tomatoes (curve I), return above fertilizer cost (curve II) and return with fertilizer cost doubled (curve III) as affected by application of P. Points were determined by calculation from the respective regression equations with the variables set at -2N, -2S, -2Zn and -1Cl. The value of tomatoes was set at .09 L.L./kg. and the cost of P at 1.45 L.L./kg. of P.

application (for a yield of about 135 tons/ha.), a tentative critical level for the seasonal phosphate-phosphorus concentration in the youngest mature tomato leaves (figure 7) was established. The fact that the critical level falls below the leaf concentration of PO_4-P and that fruit setting and development was manifested in successive waves suggested that the critical level would be subject to considerable variation depending on the degree of the nutrient assimilation within the plant. However, there still existed a possibility of establishing such critical levels for leaf samples early in the season before fruit set and production become a dominant factor.

Apparently the relatively long days, warm summer temperatures and the ample water supply available had increased the tomato crop response for P in the Beka'a, Lebanon and consequently high yields were possible.

With regards to leaf composition application of any of the elements was followed by a consequent increase of that particular element in the tomato leaves (table 4) except for the effect of P on its total concentration which was negligible. Application of N, P and Cl had a depressing effect on Zn concentration of the tomato leaves contrary to S application which enhanced it markedly. Also, N and P tended to interfere with the accumulation of water soluble Cl whereas N significantly reduced the leaf concentration of SO_4-S. However, addition of Cl and Zn significantly reduced the average seasonal concentration of water soluble NO_3-N. Similarly, S and Cl tended to reduce total P and concentration of soluble PO_4-P in the youngest mature tomato leaves, respectively.

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APPENDICES

Table 5. Actual and predicted values for total and marketable yields of tomatoes, size of fruits, percent cracking, number of fruits and vegetative performance of the tomato plant as affected by various combinations of levels of N, P, S, Zn and Cl. (continued on next page).

Treatment levels					Total yield, m. tons / ha.		Marketable yield, m. tons/ha.		Relative Vegetative growth
N	P	S	Zn	Cl	actual	predicted	actual	predicted	July 11
2	2	2	2	4	55.49	59.30	53.65	58.08	5.3
4	2	2	2	2	57.01	56.86	56.02	56.54	2.7
2	4	2	2	2	96.43	92.94	93.58	90.66	9.8
4	4	2	2	4	90.84	88.78	87.74	86.32	8.9
2	2	4	2	2	74.98	77.60	72.10	75.30	7.3
4	2	4	2	4	64.30	68.36	62.60	67.32	4.7
2	4	4	2	4	83.89	84.60	82.04	83.32	7.1
4	4	4	2	2	62.49	59.24	60.37	57.74	8.7
2	2	2	4	2	55.70	55.82	53.46	54.50	8.9
4	2	2	4	4	58.79	60.38	54.34	56.84	4.2
2	4	2	4	4	87.49	85.74	84.78	83.84	7.6
4	4	2	4	2	67.58	61.86	65.10	60.26	6.2
2	2	4	4	4	71.97	76.28	69.28	74.48	8.0
4	2	4	4	2	61.98	62.36	59.74	61.02	3.1
2	4	4	4	2	87.09	84.12	81.01	78.86	10.0
4	4	4	4	4	73.68	72.16	70.46	69.80	7.6
1	3	3	3	3	78.77	76.71	76.04	74.08	8.9
5	3	3	3	3	52.16	55.11	50.47	53.28	1.1
3	1	3	3	3	52.06	43.25	50.29	41.42	4.9
3	5	3	3	3	61.74	71.37	58.37	68.10	8.9
3	3	1	3	3	75.06	78.47	72.20	75.56	9.6
3	3	5	3	3	86.77	84.23	83.27	80.76	9.8
3	3	3	1	3	90.35	88.81	87.58	86.58	6.2
3	3	3	5	3	79.15	81.59	75.83	77.66	8.2
3	3	3	3	1	53.87	59.71	51.98	57.76	7.1
3	3	3	3	5	75.90	70.91	74.01	69.04	6.7
3	3	3	3	3	53.90	68.47	51.91	66.40	8.7
3	3	3	3	3	81.98	68.47	79.71	66.40	6.2
3	3	3	3	3	71.78	68.47	70.18	66.40	8.0
3	3	3	3	3	59.54	68.47	57.42	66.40	8.9
3	3	3	3	3	74.82	68.47	72.48	66.40	7.1
3	3	3	3	3	69.65	68.47	67.54	66.40	8.4
		r			0.91		0.90		—

Table 5. continued.

