TOMATO YIELDS, QUALITY AND COMPOSITION IN RELATION TO POTASSIUM APPLIED TO A VERMICULITIC SOIL

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This is to certify that the

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ABSTRACT

TOMATO YIELDS, QUALITY AND COMPOSITION
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By

Knudt John Miller

The results obtained on a Genesee sandy clay loam from 1967 plantings of transplanted and direct seeded H1350 tomatoes focused attention on the extremely high K fixation capacity of this soil. Subsequent studies were directed toward determining means of providing economically optimum levels of available K for tomato production on this soil, which contained low levels of available K (70 to 126 lb./A) and possessed high K fixation capacity due to the type of clay (19% vermiculite).

Fixation averaged 92.1% of up to 500 lb. applied K/A with no significant treatment effects on Ca and Mg levels as indicated by soil tests. Total yield of transplanted H1350 marketable and No. 1 fruit increased an average 4282 and 3682 lb./A respectively with each 100 lb./A increment of applied K. Single harvest early yields of direct seeded H1350 tomatoes for processing increased an average 1.26 ton/A with each 100 lb./A increment of

applied K. Marketable yield response directly related to increased potassium fertilizer was primarily a result of increased fruit size and improved color-quality. Based on petiole analysis, available soil K was depleted much earlier in the high plant population direct seeded plots than in transplanted plots containing 12.5% as many plants per acre. Sidedress N treatments did not consistently affect either transplant or direct seeded tomato yields, quality, or nutrient composition, nor alter responses to variation in soil test K level.

Marketable C1327 tomato yields (fresh market and processing) were increased significantly with up to 1742 lb. broadcast K/A, from KCl, and levels of 73 and 146 lb. sidedress K/A from KNO_3. Based on differentiation of the production function, it was estimated that 1126 and 150 lb./A of broadcast and sidedress K respectively would be required to provide the estimated optimum yield of 44,000 lb. of fresh market tomatoes per acre. Fruit harvested during the first week declined from 32 to 13 per cent of the season total with K application increasing from zero to 1529 lb./A indicating a delaying effect of K on fruit maturity.

Potassium concentrations in tomato plant tissues (dry wt basis) corresponding to maximum production obtained with 1300 lb./A of broadcast K and 150 lb./A of sidedress

K were: petiole at first fruit set, 7.83%; petiole at midseason, 7.38%; petiole prior to fruit pigmentation, 1.71%; ripe fruit, 5.48%; and root, 1.35%. A total tomato yield, including green fruit, of 35 ton/A removed an estimated 187 lb. K/A in the fruit. Average rates of up to 1142 lb. K/A significantly increased marketable fruit citric acid concentration and showed trends of increased pH, color index, and decreased sucrose content.

The portion of the total yield showing blotchy ripening symptoms decreased from 84.7% with lowest K to 15.1% with highest K application rates. A midseason K concentration of 11.6% in petioles and 7.4% in fruits were estimated by regression to be required to minimize blotchy ripening. Even at high rates of K application, which provided more than adequate K levels in plant tissue early in the season, late season values fell below the 1.5% critical level.

No evidence of either critically deficient or toxic levels of nutrients other than K were found with K applications ranging to 1742 lb./A in this high K-fixing soil.

Sidedress K in combination with foliar K treatments failed to meet the K requirements of high tomato yields and quality in this high K-fixing soil testing 72 to 126 lb. of available K/A.

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The implications of this two-year study are that rates of K up to approximately 1250 lb./A would be profitable at prevailing crop prices even with the extreme fixation rate characteristic of the soil.

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INTRODUCTION

Although the soil, on most southwestern Michigan commercial fruit and vegetable farms, tests high or very high in potassium, there remains the need for determining either the economy of maintaining these levels or attaining them for the production of various crops, as a part of a program of continually improving fertilizer recommendations. Recommended levels of K based on routine soil tests, which do not determine the fixation ability of the soil may be inadequate to meet the demands of high levels of crop production[1].

To establish a broad range in fertility with respect to a nutrient, an area of uniformly low fertility is essential. Such an area was found on the river terrace soil of the Sodus Horticultural Experiment Station. Since the Station was established in 1954, there has been a problem with poor crop growth, plant development, and production on the terrace soil adjacent to the St. Joseph River. Numerous vegetable and small fruit crops have not responded consistently to experimental treatments aimed at alleviating the problem.

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[1] Fertilizer Recommendations for Vegetable and Field Crops in Michigan. Mich. Coop. Ext. Ser. Bull. E-550. 1966.

Crop production statistics[2] show that, in Michigan, the 1968 average production of fresh market and processing tomatoes were 5 and 14.1 T/A, respectively. Although these estimates do not reflect the situation common to Michigan in which fresh market and processing tomatoes are harvested from the same field, they do indicate uneconomic levels of production. Moreover, if the estimated increases in human population are to be provided with an adequate food supply from a declining land area in cultivation, an increase in per acre yields are imperative. Production has become localized and specialized due to marketing advantages, facilities, interest, climate, and knowledge. Therefore within an efficient production area, marginal land might be utilized more economically than distant acreages if factors limiting production are overcome.

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[2] Vegetables. Fresh Market. Processing. 1969. Statistical Reporting Service. United States Department of Agriculture. Washington, D. C.

LITERATURE REVIEW

Potassium in the Soil

Mineral soils, with few exceptions, contain more potassium than any other major element considered necessary for plant growth. Plant roots are in contact with the soil solution containing a K^+ concentration ranging from 0.2 to 2.9 mM. The soil solution is in turn in contact with an ion exchange system in the form of clay particles, which have a mean spherical diameter of 2μ or less. Each particle may contain as many as 8,000 exchangeable cations which are released to the soil water under favorable conditions.

Soil Content of Potassium and Other Ions

Attoe and Truog (1946) stated that K exists in water soluble, exchangeable and difficultly or nonavailable forms in the soil. Boischot and Simon (1958) working with 11 different soil types found that for ordinary cultivated soils and practical application rates, the majority of applied K was fixed. A soil might contain 2 tons per acre of acid-extractable K_2O. They reported that high K applications increased the concentration of soil solution K very little, but built up a reserve which was more easily mobilized than the original soil K. They concluded that there were no K-starved soils; however, there were soils with varying capacities to release reserve K.

Bear and Toth (1948) analysed 20 New Jersey soils and concluded that the ideal soil would contain Ca, Mg and K base saturation levels of 65, 10 and 5 per cent respectively of the cation exchange capacity (CEC). In the compilation of data from various sources, Lucas and Scarseth (1947) reported that the sum of the equivalents of soil bases tend to be constant.

Factors Influencing Soil Potassium

Matthews and Smith (1957) found the rate of nonexchangeable K release was an individual characteristic of a given soil type. The Ontario soils which they studied had a relatively constant K equilibrium level of 1.11 $\pm$ .12% K saturation of the CEC regardless of soil type. Mehlich and Reed (1945) reported high leaching losses of K from sandy loam soils. In contrast, Munson and Nelson (1963) noted that vermiculitic clays were capable of bonding added K in a nonexchangeable form which retarded its movement in soils.

Mehlich and Reed (1945) also showed increased availability of K with high levels of Ca saturation of the soil. However, Allaway (1945) pointed out that in addition to considering the total amount of available ions present in soils, one must consider, also, the nature of the clay minerals.

The exchange capacity of plant roots does not increase significantly above pH 5.5 - 6.0. According to Puustjarui (1959), the corresponding reaction in soils would be considered to be pH 6.0 - 6.5. Therefore, there would be no reason to raise the soil pH above 6.0 - 6.5 in order to facilitate uptake of bases by plants.

Greenhouse studies by MacLean, Lutwich and Bishop (1955) on the K supplying power of Canadian soils showed the exchangeable K content significantly decreased as a result of continuous cropping. Average reductions in nonexchangeable and exchangeable K were 44 and 12 per cent, respectively, of the amount of K removed by the harvested crops. In addition to removing K from the soil, Mortland, Lawton and Uehara (1956) have shown plants to be directly responsible for altering the lattice structure of a soil mineral within the short time of a greenhouse experiment. This not only altered nutrient availability but increased the difficulty of extracting from and testing of soil nutrient levels which would be comparable to the amounts extracted by plants.

Measurement of Potassium in Soils

Jackson (1958) suggested emission spectrophotometry (flame photometer) for measuring soil K because of its speed and flexibility. He advocated the use of N NH_4OAc extractant because the level of exchangeable soil K did not change due to replacement with H or Ca after NH_4OAc treatment. Pratt (1965) stated that exchangeable K, by definition, was that free to exchange with cations of salt solutions added to soil. Since the amount of K exchanged from the soil was dependent upon the nature of the replacing solution, exchangeable K was defined more specifically as K extracted by 1.0 N NH_4OAc minus water-soluble K. The amount of water-soluble K was found to be so small in nonsaline soils that the most universally employed index to K availability has become the total K extracted by 1.0 N NH_4OAc.

Lucas and Scarseth (1947) concluded that a measure of K could not be evaluated adequately unless the Ca and Mg content of the soil were known.

Other relationships of soil K and plants have been studied. After testing many surface and subsoil samples from Ohio and New York, Garman (1957) obtained the highest correlation of K extractable by chemical methods with that by continuous cropping utilizing a continuous leaching method with 0.1 N HCl. A percolation method for measuring the K-supplying power of Canadian soils devised by Matthews and Smith (1957) showed little correlation of nonexchange-K with the original levels of exchangeable K.