Treatment levels					Size of fruit, g.		% Cracking		Number
N	P	S	Zn	Cl	actual	predicted	actual	predicted	of fruits
2	2	2	2	4	161.9	163.6	40.9	42.0	44
4	2	2	2	2	193.8	195.5	57.6	59.5	42
2	4	2	2	2	170.4	170.5	34.3	34.9	71
4	4	2	2	4	169.5	168.5	26.1	31.0	73
2	2	4	2	2	153.3	153.8	28.7	28.4	62
4	2	4	2	4	184.5	183.8	32.2	36.2	45
2	4	4	2	4	182.6	180.2	39.6	42.2	57
4	4	4	2	2	173.1	170.8	27.6	31.1	47
2	2	2	4	2	148.8	155.2	34.6	32.7	48
4	2	2	4	4	182.3	187.5	50.7	53.1	41
2	4	2	4	4	169.6	173.2	35.6	36.7	65
4	4	2	4	2	170.1	173.7	30.0	32.0	50
2	2	4	4	4	172.9	176.9	34.7	34.8	51
4	2	4	4	2	163.9	167.9	48.3	49.3	49
2	4	4	4	2	150.2	152.5	31.8	31.4	72
4	4	4	4	4	143.5	144.6	37.0	40.9	64
1	3	3	3	3	172.3	167.7	43.4	45.3	58
5	3	3	3	3	186.6	184.3	66.1	57.7	34
3	1	3	3	3	177.0	169.1	44.3	43.5	37
3	5	3	3	3	155.5	156.6	35.2	29.5	50
3	3	1	3	3	189.0	181.9	40.8	38.1	49
3	3	5	3	3	167.4	167.6	35.1	31.3	65
3	3	3	1	3	167.3	172.0	42.2	36.3	68
3	3	3	5	3	169.8	158.2	38.3	37.7	58
3	3	3	3	1	176.2	171.5	34.2	34.4	40
3	3	3	3	5	183.3	181.1	45.3	38.7	52
3	3	3	3	3	182.7	175.5	52.1	42.3	37
3	3	3	3	3	173.2	175.5	38.1	42.3	60
3	3	3	3	3	167.5	175.5	34.7	42.3	53
3	3	3	3	3	165.7	175.5	38.5	42.3	45
3	3	3	3	3	175.6	175.5	39.0	42.3	52
3	3	3	3	3	181.5	175.5	44.6	42.3	48
r					0.92		0.89		—

Table 6. Observed N, P, S and Zn concentrations of the youngest mature tomato leaves as affected by various combinations of levels of N, P, S, Zn and Cl. (continued on next page).

Treatment Levels					Nitrogen					Sulfur	
					Water Soluble NO_3-N, ppm. Sample				total, %	HAc soluble, %	Total, %
N	P	S	Zn	Cl	1st	2nd	3rd	aver.	2nd sample	2nd sample	2nd sample
2	2	2	2	4	890	124	375	463	3.08	.867	.877
4	2	2	2	2	1544	451	367	787	3.68	.248	.569
2	4	2	2	2	1140	333	593	689	3.33	.861	.871
4	4	2	2	4	1014	550	598	721	3.77	.349	.646
2	2	4	2	2	967	112	580	553	3.69	1.026	1.166
4	2	4	2	4	1361	201	596	719	3.68	.730	.928
2	4	4	2	4	754	97	820	557	2.96	1.142	1.191
4	4	4	2	2	1389	324	720	811	3.53	.929	.934
2	2	2	4	2	1204	294	445	648	3.75	.840	.958
4	2	2	4	4	615	200	417	411	3.10	.508	.580
2	4	2	4	4	722	404	291	472	4.16	.607	.904
4	4	2	4	2	1097	103	379	526	3.53	.732	.797
2	2	4	4	4	604	105	496	402	3.44	1.094	1.130
4	2	4	4	2	1023	218	294	512	3.56	.645	.846
2	4	4	4	2	673	211	897	594	3.17	.941	1.161
4	4	4	4	4	621	198	495	438	3.27	.604	.795
1	3	3	3	3	305	127	614	349	2.61	.819	.942
5	3	3	3	3	1046	331	356	578	4.44	.265	.575
3	1	3	3	3	823	255	180	419	2.65	.625	.758
3	5	3	3	3	627	100	593	440	3.10	.536	.680
3	3	1	3	3	924	94	217	412	4.07	.621	.934
3	3	5	3	3	945	200	449	531	2.81	.765	.943
3	3	3	1	3	524	110	481	372	3.39	.686	.868
3	3	3	5	3	528	89	320	312	2.87	1.020	1.151
3	3	3	3	1	374	286	289	316	3.38	.521	.850
3	3	3	3	5	590	285	163	346	3.30	.605	1.025
3	3	3	3	3	733	203	177	371	2.57	.472	.779
3	3	3	3	3	536	204	446	395	2.89	.612	.955
3	3	3	3	3	681	284	670	545	3.84	.639	.939
3	3	3	3	3	629	207	346	394	2.84	.723	1.086
3	3	3	3	3	594	292	439	442	2.68	.667	1.101
3	3	3	3	3	203	270	381	285	3.34	.564	.813