Nuttall, Warkentin and Carter (1967) developed a technique to measure "A" values of K with oat plants grown in a greenhouse study. For 11 soils, they found that the total of exchangeable K plus nonexchangeable K accounted for 56% of the variability in K uptake compared to 92% of the variability with "A" values. Since the "A" values were highly correlated with both the exchangeable and nonexchangeable K, they recommended the measurement of both forms of K to be used as availability indexes.

Studies in Texas by Hipp and Thomas (1967) on 4 soils with differing clay types indicated that only solution K, exchangeable K and clay type need to be considered in assessing the availability of soil K.

Movement of Potassium in Soils

After 10 years of surface applications of commercial fertilizers to an Ohio silt loam soil, Chadwick (1943) found no K below a soil depth of 11 inches. The amount and depth of penetration were related to application rates. On the contrary, Paterson and Richer (1966) reported significant increases in exchangeable K to a 24 inch depth. Their investigations were carried out in Pennsylvania Hagerstown silt loam soil permanent fertility plots which had received applications of manure and KCl for 77 years.

Potassium Application to the Soil

Potassium applications were less flexible than P applications because of greater fixation by the soil and greater removal by the crop. In a 16 year study at Purdue, Barber (1969) found that a single application of 500 lb. K/A during a 4 year rotation maintained corn yields. Row applications of K were not necessary with high broadcast rates. He concluded that one liberal K application was relatively effective for 2 years with time and method of application unrestricted.

Greenhouse studies conducted by Grimes and Hanway (1967) showed that 90% of the K added in crop residues was recovered. Potassium added by the crop residues did not differ from fertilizer K in either availability or utilization in plant growth.

Nature of Soil Potassium Fixation

Barshad (1954a) discussed in detail K^+ exchange in micaceous minerals. He stated that vermiculite is a mica in which Mg^{2+} or Ca^{2+} have replaced K^+ causing interlayer expansion and hydration characteristics of the mineral. These interlayer cations are easily replaced through exchange for other cations. When K^+ or NH_4^+ occur in the interlayer position, the crystal lattice becomes nearly identical to that of a potash mica. Replacement of the interlayer Mg^{2+} or Ca^{2+} by either K^+ or NH_4^+ contracts the crystal lattice of vermiculite and further ion exchange is increasingly difficult. He further stated (1954b) that illite becomes vermiculite upon the release of K and then vermiculite is of major importance in K fixation. He concluded that the magnitude of interlayer charge rather than the origin of the charge determined the fixation of NH_4^+ and K^+.

Supplementing the above concept, Barshad and Kishk (1968) reported that a reduction of octahedral ferric to ferrous ions in the crystal lattice of several soil samples containing vermiculite and biotite exhibited a decrease in K fixation even though there was an increase in layer charge. This effect was attributed to an increase in attractive forces between K and oxygen ions of the surface layers, caused by a tilting of the dipole of the octahedral hydroxyl ions.

Page and Ganje (1964) concluded that the formation of mica-like minerals, through the entry of K^+ into interlayer spaces of either vermiculite or other mica weathering products, was the most important reaction responsible for K fixation in California soils. Jackson et al. (1952), DeMumbrum and Hoover (1958) and Rich (1964) all attributed K fixation to entrapment of ions in the interlayers and terminal wedge-shaped zones of vermiculite upon saturation with K and subsequent collapse of the mineral layers from 14 Å to 9.8 Å.

Munson and Nelson (1963) found vermiculitic clays capable of bonding added K in either nonexchangeable or slowly releasable forms which were not extractable by the NH_4OAc method.

A chemical method based on K fixation for the quantitative determination of vermiculite in soils was proposed by Alexiades and Jackson (1965). The procedure includes a series of cation - exchange capacity determinations following the replacement of Ca with $MgCl_2$ and subsequent replacement of Mg with KCl.

Factors Influencing Soil Potassium Fixation

Factors which have been found to influence soil K fixation are type of clay mineral, particle size, pH, wetting and drying, and the nature of associated ions.

Type of clay mineral. Probably the most influential factor in relation to soil K fixation is the mineral composition of the soil. MacLean (1961) found that K fixation increased linearly with increasing clay content from 5 to 35 per cent in Ontario soils. Studies in the Province of Skåne by Wiklander (1960) on 140 samples of top soil and subsoil from 18 different fields showed that the variations in K availability could be largely explained by the soil clay content; particularly by the clay particle size and surface area. Kentucky soils, described by Dowdy and Hutcheson (1963), with clay concentrations ranging from 7.3 to 73.0 per cent showed decreasing K availability as soil content of vermiculite increased from 30 to 50 per cent. DeMumbrum and Hoover (1958) stated that a vermiculitic clay content of 10% significantly influenced the character of the K release curve of a Mississippi soil which they tested. They noted that K fixation and release was reversible only when illite and vermiculite were present in the soils.

Particle size. According to Barshad (1954b), soil particle size does not influence adsorption of either Mg, Ca or Na, but does influence NH_4 and K adsorption. The larger the particle and more perfect their degree of crystallinity, the smaller the adsorption of NH_4 and K found in Sheridan soils of California.

pH. Rich (1964) reported Virginia soils which contained 61% clay with a pH of 4.68. Forty-five per cent of the clay fraction was dioctahedrol vermiculite. He found increased K fixation with treatments which raised the pH and attributed the response to a lack of Ca and Mg reaching the exchange sites.

Fixation of K in California soils containing vermiculite was independent of both soil and clay-solution pH. Page and Ganje (1964) attributed decreased K fixation under acid soil conditions to exchangeable and/or non-exchangeable Al^{3+} rather than H^+.

Wetting and drying. Richards and McLean (1963) extracted clay minerals from soils and studied the influence of wetting and drying cycles on K fixation in various mixtures. They found that natural soil clays fixed much more K on drying than corresponding mixtures of clay minerals. Exchangeable K remained relatively unchanged with rewetting after drying.

MacLean (1962) reported 16 to 71 per cent of added K fixed into a form not extractable with 1N neutral NH_4OAc with alternate wetting and drying treatments of Ontario soils.

Nature of associated ions. Studies in Vermont by Bartlett and Simpson (1967) on the influence of different levels of NH_4 and K supplied to a K-fixing soil showed a definite interaction between ions and timing of application. When K was equilibrated with the soil first, addition of NH_4 had no influence on K availability. Where as, equilibration with NH_4 before addition of K, increased the amount of K extracted. Furthermore, simultaneous addition of NH_4 and K was equally as effective as NH_4 additions prior to K application. They concluded that extremely high application rates of both NH_4 and K fertilizer were needed in order to establish a favorable plant growth environment. Thus higher rates of K would be required if only NO_3 was used as a source of N.

Liming increased K fixation slightly in Ontario soils as shown by MacLean (1962). He found no significant difference between chloride or carbonate salts on K fixation with rates of 0 to 750 pounds K_2O per acre.

Potassium in the Plant

Potassium is the only univalent cation which is generally indispensable for all living organisms. The concentration of K^+ in plants exceeds that of any other cation.

Tomatoes are grown on a large number of differing soil types and under varied environmental conditions. Certain sections of the country and certain soils in these sections produce maximum yields with desirable quality.

Influence of Potassium on Tomatoes

Growth and Yield

Tiedjens and Wall (1938) and Wall (1939) reported two stages of K deficiency in tomato plants. The initial symptoms were stunted growth with intense anthocyanin pigmentation of the upper portion of stems and petioles followed by succulent growth, development of brown peppery leaf spots, and death of lower leaves. In addition, Lawton and Cook (1954) describe bronzing and chlorosis of the mature leaves and poorly developed root systems. They concluded that the critical K content of leaves ranged from 0.75 to 1.50 per cent dry weight.

In a fertility study of KC-146 tomato transplants (grown on a Miami silt loam soil testing 100 lb. K/A), Wilcox (1964) obtained a yield response to the first increment (150 lb./A) of up to 1,000 lb./A applied K. Potassium deficient plants were spike-like in appearance due to slow development of the laterals. Interveinal necrosis did not develop until fruit began to ripen. Many fruits dropped when ripened on K deficient plants due to the formation of a premature abscission layer as previously reported by Wall (1940).

Solution culture experiments by Wall (1940) demonstrated the reversal of initial K deficiency symptoms and restoration of normal growth with subsequent K application. He found that K deficient plants tend to form fruits approaching normal size and weight at the expense of vegetative development.

Halstead and Heeney (1959) found that tomato yield responses to K fertilizer were related to the amount of exchangeable K in sandy loam soils, but not in loam or clay loam soils. Vittum et al. (1962) also obtained yield increases of 12 and 17 per cent with an additional 65 lb./A applied K. Soil test K increased 14 and 48 lb./A due to applied K.

Recently, Humble and Hsiao (1969) demonstrated for the first time a physiological process specifically requiring K^+. They clearly demonstrated a light-activated specific affect of K^+ on the opening of stomata with no specific anion requirement. Potassium appeared to act in the guard cells around stomata by causing them either to expand or contract with corresponding shifts in osmotic pressure.

Composition

Cannell et al. (1963) found that tomato leaf samples contained 4.78% K on a dry wt basis at the beginning of fruit set. Seasonal ranges of 0.62 to 8.38 per cent K in leaf tissue and 2.39 to 5.89 per cent K in fruit tissue were reported by Walsh and Clarke (1945). Average per cent K composition of 2.29 and 4.25 for leaves and fruit, respectively, were determined by Campbell (1953).

Studies by Lewis and Marmony (1939) showed a removal of 490 to 575 lb. K/A with a production level of 10 pounds per plant which was equivalent to 27 T/A with a 4 x 2 foot spacing. Average per cent K composition reported for various plant parts were: stems, 2.50; leaves, 2.69; ripe fruit, 4.58; unripe fruit, 3.66; and roots, 2.08. Another report by Urquijo (1963) showed the total K removal with a 32 T/A tomato crop to be 720 lb./A. Working with tomato petioles, Chapman (1967) considered a K concentration of 1.5% in the fourth petiole (extracted with 2% acetic acid) as the minimum level required for satisfactory production.

Nutrient solution experiments by Arnon and Hoagland (1943) showed the per cent dry weight concentration of K markedly lower in fruit than in leaves of tomato. Defloration of plants in low K solutions delayed the onset of deficiency symptoms and was associated with a higher K content in the young leaves of the deflowered than fruiting plants.

Greenhouse tomato plants are generally maintained at higher nutrient levels than field grown plants. Weekly samples of the 5th leaf analyzed by MacLean, McLaughlin and Brown (1968) showed minimal nutrient concentrations occurring between the 3rd and 6th, and the 12th and 15th weeks of development corresponding to rapid vegetative growth and heavy fruit loads respectively. Average K concentration ranged from 4.02 to 6.16 per cent throughout the total growing period. Heavy applications of nutrients were less beneficial than frequent small applications due to possible salt accumulation and ion antagonism.

Generally, by the time tissue analysis showed evidence of either minimum levels or deficiency symptoms, it was too late for fertilizer applications to benefit plant demands.

With an application of 347 lb. K/A to greenhouse tomatoes, Ward (1967) found that total absorption for the 101.6 T/A yield of fruit and foliage was 510 lb. K/A. The fruit and foliage accounted for 376 and 134 lb. K/A, respectively. He reported average dry weight composition of 3.25 to 6.38 and 3.40 per cent K for foliage and fruit respectively. Generally, Owen (1949) agreed with the above results. He calculated that a reasonable greenhouse crop including fruit and foliage, removed 550 lb. K/A.

Interaction With Other Ions

Janssen and Bartholomew (1929) found total and soluble N much higher in K deficient tomato plants and conversely, a high K content correlated with a low N content.

The development of tomato stem lesions were noted when NH_4^+ were applied in excess of plant needs. Barker, Maynard and Lachman (1967) attributed lesion formation to excess NH_4^+ which caused soil K entrapment resulting in K deficient plants. Added K markedly reduced the plant content of NH_4^+. They also stated that added Mg released soil K in the presence of excess NH_4^+ and reduced lesion development.

Maynard, Barker and Lachman (1968) discussed the NH_4:K ratio as a good measure of NH_4 toxicity and utilization involved in the severity of tomato stem lesions. They speculated that an unfavorably high NH_4:K ratio could result in substitution of NH_4^+ for K^+ in plant metabolism, thereby encouraging proteolysis and subsequent lesion formation.

Walsh and Clarke (1945) demonstrated that Mg deficiency may result from an excess accumulation of K in tomato leaves. Concentrations of 6 to 8 per cent K resulted in depressed growth and yield accompanied by typical Mg deficiency symptoms. They reported a critical concentration of 0.3% for Mg. Calcium content was depressed in general, but no deleterious effects were discussed. In addition, broadcast applications of more than 1,000 lb./A K_2SO_4 followed by top-dressings of more than 125 lb./A depressed uptake and induced Mg deficiency in tomato transplant experiments conducted by Clark (1946).

Wall (1940) stated that the ion-absorbing capacity of roots from K deficient tomato plants was not diminished, since the uptake of other ions actually increased.

Kirkby and Mengel (1967) found a very close balance between total cations and total anions plus organic acids irrespective of the type of tomato tissue sampled. According to Noggle (1966), the total concentration of inorganic cations exceeded the total concentration of inorganic anions equalling the concentration of organic anions. He found that reducing the organic anion concentration in plants reduced yield. Chloride treated plants had lower organic anions, therefore, increasing the Cl content of the soil reduced plant yields before the salt concentration became sufficiently high to cause osmotic stress.

Quality

In a fertility study of KC-146 tomato transplants (grown on a Miami silt loam soil testing 100 lb. K/A), Wilcox (1964) found early fruit size unchanged with treatments up to 1,000 lb. K/A. The response of No. 1 and No. 2 grade yield was greater than that of total yield. As the season progressed, the quality from deficient plants deteriorated to 26% cull fruit. With an additional 65 lb. applied K/A, Vittum et al. (1962) reported an increase in total acidity, soluble solids and total solids without pH changes in mature canning fruit. Juice had a more intense red color as indicated by a higher Hunter a:b ratio. Similar results were obtained by Hester (1951) with increasing K in mixed fertilizers; and by Davies and Winsor (1967) in greenhouse studies.

The results of Davies (1964) show that the concentrations of the two principal organic acids (citric and malic) in whole ripe tomato fruit were increased significantly with high levels of K in the soil. Pronounced changes in titratable acidity were primarily associated with changes in citric acid content.

On a silt loam soil of unknown nutrient status, Kattan, Stark and Kramer (1957) obtained no beneficial effects from applications of 100 and 200 lb. K/A on processing tomatoes. They demonstrated a nonsignificant influence of "luxury" K consumption on fruit firmness, yield, per cent waste, per cent trimming loss, color, pH, viscosity, per cent soluble solids and total solids.

Metabolism

In a review of the pertinent literature, Evans and Sorger (1966) found 41 enzymes strikingly stimulated by K^+. A mechanism involving cation-induced conformation changes in enzymes (proteins) could account for most of the observations. Amino acid accumulation and reduced protein content were two of the consistent symptoms of K deficiency in higher plants. Potassium was singled out as the only univalent cation in nature available in sufficient quantity, and with the required chemical properties, to satisfy the requirements of the numerous univalent cation-activated enzymes. They proposed that the capacity of K^+ to function as a univalent cation activator for a wide variety of important enzymes offered a logical and feasible explanation for its requirement in the growth processes of higher plants.

McCollum, Hageman and Tyner (1960) demonstrated that pyruvic kinase has a specific K requirement. They concluded that activation of pyruvic kinase by K^+ was a general phenomenon found in seeds of higher plants including tomatoes. Furthermore, ^{14}C studies by Jones

(1966) provided evidence that pyruvate, an intermediate in the pathway of lycopene synthesis, was not readily synthesized in K deficient tomato leaves.

Nitsos and Evans (1966) found that under conditions of adequate K the activity of pyruvic kinase was not influenced by the presence of other univalent cations. In addition, they obtained evidence that K^+ function more effectively than other univalent cations for the inductive synthesis of nitrate reductase.

The role of K in protein synthesis was directly related to nitrate reductase activity by Nightingale (1937). During early deficient growth stages, carbohydrate and nitrate accumulations were associated with the plants' inability to synthesize organic N from stored nitrate. Late stages of K deficiency were characterized by carbohydrate depletion with a proteolytic response yielding amino acids and related compounds. When K was supplied, nitrite and proteins appeared with subsequent rapid utilization and decrease in concentrations of nitrate and carbohydrates.

Regarding other K functions, Hartt (1934) concluded the synthesis and translocation of proteins were diminished by K starvation. He also reported greater amylase activity in deficient plants.

Jones (1961) suggested that K functions in two groups of metabolic processes: it functions as an essential micronutrient in vital phases of metabolism which are satisfied with 0.5 meg./1; and above this level, it stimulates less essential reactions which result in increased growth.

Nutritional Disorders

Confusion has resulted from the various terms used in reporting ripening disorders of tomatoes. Throughout the literature, such terms as waxy patch, green patch, green back, piebald, internal browning, blotchy ripening, cloud, gray wall and vascular browning can be found. In many cases, adequate descriptions were not available or reference has been made to more than one abnormality with no definite treatment controls.

Bewley and White (1926) first used the term "blotchy ripening" and reported that tomato fruits displayed an uneven ripening which occasionally was accompanied by necrosis of the vascular bundles and a breakdown of the adjacent tissue with the formation of canals. They concluded that the disorder resulted from malnutrition with respect to potash.

Jones and Alexander (1956) obtained increased numbers of blotchy fruits as the K level decreased. They reported variable and inconclusive results with Tobacco Mosaic Virus (TMV) innoculation.

Two distinct disorders were recognized by Murakishi (1960). He attributed internal browning to lack of TMV resistance and indicated that gray wall could be induced in TMV-free plants by low light intensity or shading.

Nutrient solution culture of Rutgers tomato transplants by Cotter (1961) showed no treatment effects on internal browning. Blotchy ripening increased with high levels of N and decreased with high levels of K.

There are several reports of nutritional effects on blotchy ripening of greenhouse tomato fruit. Data collected by Owen (1949) for eight consecutive production years, showed ranges of 0 to 6.36 and 8.92 to 45.61 per cent blotchy fruit with and without applied K respectively. Clay and Hudson (1960) noted a reduction in blotchy ripening with increasing levels of soil salinity induced by additions of K_2SO_4 and $MgSO_4$ mixtures up to 27 T/A. Up to 12 times as many severely blothcy fruits in low compared to high K plots were obtained by Hobson (1963).

Ells (1961) concluded that water relations were not a major cause of blotchy ripening because treatments were not effective in inducing the disorder. He did not consider TMV to be more than a contributing factor, since three-fourths of the blotchy fruit and one-third of the nonblotchy fruit gave a positive assay for the presence of the virus. Normal and blotchy fruit contained 4.2 and 2.5 per cent K respectively, with blothcy fruit lower in soluble solids.