Table 6. continued.

Treatment Levels					Phosphorus				Phosphorus	Zinc
					Acetic Acid Soluble, % Sample				Total, % 2nd sample	Total, ppm. 2nd sample
N	P	S	Zn	Cl	1st	2nd	3rd	aver.		
2	2	2	2	4	.242	.122	.225	.196	.254	38.9
4	2	2	2	2	.218	.157	.190	.188	.273	48.9
2	4	2	2	2	.239	.121	.191	.184	.219	51.8
4	4	2	2	4	.280	.151	.160	.197	.264	40.9
2	2	4	2	2	.198	.133	.165	.165	.263	64.7
4	2	4	2	4	.291	.114	.170	.192	.232	40.9
2	4	4	2	4	.255	.126	.197	.193	.231	61.1
4	4	4	2	2	.275	.118	.174	.189	.232	55.4
2	2	2	4	2	.215	.132	.156	.168	.254	79.1
4	2	2	4	4	.227	.099	.158	.161	.221	54.8
2	4	2	4	4	.311	.192	.177	.227	.340	46.1
4	4	2	4	2	.309	.130	.171	.203	.223	36.3
2	2	4	4	4	.260	.134	.226	.207	.258	55.7
4	2	4	4	2	.223	.150	.179	.184	.273	61.6
2	4	4	4	2	.235	.119	.193	.182	.231	41.4
4	4	4	4	4	.287	.140	.196	.208	.226	34.1
1	3	3	3	3	.280	.121	.212	.204	.213	38.8
5	3	3	3	3	.192	.190	.162	.181	.313	31.9
3	1	3	3	3	.246	.121	.204	.190	.216	55.6
3	5	3	3	3	.289	.145	.168	.201	.253	51.0
3	3	1	3	3	.248	.150	.216	.205	.263	40.7
3	3	5	3	3	.228	.108	.199	.178	.183	50.8
3	3	3	1	3	.286	.108	.200	.198	.231	48.6
3	3	3	5	3	.268	.118	.180	.189	.180	55.5
3	3	3	3	1	.280	.111	.227	.206	.251	41.2
3	3	3	3	5	.266	.139	.223	.209	.239	36.5
3	3	3	3	3	.290	.104	.217	.204	.199	53.1
3	3	3	3	3	.224	.110	.193	.176	.222	51.0
3	3	3	3	3	.275	.148	.192	.205	.288	53.5
3	3	3	3	3	.291	.125	.197	.204	.219	52.9
3	3	3	3	3	.331	.124	.232	.229	.242	50.8
3	3	3	3	3	.261	.143	.186	.197	.270	55.6

Table 7. Observed concentrations of Cl, Na, K, Ca and Mg in the youngest mature tomato leaves as affected by various combinations of levels of N, P, S, Zn and Cl. (continued on next page).