The incidence of "cloud" reported by Kidson and Stanton (1963) was decreased not only by KCl but also by N fertilizers and by $CaCl_2$. Treatments combining additional N and K were superior to separate applications.

Collin and Cline (1966) recognized K affects on fruit color, however, they concluded from nutrient culture studies that blotchy ripening was not caused by K deficiency but rather by a replacement of K in the nutrient solution with Ca or Na. They based their conclusion on the finding that blotchy ripening was not increased by replacing part of the K with NH_4 while replacement with Ca or Na did increase the disorder. Various other descriptive disorders were attributed to low K, light, injury or interactions.

Probably the best attempts to decrease the existing confusion in relation to blotchy ripening were presented in a series of papers by Minges and Sadik (1964), Sadik and Minges (1966) and Ozbun, Boutonnet, Sadik and Minges (1967). They precisely described external and internal symptoms of what they consider to be blotchy ripening of tomato fruit. Their investigations showed that the development of white tissue was the basic abnormality associated with irregular coloration of the ripening fruit. First symptoms were observed microscopically in immature green fruit about 25 mm in diameter. The main structural changes which they reported during fruit development were lignification and accumulation of starch. Greenhouse tests with sand cultures proved that white tissue could be induced by low levels of K.

Recently, Trudel, Martin and Ozbun (1969) reported that K nutrition was critical in the development of normal pigmentation of tomatoes. Lycopene concentrations were found to increase as the K level increased. However, beta-carotene, a yellow pigment, decreased as the concentration of K increased. They concluded that K may be involved in fruit ripening disorders such as blotchy ripening.

MATERIALS AND METHODS

Field Plot Description

In October, 1966, 24 plots 25 x 40 feet each were laid out on a river bottom alluvial soil adjacent to the St. Joseph River on the Sodus Horticultural Experiment Station in Berrien County, Michigan. The land in these original plots tested 1 to 14 pounds P and 70 to 126 pounds K per acre. Soil pH ranged from 6.2 to 7.1.

1967 Treatments

Broadcast applications of 0, 33, 110, 220, 350 and 500 lb. K/A (equivalent to 0, 66, 220, 440, 700 and 1,000 lb. KCl/A) and 310 lb. P/A were disced in prior to shallow plowing in October, 1966. The six broadcast treatments were arranged randomly in four replicates with the objective of establishing a broad range in soil test K levels for cropping in 1967. All plots received 60 lb./A of pre-plant N as NH_4NO_3.

Direct seeded and transplant Heinz 1350 tomatoes were planted in rows 40 feet long within each main plot on May 18 and May 31, 1967, respectively. A Planet Jr. was used to seed rows 2½ feet apart, and the seedlings were subsequently thinned to an average spacing of nine inches within rows. Transplants were set three feet apart within five foot rows with a mechanical transplanter.

Two rows each of direct seeded and transplanted tomatoes were divided into 20 foot sections, resulting in eight single row subplots. Subplot treatments of 0, 30, 60 and 90 lb./A of N as NH_4NO_3 were randomly applied to each type of planting when the first fruit reached one-inch in diameter.

Guard rows were maintained between main plots and between subplots to minimize adjacent fertility and spacing effects.

Fruits from the transplanted plots were harvested from August 1 to September 19 and graded according to Michigan fresh market tomato standards. At each harvest the fruits were belt sized into three marketable groups (salad - less than 2 1/8", crate - 2 1/8" to 2 5/8", and carton - greater than 2 5/8" in diameter). Fruits from the direct seeded plots were harvested on September 22 and graded according to Michigan processing tomato market standards. In addition, the direct seeded plants were stripped of all fruit on October 10 to determine total production.

1968 Treatments

The same 25 x 40 foot main plots used in 1967 were employed in 1968. Based on the 1967 results, early spring broadcast applications of 0 to 1742 lb. K/A (equivalent to 3484 lb. KCl/A) were disced in prior to cropping to achieve six groups of soil test K levels averaging from less than

100 to 500 lb./A. Because of the previous year's results and the various calculated application rates, four main plots of each soil test group were randomly located in the field. Nitrogen and P broadcast applications of 100 and 310 lb./A respectively were disced in prior to planting.

Each main plot contained five 40 foot rows of Campbell 1327 transplants spaced 2½ feet apart in 4 foot rows with single guard rows on each plot border. The plants were grown in three-inch peat pots and set in the field by hand on May 22. Each of the 5 main-plot rows were divided into 20 foot sections resulting in 10 single-row subplots. A 3 x 3 factorial of sidedress K (0, 73, and 146 lb./A) and Ca (0, 31, and 62 lb./A), plus a treatment combination of the highest rates of K and Ca with 90 lb. Mg/A, were randomly applied to the subplots. The specified rates of sidedress treatment were applied twice during the growing season on July 2 and 24. The materials used were KNO_3, $Ca(NO_3)_2$ and $MgSO_4$. All applications were balanced with NH_4NO_3 to provide a total of 100 lb./A of supplemental N.

Fruits were harvested from July 31 to September 6 and graded according to Michigan fresh market tomato standards. At each harvest the fruits were belt sized into three marketable groups of No. 1 fruit (salad - less than 2 1/8", crate - 2 1/8" to 2 5/8", and carton - greater than 2 5/8" in diameter) and one marketable group of No. 2 fruit which included all fruits greater than 2 3/8" diameter.

Processing yields were determined by combining No. 1 and No. 2 fruit of all sizes.

A second group of 20 x 25 foot plots, with similar soil characteristics as previously mentioned, received 750 pounds 13-39-0 per acre prior to discing and transplanting with Campbell 1327. Treatments included four levels of main plot sidedress K and five levels of subplot foliar applied K randomized in four complete blocks. Muriate of potash was applied on July 2 to provide sidedress levels of 0, 100, 200, and 400 lb. K/A. Five weekly foliar applications of KNO_3 at 0, 3, 6, 9, and 12 lb. K/A per 100 gallons water commenced on July 19 and season totals accumulated to 0, 15, 30, 45 and 60 lb./A, respectively. Fruits were harvested from August 2 to September 3 and graded according to Michigan fresh market tomato standards.

Soil Sampling Procedures

Soil samples were collected prior to treatment in the fall of 1966, prior to cropping in the spring of 1967, after cropping in the fall of 1967, and after cropping in the fall of 1968. The samples consisted of nine 6-inch soil cores from random areas in each 25 x 40 foot main fertility plot. Soils adjacent to crop rows were not sampled in order to avoid nutrient concentrations in sidedress areas.

Plant Sampling Techniques

Petiole samples selected for nutrient analyses were obtained from the most recent fully developed leaves as suggested by Lawton and Cook (1954), Tyler and Lorenz (1962), and Lucas and Wittwer (1963). In most instances this was the fourth leaf from the growing point. Petiole samples were collected from all plots at three intervals during the growing season beginning in late June with first fruit set and ending in August with full fruit load.

The youngest fully developed leaves with intact petioles were collected for respiration analyses. Leaflets from similar tissue were sampled for chlorophyll determinations. Only tissue from main plot broadcast treatments were utilized for the determinations.

Samples of ripe marketable fruit for quality measurements were randomly selected from each plot during the last harvest grading process.

After the harvest season, plants from the main plot treatments were dug from the soil and the intact roots were removed, washed carefully, and dried for nutrient analyses.

Soil Analysis

Soil samples were submitted to the Michigan State University Department of Soil Science - Soil Testing Laboratory for analysis. Their procedures according to Doll (1967), involve a 1:2 soil-water mixture for pH measurements and a 1.0 N ammonium acetate (1:8 soil-solution ratio) extraction for potassium, calcium and magnesium.

Plant Analysis

Nutrient Composition

Petiole, root and fruit samples were dried in a forced air oven at 90 C and ground in a Wiley mill to pass through a 40 mesh screen. After ashing in a muffle furnace at 525 C for eight hours; phosphorus, calcium, magnesium, sodium, manganese, iron, copper, boron, zinc and aluminum were determined spectrographically. Potassium was determined by flame photometry from water extracts.

Respiration

Respiration was measured by use of an oxygen-carbon dioxide gas analyzing respirometer[3] on 100 grams of fresh tissue. All gas volumes were adjusted to standard temperature and pressure (STP).

Chlorophyll

Chlorophyll of fresh tomato leaves was determined according to the method of MacKinny (1941). One hundred milligrams of tissue were crushed with a glass homogenizer

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[3] Automatic Photosynthetic Respiration Integrating Laboratory, Horticulture Department, Michigan State University.

and, after centrifuging twice, brought up to a volume of 50 ml with 2% acetone. Absorbance was recorded at wavelengths of 645 and 663 with a Baush and Lomb Spectronic 20. Concentrations were calculated from formulas reported by Arnon (1949).

Color

Fruit color was measured by reflectance, using a Hunter Color and Color Difference Meter, Model D25[4]. Samples of fruit were run through a Squeezo Strainer[5] to remove the skins and seeds prior to color determinations.

Soluble Solids

Fruit samples were homogenized in a Waring blender for 5 minutes prior to soluble solids determination on an Abbe refractometer, Model 3L.

Titratable Acidity and pH

Tomato fruits were homogenized for 5 minutes in a Waring blender, strained through a double layer of cheesecloth, and a 10 ml aliquot of the resulting slurry was diluted to 100 ml with distilled water. Titratable acidity as citric acid was determined by titrating to pH 8.0 with 0.1 N NaOH. Prior to dilution, a portion of the slurry was used to determine pH on a Beckman pH meter.