Treatment					Chlorine Water Soluble,% Sample				Sodium Acetic Acid Soluble, % Sample			
Levels												
N	P	S	Zn	Cl	1st	2nd	3rd	aver.	1st	2nd	3rd	aver.
2	2	2	2	4	1.55	1.39	2.04	1.66	.110	.088	.141	.113
4	2	2	2	2	1.34	.94	1.92	1.40	.114	.074	.160	.116
2	4	2	2	2	1.03	1.15	1.77	1.32	.145	.087	.153	.128
4	4	2	2	4	1.27	1.51	2.01	1.60	.110	.106	.169	.128
2	2	4	2	2	1.23	1.23	1.54	1.34	.103	.076	.130	.103
4	2	4	2	4	1.09	1.22	1.81	1.38	.102	.111	.157	.123
2	4	4	2	4	1.13	1.25	2.04	1.47	.095	.079	.148	.107
4	4	4	2	2	1.16	1.16	1.70	1.34	.087	.088	.152	.109
2	2	2	4	2	1.33	1.19	1.62	1.38	.138	.081	.160	.126
4	2	2	4	4	1.29	1.15	1.96	1.46	.116	.082	.145	.114
2	4	2	4	4	1.51	1.36	1.75	1.54	.116	.078	.151	.115
4	4	2	4	2	1.01	1.04	1.57	1.21	.092	.100	.182	.125
2	2	4	4	4	1.39	1.89	2.77	2.01	.107	.086	.185	.126
4	2	4	4	2	1.00	1.07	2.22	1.43	.087	.072	.174	.111
2	4	4	4	2	1.17	1.50	1.91	1.53	.097	.081	.189	.122
4	4	4	4	4	1.11	.90	1.80	1.27	.079	.072	.189	.113
1	3	3	3	3	1.02	1.15	2.07	1.41	.110	.071	.172	.118
5	3	3	3	3	1.14	.74	1.32	1.07	.096	.073	.184	.118
3	1	3	3	3	1.13	1.07	2.03	1.41	.087	.066	.162	.105
3	5	3	3	3	1.20	1.24	2.04	1.49	.100	.080	.158	.113
3	3	1	3	3	1.06	1.22	1.65	1.31	.085	.083	.160	.109
3	3	5	3	3	1.06	1.09	2.20	1.45	.091	.085	.163	.113
3	3	3	1	3	1.00	1.21	2.07	1.43	.085	.134	.159	.126
3	3	3	5	3	1.17	1.33	2.03	1.51	.123	.148	.171	.147
3	3	3	3	1	1.07	1.33	1.97	1.46	.096	.115	.152	.121
3	3	3	3	5	1.67	1.66	2.25	1.86	.082	.122	.145	.116
3	3	3	3	3	1.06	.97	1.59	1.21	.072	.120	.141	.111
3	3	3	3	3	1.12	1.37	1.81	1.43	.076	.132	.148	.119
3	3	3	3	3	1.34	1.29	1.97	1.53	.101	.124	.147	.124
3	3	3	3	3	1.11	.99	1.93	1.34	.097	.128	.165	.130
3	3	3	3	3	1.14	1.46	2.06	1.55	.091	.132	.162	.128
3	3	3	3	3	1.17	1.35	2.06	1.53	.126	.124	.157	.136

Table 7. continued.

Treatment Levels N	P	S	Zn	Cl	Potassium Acetic Acid Soluble,% Sample 1st	2nd	3rd	aver.	Calcium Total, % 2nd sample	Magnesium Total,% 2nd sample
2	2	2	2	4	3.56	2.39	2.58	2.84	3.48	.760
4	2	2	2	2	3.64	2.50	2.39	2.84	2.87	.636
2	4	2	2	2	3.28	2.37	2.70	2.78	3.98	.826
4	4	2	2	4	3.63	2.84	2.81	3.09	3.47	.823
2	2	4	2	2	3.68	2.89	2.89	3.15	2.89	.685
4	2	4	2	4	3.38	2.86	2.62	2.95	3.32	.701
2	4	4	2	4	3.23	2.35	2.59	2.72	3.01	.701
4	4	4	2	2	3.53	2.61	2.36	2.83	3.37	.960
2	2	2	4	2	3.48	2.86	2.45	2.93	3.22	.781
4	2	2	4	4	3.69	2.43	2.18	2.77	2.90	.652
2	4	2	4	4	3.25	2.83	2.60	2.89	3.09	.867
4	4	2	4	2	3.72	2.75	2.52	3.00	3.55	.798
2	2	4	4	4	3.64	2.67	2.17	2.83	3.52	.858
4	2	4	4	2	3.54	2.49	2.16	2.73	2.66	.822
2	4	4	4	2	2.92	2.54	2.70	2.72	4.05	.896
4	4	4	4	4	3.37	2.49	2.31	2.72	3.03	.682
1	3	3	3	3	2.90	2.15	2.28	2.44	3.28	.809
5	3	3	3	3	3.47	2.87	2.25	2.86	2.63	.928
3	1	3	3	3	3.31	2.02	1.97	2.43	3.10	.818
3	5	3	3	3	2.86	2.40	2.47	2.58	3.43	.839
3	3	1	3	3	3.31	2.78	2.89	2.99	3.59	.867
3	3	5	3	3	2.99	2.25	2.38	2.54	2.81	.509
3	3	3	1	3	3.13	2.51	2.60	2.75	3.27	.667
3	3	3	5	3	3.12	2.44	2.09	2.55	3.70	.898
3	3	3	3	1	3.19	2.68	3.03	2.97	3.37	.556
3	3	3	3	5	3.11	2.62	2.87	2.87	3.70	.750
3	3	3	3	3	3.39	2.12	2.35	2.62	2.79	.769
3	3	3	3	3	3.49	2.26	2.42	2.72	3.90	.793
3	3	3	3	3	3.39	2.72	2.84	2.98	2.95	.847
3	3	3	3	3	3.25	2.19	2.46	2.63	2.96	.689
3	3	3	3	3	3.28	2.71	2.22	2.74	4.22	.935
3	3	3	3	3	3.18	2.50	2.31	2.66	2.92	.659