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[4] Manufactured by Hunter Associates Laboratory, Fairfax, Va.

[5] Manufactured by Berarducci Bros. Manufacturing Co., Inc., McKeesport, Penn.

Statistical Analysis

Data obtained from the completely random, randomized complete block, and split plot designs were subjected to analysis of variance procedures outlined by Steel and Torrie (1960). The regression analysis methods of Draper and Smith (1966) were utilized to determine parameter-treatment relationships when significant differences existed. Methods used in economic analysis were described by Hulett (1968) and Doll, Heady and Pesek (1958).

RESULTS AND DISCUSSION - 1967 DATA

Soil Analysis

Average spring soil tests following six levels of fall broadcast K application are presented in Table 1. Soil contents of available Ca and Mg were not altered by K treatments. Although soil K increased with increasing levels of applied K, the soil test range obtained was far below the expected 100 to 500 lb./A.

Table 1. Spring soil test K, Ca and Mg following fall applications of six levels of K beginning with soil test K levels of 77 to 126 pounds per acre.

Lb./A K Applied	1967 Spring Soil Test - Lb./A[a] (pp2m)		
	Potassium	Calcium	Magnesium
0	104	5220	402
33	112	5374	490
110	125	5411	438
220	124	5178	446
350	131	4831	359
500	180	5062	428

[a] Average of 4 replicates. Nine 6-inch soil cores per plot.

Figure 1 shows the relationship of lb. K/A applied (K_{A66}) and subsequent spring soil test K levels. The increase in available soil test K was related consistently to the square of applied K and ranged from 0.4 to 30.3 lb./A. Most sandy loam soils of Michigan show 30 to 50% recovery of applied K. In the Genesee sandy clay loam

Figure 1. Effect of six levels of fall broadcast K application on subsequent spring soil test K of a sandy clay loam soil.

$$K_{S67} = 109.99 + .00026684\ K_{A66}^{2}$$

$$R^2 = .783^{**} \quad sy.x = 25$$

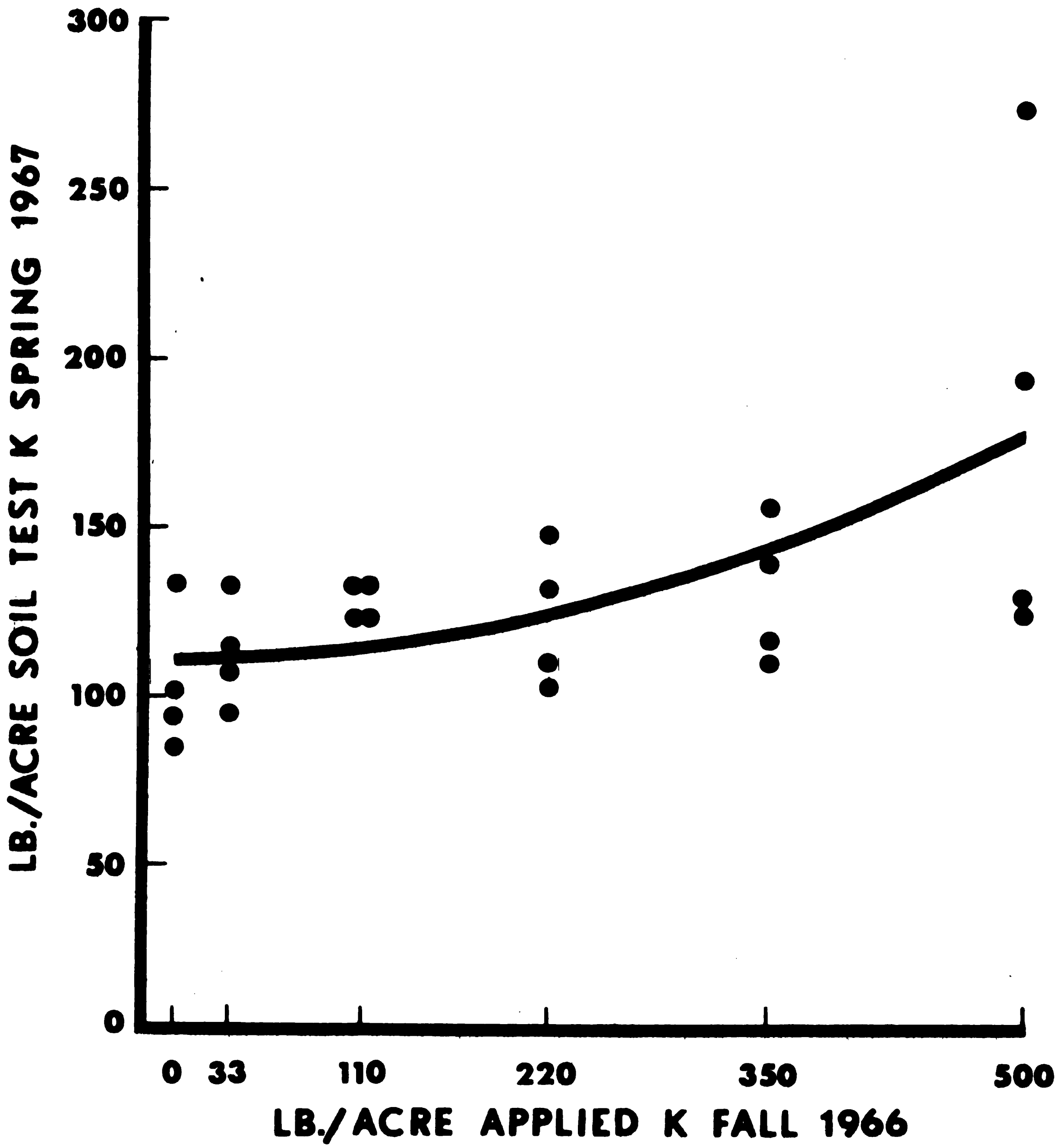
300
250
200
150
100
50
0
LB./ACRE SOIL TEST K SPRING 1967
0
33
110
220
350
500
LB./ACRE APPLIED K FALL 1966

Figure 1

soil used in this study fixation of added K linearly decreased with increasing levels of applied K as shown in Equation 1.

$$\% \text{ Fixation} = 100.027 - 0.028\ K_{A66} \qquad r = .998^{**} \quad sy.x = 2.1 \qquad (1)$$

Fixation here averages 92.1% of applied K.

Lucas (1968a) reported that laboratory fixation studies on soil samples from the experimental area substantiated field results. Potassium fixation averaged 93.9% with a number of alternate wetting and drying time periods and K additions of 250 to 1,000 pp2m. He classified the soil as a Genesee sandy clay loam.

Veatch (1941) defined the Genesee soil series as alluvial soils, high in fertility, moist at shallow depths, and variable in texture and depth. He described it as a mixture of sand, silt and clay bottom land, widely distributed along large streams but with small aggregate acreages. His description adequately characterizes the bottom land soil on the Sodus Horticultural Experiment Station. The Genesee soil series has been categorized as 72% first class, 26% second class, and 2% third class corresponding to profitable, marginal, and sub-marginal land respectively for agricultural use and value.

Lucas (1968b) noted that mechanical analysis of soil sampled from the experimental area showed 31% clay, 18% silt and 51% sand. Sixty per cent of the clay fraction was vermiculite which would represent about 19% of the total soil constituents.

The presence of 19% vermiculitic clay in the soil accounts for the high K fixation and lack of substantial increases in soil test K with up to 500 lb./A applied K. This problem is not limited to either the Sodus Horticultural Experiment Station or Michigan soils. Sheridan soil in California was reported to contain vermiculite (Page and Ganje, 1964) and had the capacity to fix up to 90 meq. K per 100 grams of soil (Barshad, 1954b). Similar fixation capacities have been reported for some Mississippi soils (DeMumbrum and Hoover, 1958), in which vermiculite contents of 10% significantly influenced the potassium release curve. Soils in Virginia have been found (Rich, 1964) to contain up to 60% clay with as much as 45% vermiculite. Soils ranging in clay content from 7 to 73 per cent with up to 50% of the clay as vermiculite were reported in Kentucky (Dowdy and Hutcheson, 1963). In all cases, high K fixation was attributed to the presence of vermiculite.

Production from Tomato Transplants

The influence of broadcast K applications on the No. 1 grade fresh market packs from H1350 tomato transplants is shown in Table 2. Increasing levels of applied K did not alter significantly the early production of either salad, crate or carton tomatoes. After the first

2 weeks of harvest, yields of crate and carton size tomatoes significantly increased with increasing levels of applied K, but the yield of small salad tomatoes remained relatively constant. At the end of the harvest season (September 22), 82 to 118 cwt/A of green fruit, representing an average 19% of the total yield, were stripped from the plants. Based on the measurements of early production and immature fruit at the end of harvest, no significant maturity differences could be attributed to potassium fertilization.

Table 2. Influence of six levels of K application on No. 1 grade fresh market packs of transplanted H1350 tomatoes grown on a Genesee sandy clay loam soil.

Lb./A K Applied	Cwt Per Acre[a]					
	8/1 to 8/18 Harvest			8/19 to 9/22 Harvest		
	Salad	crate	Carton	Salad	Crate	Carton
0	8.03	40.05	20.58	15.54	29.78	6.51
33	8.98	38.03	21.75	21.67	41.52	13.56
110	6.67	33.90	29.40	15.95	50.69	27.82
220	13.10	49.20	23.00	25.10	62.43	18.43
350	9.42	41.22	33.27	22.84	78.90	40.51
500	9.53	48.27	35.04	32.70	130.71	68.69
Sig.[b]	n.s.	n.s.	n.s.	n.s.	**	**
$s_{\bar{x}}$	2.38	5.64	5.42	5.46	12.62	9.01

[a] Average of 16 plots. Yield belt sized into salad - less than 2 1/8", crate - 2 1/8" to 2 5/8", and carton - greater than 2 5/8" diameter.

[b] n.s. = no significant difference. ** = significant at .01 level. Based on analysis of variance.

Total marketable and No. 1 cwt/A yields linearly increased with increasing K applications up to 500 lb./A as summarized in Equations 2 and 3.

$$\text{Mkt. } Y = 167.41 + 0.4282\ K_{A66} \qquad r = .980^{**} \quad sy.x = 31.7 \tag{2}$$

$$\text{No. 1 } Y = 120.9 + 0.3682\ K_{A66} \qquad r = .976^{**} \quad sy.x = 27.3 \tag{3}$$

For each 100 lb./A increment of broadcast K applied (K_{A66}), marketable and No. 1 tomato yields increased 4282 and 3682 pounds per acre, respectively.

As shown in Table 3, increases in crate, carton, No. 1, and marketable fruit of approximately 13, 12, 26, and 26 per cent, respectively, were obtained with 500 lb./A applied K. The proportion of cull fruit decreased from 48 to 22 per cent. Most of the cull fruit were those showing symptoms of blotchy ripening. Thus, the yield data demonstrate that increased production was a result of increased fruit size and improved color-quality directly related to increased K fertilizer.

Although a slight trend toward increased early production was evident, the increase in midseason and late fruit size and quality indicates the importance of providing adequate available K during the latter part of the season. Working with a Crosby silt loam soil, which does not have a high K fixation capacity, Wilcox (1964) found

Table 3. Effect of six levels of K application on the distribution of total ripe fruit harvested in various yield categories from transplanted tomatoes grown on a Genesee sandy clay loam soil.

Lb./A K Applied	Cwt/A Ripe Fruit	Per Cent of Total Ripe Fruit[a]				
		Crate	Carton	No. 1	Mkt.	Cull
0	323.32	21.7	8.0	37.3	52.0	48.0
33	340.26	23.4	10.2	42.9	56.0	44.0
110	381.56	22.8	14.4	43.6	59.4	40.6
220	349.02	31.8	11.5	54.4	68.0	32.0
350	455.01	27.4	15.3	50.4	66.3	33.7
500	514.80	35.0	20.1	63.2	77.9	22.1
Sig.[b]	**	**	**	**	**	**
$s_{\bar{x}}$	37.52	2.9	2.1	4.3	4.5	4.5

[a] Average of 16 plots. Yield belt sized into salad - less than 2 1/8", crate - 2 1/8" to 2 5/8", and carton - greater than 2 5/8" diameter.

[b] ** = significant at .01 level. Based on analysis of variance.

no consistent effects of K on early fruit size; however, quality progressively deteriorated throughout the season with the production of 26% cull fruit where no K was added.

An average 20.6 tons of marketable fruit per acre with 22% of the total yield grading cull fruit obtained with 500 lb. of applied K/A did not reflect the typical yield and quality of the H1350 variety. Under normal cultural conditions in a variety trial on an Oshtemo loamy sand, Miller (1967) reported an average production of 24.5 T/A marketable fruit with 6% cull fruit from transplanted H1350 tomatoes in a 3 x 5 foot spacing. In this study, the linear responses obtained when up to 500 lb. of K were applied are indicative of even higher K requirements on this Genesee sandy clay loam soil to realize maximum production.

Sidedress N treatments of 0, 30, 60, and 90 lb./A did not consistently affect production from transplanted tomatoes. There was a trend toward decreased production of early harvest carton size fruit and increased production of cull fruit with increasing N. However, these trends did not persist throughout the harvest season. There was no evidence of interaction of N and K treatments. The lack of either response or interaction indicated that either 60 lb. of preplant N per acre was sufficient, or that the N requirements were reduced because of K deficiency, even though up to 500 lb. K/A had been applied. The latter may be reasonable because vermiculite has been reported as capable of fixing NH_4^+ (Barshad 1954a) and, if a N need existed, the sidedress treatments should have sufficed.

Nutrient Composition of Transplant Tomatoes

Nutrient composition values, excluding K, of transplant tomato petioles sampled throughout the growing season from plots receiving six levels of broadcast K are presented in Table 4. June petiole concentration of P and Al were increased, Fe and Cu varied little from their means, and all other elements decreased with increasing K applications. July sample values of P increased, Mg and Mn decreased, and all other nutrient values were unchanged

Table 4. Nutrient composition (dry wt basis) of petioles from transplanted tomatoes receiving six levels of applied K on a Genesee sandy clay loam soil.

Sample Time	Lb./A K Applied	Per Cent[a]				ppm[a]					
		P	Na	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
June 21	0	.59	.26	3.64	1.56	120	253	51	36	57	288
	33	.60	.29	3.64	1.51	128	335	69	36	60	387
	110	.64	.23	3.44	1.34	116	275	54	35	53	311
	220	.60	.20	3.37	1.31	108	246	51	35	53	303
	350	.66	.16	3.12	1.14	103	251	45	33	46	318
	500	.68	.13	3.12	1.08	101	264	52	33	45	366
	sy.x	.03	.03	0.14	0.06	5	23	7	1	3	29
July 12	0	.17	.26	3.26	1.91	259	163	21	29	47	301
	33	.18	.26	3.08	1.74	240	139	16	28	41	261
	110	.20	.28	3.18	1.60	232	127	16	28	41	244
	220	.29	.29	3.10	1.52	256	146	19	28	48	258
	350	.21	.27	3.33	1.58	239	143	15	28	44	252
	500	.23	.27	3.10	1.31	224	138	17	29	42	267
	sy.x	.03	.08	0.13	0.09	12	12	1	1	3	14
August 3	0	.20	.31	4.25	2.39	362	228	24	29	62	387
	33	.15	.27	3.67	2.27	351	172	18	26	57	320
	110	.16	.33	4.12	2.18	332	150	17	26	61	301
	220	.14	.29	4.47	2.26	348	169	20	26	67	341
	350	.14	.29	4.47	2.17	350	188	21	25	70	345
	500	.14	.29	4.52	2.02	348	164	18	27	68	311
	sy.x	.01	.02	0.17	0.08	18	18	2	1	4	20

[a] Average of 3 replicates. Petioles from first fully developed leaves.

by treatment. In August, K treatments increased tissue content of Ca, decreased P, Mg, Fe and Al but did not affect Na, Mn, Cu, B or Zn.

The only significant treatment effects on nutrient composition throughout the season were the reductions of tissue Na, Mg, and Mn in June and a reduction in Mg in July. Composition values obtained compare favorably with the desired ranges in concentration suggested by Lucas and Wittwer (1963) and MacLean et al. (1968) for greenhouse grown tomatoes. The reduction in Mg composition did not approach the critical level of 0.3% reported by Walsh and Clarke (1945) in field experiments. The treatment differences and changes in plant nutrient status throughout the season may be attributed to dilution with increased plant growth, mobilization to new vegetative growing areas, and/or translocation to developing fruit.

Figure 2 shows the relationships of applied K and % K in tomato petioles sampled early and midway through the growing season from the transplanted crop. During first fruit set (June), petiole K ranged from 2.1 to 7.2 per cent and was related significantly to the square of applied K (K_{A66}^2). Petiole K composition ranged from 0.4 to 5.7 per cent during midseason (July) sampling and was related significantly to the cube of applied K (K_{A66}^3).

Table 5 shows the correlation coefficients between applied K, petiole K concentration, and yields of No. 1 and marketable tomatoes. Plant tissue K was more closely

Figure 2. Effect of applied K on K composition of transplant tomato petioles sampled during first fruit set and midway in the growing season.