Table 8. Regression coefficients (b) and the probability of a true effect (p) for the acetic acid soluble PO_4-P and for the water soluble NO_3-N and Cl in the youngest mature tomato leaves. (continued on next page).

Equation variables	Water Soluble NO_3-N, ppm.						Acetic Acid Soluble PO_4-P, %					
	1st sample		2nd sample		3rd sample		1st sample		2nd sample		3rd sample	
	b	p	b	p	b	p	b	p	b	p	b	p
Mean	+511.56	---	+230.33	---	+379.39	---	+.2785	---	+.1255	---	+.2056	---
N	+89.42	.94	+40.54	.99	-47.79	.79	-.0009	.08	+.0049	.77	-.0097	.96
P	-49.58	.74	+ 8.54	.63	+85.38	.95	+.0168	.93	+.0043	.72	-.0034	.61
S	-33.00	.58	-32.54	.99	+79.04	.94	-.0024	.23	-.0064	.87	+.0016	.30
Zn	-103.83	.96	-20.88	.94	-52.42	.83	+.0014	.15	+.0031	.58	-.0023	.44
Cl	-84.33	.92	- 7.04	.54	-18.29	.39	+.0089	.72	+.0031	.58	+.0034	.61
NN	+79.31	.93	- 9.42	.72	+49.23	.84	-.0105	.82	+.0077	.94	-.0067	.90
PP	+91.68	.95	- 3.45	.30	+24.61	.56	-.0026	.27	+.0020	.43	-.0070	.91
SS	+144.06	.99	-11.08	.77	+11.23	.26	-.0100	.81	+.0010	.21	-.0016	.34
ZnZn	+41.93	.71	-22.95	.97	+28.11	.61	-.0092	.02	-.0030	.61	-.0060	.87
ClCl	+30.93	.59	+23.55	.97	-15.52	.36	-.0012	.12	+.0001	.02	+.0028	.57
NP	- 2.88	.04	-19.06	.86	-11.69	.20	+.0042	.33	-.0011	.17	+.0011	.16
NS	+67.63	.78	+16.69	.82	-46.56	.70	+.0063	.50	+.0025	.40	+.0005	.08
NZn	-87.75	.88	-72.19	.99	-28.56	.50	-.0066	.52	-.0060	.76	+.0023	.36
NCl	-26.75	.40	+17.06	.82	+54.94	.77	-.0076	.57	-.0075	.85	-.0094	.91
PS	-14.88	.22	- 7.94	.51	+44.31	.68	-.0098	.68	-.0070	.83	+.0031	.48
PZn	+ 8.25	.12	-19.81	.87	-25.19	.44	+.0073	.55	+.0048	.68	+.0029	.44
PCl	+ 5.00	.08	+45.19	.99	-36.44	.60	-.0057	.44	+.0140	.98	-.0055	.72
SZn	-37.50	.54	+28.44	.96	- 8.31	.14	-.0061	.48	+.0031	.50	+.0120	.96
SCl	+64.50	.77	-22.56	.91	+ 1.19	.02	+.0052	.41	-.0019	.31	+.0041	.60
ZnCl	-25.88	.38	+20.56	.89	-27.81	.48	-.0022	.17	+.0031	.50	+.0016	.25

Table 8. continued.