$$\text{June } K = 3.407 + 0.0000137\, K_{A66}^{2}$$

$$R^2 = .707^{**} \quad sy.x = 0.84$$

$$\text{July } K = 0.738 + 0.00000004\, K_{A66}^{3}$$

$$R^2 = .937^{**} \quad sy.x = 0.44$$

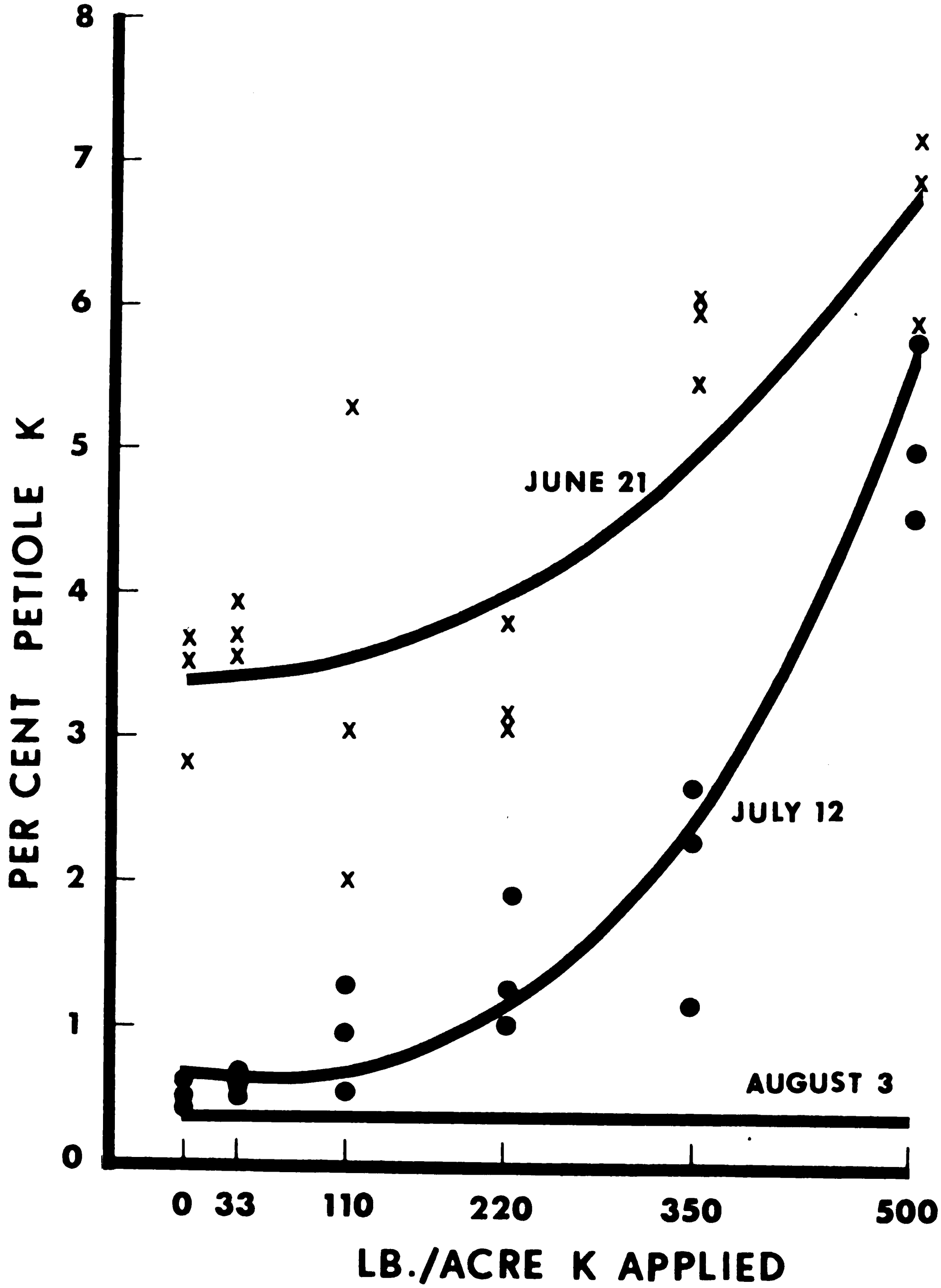
8
7
6
5
4
3
2
1
0
PER CENT PETIOLE K
JUNE 21
JULY 12
AUGUST 3
0
33
110
220
350
500
LB./ACRE K APPLIED

Figure 2

related to applied K and to yields when expressed as the ratio of K:Ca + Mg in meq./100 grams than as per cent on a dry weight basis. July composition data were more closely associated with yield results than were early season composition data in June.

Table 5. Correlation coefficients relating applied K (K_{A66}), petiole K composition, and 1967 yields of No. 1 and marketable tomatoes.

	Ratio meq./100 g K:Ca + Mg		Per Cent Petiole Potassium		
	June	July	June	July	K_{A66}
K_{A66}	.930**	.915**	.806**	.906**	
No. 1	.920**	.975**	.594**	.828**	.976**
Mkt.	.943**	.965**	.663**	.845**	.980**

Although all the correlation coefficients in Table 5 are highly significant, the factor most consistently accounting for the variation in No. 1 and marketable yields was the level of broadcast K applied (K_{A66}) prior to planting (r = .976 and r = .980).

Petiole K composition at the time of color development of first fruits on August 3 was not related to applied K and averaged only 0.36 $\pm$ 0.11% for all treatments. The potassium composition data demonstrates why early transplant tomato yields were not related to treatment and clearly illustrates the high late season potassium requirement of tomato plants. Although June and July petiole

K concentrations of 7.2 and 5.2 per cent, respectively, were obtained with 500 lb. K/A, the high demands and transport of K to developing fruit depleted the plant tissue supply of K to critically deficient levels. These results emphasize that early tissue analysis may fail to predict actual needs as the development of the crop load later in the season greatly increased the demand for K. Consequently, maximum total yields and quality, particularly in terms of color, were not achieved.

The results were consistent with the report of Tiessen and Carolus (1963) which indicated that K did not critically affect early tomato growth and probably was seldom limiting. Even under conditions of high fixation, enough K was available to maintain an average 3.35% K in tomato petioles from plots receiving no treatment. By midseason, only those plots receiving 350 to 500 lb./A K maintained plant petiole K above 1.5% which was considered by Chapman (1967) to be the lowest sufficient level in tomato plants.

Production From Direct Seeded Tomatoes

Yield results from direct seeded H1350 tomatoes grown on the Genesee sandy clay loam soil with six levels of applied K are shown in Table 6. In contrast to the results obtained with transplants, early yields of direct seeded tomatoes for processing were influenced by treatment.

Table 6. Effect of six levels of K application on the yield of direct seeded tomatoes grown on a Genesee sandy clay loam soil.

Lb./A K Applied	Harvest 1[a] Tons/A Processing Grade			Total Tons/A Harvest 2[b]	Total Tons/A
	No. 1	No. 2	Cull		
0	5.00	3.16	1.90	12.83	22.89
33	5.88	3.41	1.74	14.11	25.14
110	7.34	4.57	2.43	13.44	27.77
220	7.83	3.96	1.63	12.68	26.11
350	10.06	3.91	1.83	12.21	28.02
500	11.55	2.82	1.38	15.48	31.24
Sig.[c]	**	n.s.	n.s.	n.s.	**
$s_{\bar{x}}$	1.07	0.79	0.45	1.29	1.75

[a] Harvest 1 on 9/22/'67.

[b] Harvest 2 on 10/10/'67.

[c] n.s. = no significant difference. ** = significant at .01 level. Based on analysis of variance.

Total yields of ripe fruit from a single harvest on September 22 linearly increased from 10.1 to 15.8 T/A with up to 500 lb./A K applied. Tons/acre of No. 1 fruit significantly increased with increasing applied K. As shown by Equation 4, the yield of No. 1 tomatoes increased an average 1.263 T/A with each 100 lb./A increment of K applied.

$$\text{No. 1 } Y = 5.388 + 0.01263\ K_{A66} \qquad r = .879^{**} \quad sy.x = 1.27 \tag{4}$$

Although the actual yields of No. 2 and cull grade fruit in the single harvest were not significantly changed by treatment, the distribution of fruit between processing grades was substantially altered. With increasing levels of K, No. 1 fruit increased from 49.9 to 73.9 per cent, No. 2 fruit decreased from 31.3 to 17.5 per cent, and cull fruit decreased from 18.8 to 8.6 per cent, reflecting again the important contribution of K to improved tomato quality. Marketable fruit yield increased an average 1.19 T/A with each 100 lb./A increment of K applied as shown by Equation 5

$$\text{Mkt. } Y = 9.186 + 0.0119\ K_{A66} \qquad r = .765^{**} \quad sy.x = 1.88 \tag{5}$$

The second harvest total shown in Table 6 was not graded because of poor quality throughout all treatments. Fruits from this harvest lacked size and were extremely blotchy in color. Total production from the direct seeded plots ranged from 22.9 to a respectable 31.2 T/A with increasing K treatments. Treatment influence on early yields accounted for nearly the entire significant increase in total production.

Direct seeded H1350 tomatoes did not respond to sub-plot applications of 0, 30, 60, or 90 lb./A sidedress N regardless of the level of main plot applied K.

The linear response to applied K indicated that increased production and quality could be achieved with higher application rates, even though soil test K levels were only modestly altered in soils such as this. With the high total yield resulting from 500 lb./A applied K, further increases in marketable fruit due to higher K applications might be a consequence of improved color and size rather than increased fruit numbers.

Nutrient Composition of Direct Seeded Tomatoes

Spectrographic analysis of petiole samples collected on July 12 and August 3 is presented in Table 7. Reduced Na and Mg in the July sample were the only significant treatment effects. These reductions appear to be simply a result of dilution with increased plant growth and did not approach deficient conditions.

The effects of six levels of applied K on petiole K composition of direct seeded tomatoes are illustrated in Figure 3. Potassium concentration in July ranged from 1.7 to 7.0 per cent and linearly increased an average 0.7% with each 100 lb./A increment of applied K. Potassium composition in August ranged from 0.3 to 2.4 per cent and showed a significant curvilinear relationship with applied K. Variable K content in August with the zero treatment level was apparently due to extreme early K deficiency with severe plant stunting and subsequent accumulations of K in the plant tissue which could not be utilized.

Available soil K was depleted much earlier with the higher plant population in the direct seeded plots compared to the transplant plots. Tissue samples collected on the same dates represented a five week difference in fruit development between the two plantings. Therefore, tissue

Table 7. Nutrient composition (dry wt basis) of petioles from direct seeded tomatoes receiving six levels of applied K on a Genesee sandy clay loam soil.