Equation	Water Soluble Chlorine, %					
	1st sample		2nd sample		3rd sample	
Variables	b	p	b	p	b	p
Mean	+1.141	---	+1.228	---	+1.918	---
N	-.034	.85	-.115	.96	-.081	.93
P	-.029	.79	+.006	.10	-.054	.80
S	-.043	.92	+.010	.16	+.094	.95
Zn	+.015	.52	+.021	.35	+.027	.51
Cl	+.094	.99	+.085	.90	+.104	.96
NN	-.005	.19	-.064	.84	-.067	.90
PP	+.016	.58	-.011	.20	+.019	.40
SS	-.011	.42	-.011	.20	-.008	.16
ZnZn	-.004	.15	+.017	.31	+.022	.46
ClCl	+.068	.99	+.074	.89	+.037	.69
NP	+.031	.74	+.042	.55	-.020	.31
NS	-.002	.06	-.066	.74	-.063	.78
NZn	-.058	.94	-.100	.89	-.033	.51
NCl	-.036	.80	-.015	.20	-.098	.92
PS	+.035	.78	-.063	.72	-.029	.45
PZn	+.026	.66	-.049	.61	-.110	.95
PCl	+.015	.43	-.066	.74	-.039	.58
SZn	+.007	.20	+.046	.59	+.152	.98
SCl	-.048	.89	-.049	.61	+.011	.17
ZnCl	+.033	.76	-.025	.33	-.001	.01

Table 9. Regression coefficients (b) and the probability of a true effect (p) for the Na, K, Ca and Mg concentrations in the youngest mature tomato leaves and for the vegetative performance of the tomato plant.

	Na, %		K, %		Ca, %		Mg, %		Relative Vegetative growth	
	acetic acid soluble average		acetic acid soluble average		Total 2nd sample		Total 2nd sample		July 11	
	b	p	b	p	b	p	b	p	b	p
Mean	+.12460	---	+2.6940	---	+3.292	---	+.7787	---	+7.897	---
N	-.00004	.01	+.0379	.77	-.140	.69	-.0026	.09	-1.396	.99
P	+.00129	.50	+.0004	.01	+.140	.69	+.0292	.78	+1.238	.99
S	-.00179	.63	-.0579	.91	-.095	.53	-.0231	.68	+.138	.44
Zn	+.00289	.81	-.0421	.81	+.020	.11	+.0303	.79	+.213	.64
Cl	-.00046	.18	-.0154	.39	-.005	.02	+.0012	.04	-.171	.55
NN	-.00160	.63	+.0123	.34	-.085	.52	+.0249	.75	-.734	.99
PP	-.00385	.94	-.0239	.62	-.008	.04	+.0149	.54	-.259	.76
SS	-.00335	.91	+.0411	.84	-.024	.14	-.0202	.66	+.441	.93
ZnZn	+.00302	.88	+.0123	.34	+.047	.29	+.0034	.12	-.184	.60
ClCl	-.00148	.60	+.0798	.98	+.060	.37	-.0289	.81	-.259	.76
NP	+.00044	.14	+.0619	.88	+.041	.18	+.0154	.42	+.731	.96
NS	-.00019	.06	-.0281	.56	-.007	.04	+.0219	.58	+.081	.21
NZn	-.00319	.79	-.0231	.48	-.088	.40	-.0373	.79	-.556	.91
NCl	+.00219	.64	+.0269	.54	+.082	.37	-.0223	.58	+.794	.97
PS	-.00244	.68	-.0656	.89	-.034	.15	-.0195	.53	-.069	.19
PZn	-.00119	.38	+.0269	.54	+.009	.04	-.0249	.63	-.456	.86
PCl	-.00256	.70	+.0219	.46	-.246	.83	-.0284	.68	-.231	.59
SZn	+.00219	.64	-.0431	.74	+.107	.49	+.0099	.27	+.044	.11
SCl	+.00306	.77	-.0156	.32	+.037	.16	-.0301	.70	-.006	.01
ZnCl	-.00194	.58	-.0106	.22	-.069	.31	-.0073	.20	+.106	.27