Sample Time	Lb./A K Applied	Per Cent[a]				ppm[a]					
		P	Na	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
July 12	0	.23	.30	2.83	1.58	160	139	18	28	44	227
	33	.26	.27	2.64	1.46	188	139	17	26	42	263
	110	.26	.22	2.69	1.38	146	121	14	25	39	200
	220	.31	.23	2.70	1.34	142	105	17	27	40	183
	350	.26	.18	2.61	1.16	162	118	16	25	33	223
	500	.36	.17	2.66	1.16	178	122	17	27	37	185
	sy.x	.04	.02	0.08	0.08	17	12	1	1	2	26
August 3	0	.15	.28	3.32	2.12	244	128	21	27	50	275
	33	.11	.26	3.08	1.92	204	112	14	25	36	240
	110	.10	.21	3.30	1.84	244	127	16	24	44	256
	220	.12	.27	3.36	1.84	246	129	16	27	45	261
	350	.12	.22	3.40	1.71	256	146	17	24	49	265
	500	.12	.32	3.52	1.70	278	178	21	30	60	334
	sy.x	.01	.02	0.14	0.09	20	13	2	1	3	25

[a] Average of 3 replicates. Petioles from first fully developed leaves.

Figure 3. Effect of applied K on K composition of direct seeded tomato petioles samples July 12 and August 3.

$$\text{July } K = 2.041 + 0.0073\ K_{A66}$$

$$r = .934^{**} \quad sy.x = 0.76$$

$$\text{August } K = 0.946 - 0.00632\ K_{A66} + 0.000017\ K_{A66}^{\ 2}$$

$$R^2 = .572^{**} \quad sy.x = 0.52$$

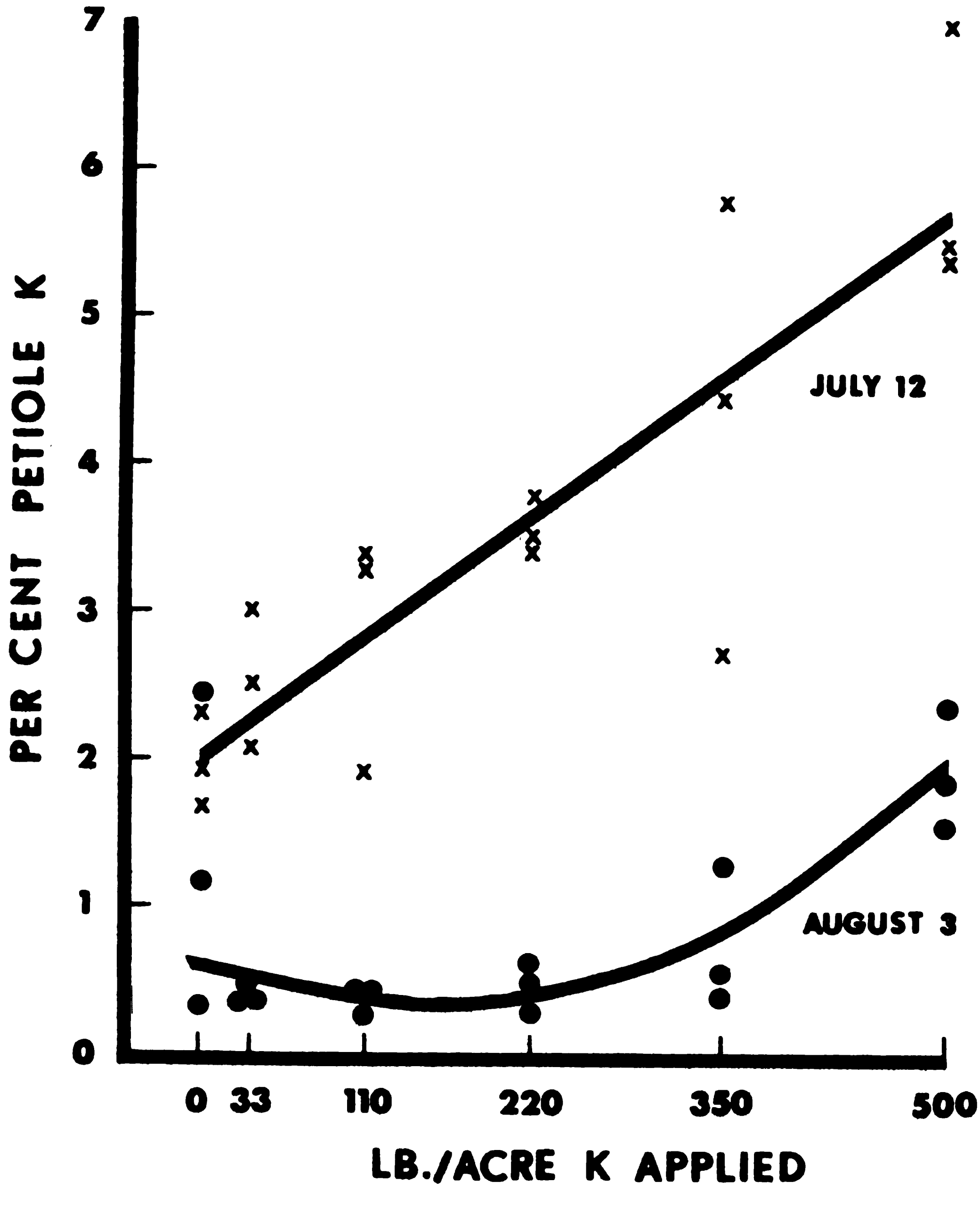
PER CENT PETIOLE K
7
6
5
4
3
2
1
0
JULY 12
AUGUST 3
0
33
110
220
350
500
LB./ACRE K APPLIED

Figure 3

K composition was much lower in direct seeded tomatoes early in plant development and early yields were markedly influenced by treatment.

Yield of No. 1 tomatoes increased an average 1.368 T/A with each 1% K in samples collected in July as shown by Equation 6.

$$\text{No. 1 } Y = 3.213 + 1.368\ K_{\text{July } 12} \qquad (6)$$
$$r = .812^{**} \quad s_{y.x} = 1.19$$

Potassium composition in August petiole samples was not significantly related to yields of direct seeded tomatoes.

As a result of the critically low tissue content of K late in the season with both transplants and direct seeded tomatoes, the ability of the plant for nutrient uptake during fruit development may be questioned. Undoubtedly, the factors of soil K fixation and high demands of heavy developing fruit loads contribute significantly to the depletion of stored K in vegetative structures. The problems of application limits, maintaining adequate tissue composition, and maximum production of high quality fruit remain questionable under conditions of high K fixation.

RESULTS AND DISCUSSION - 1968 DATA

Table 8 summarizes the 1968 main-plot broadcast K application rates (K_{A68}) and expected resultant soil test K levels based on the previous year's findings of high potassium fixation on this Genesee sandy clay loam soil. Although soil test K levels ranged from 78 to 180 lb./A prior to treatment the group means were not significantly different. Rates of application ranging from 0 to 1742 lb. K/A, equivalent to 3484 lb. KCl, were calculated from individual plot fixation factors determined from the 1967 results. The application rates and initial soil test K levels were not significantly correlated. Soil test data obtained after cropping will be discussed in a later section.

Table 8. Average K application rates, soil test K levels prior to treatment, and expected range of soil test K prior to cropping.

Lb./A[a] K_{A68}	Lb./A (pp2m) Soil Test K Fall 1967[a]	Expected Range of Soil Test K
0	90	100
134	113	101-150
514	126	151-225
738	123	226-300
1141	124	301-450
1529	133	450

[a] Average of four 25 x 40-foot plots.

Yields

Analysis of variance for yield data showed no significant main or interaction effects of either subplot sidedress Ca or Mg.

Early yields of C1327 transplanted tomatoes were not altered significantly by treatment as shown in Table 9. Applied K increased early fruit size slightly as indicated by the increase in carton size fruit. The per cent of total fruit ripening during the first week of harvest decreased from 32 to 13 per cent with increasing K, indicating a pronounced delay in maturity.

Table 9. Effects of broadcast K application on early yields of C1327 transplanted tomatoes.

Lb./A	Cwt/A Harvest 1[a]				% TY[b]
K_{A68}	Crate	Carton	No. 1	Mkt.	H1
0	7.91	15.23	24.28	40.01	32.1
134	5.69	27.27	33.05	52.23	25.4
514	6.57	29.38	35.96	48.98	20.4
738	9.64	27.87	37.77	49.97	15.8
1141	6.25	23.45	29.77	40.84	12.3
1529	5.73	20.61	26.38	34.44	13.3
Sig.[c]	n.s.	*	n.s.	n.s.	**
$s_{\bar{x}}$	1.65	2.77	3.49	4.53	2.1

[a] First week of harvest - July 31 to August 8. Yield belt sized into salad - less than 2 1/8", crate - 2 1/8" to 2 5/8", and carton - greater than 2 5/8" diameter.

[b] Per cent of the total yield obtained in the first week of harvest

[c] n.s. = no significant difference. * = significant at the .05 level. ** = significant at the .01 level. Based on analysis of variance.

Sidedress K treatments (K_{S68}) of 0, 73, and 146 lb./A did not affect either early yields or fruit maturity.

Relationships of broadcast (K_{A68}) and sidedress (K_{S68}) K application rates with total yields of crate, carton, No. 2, fresh market and processing marketable fruit are summarized in Table 10. The independent variables are common to all yield classes and collectively account for a highly significant portion of the increased total production of each grade of fruit.

Based on the relationships shown in Table 10, the calculated increases in marketable fresh market and processing tomato fruit for each lb. applied K/A in various broadcast and sidedress combinations are presented in Tables 11 and 12. Although yield changes decreased with increasing rates and combinations of K, the total production continued to increase because of the higher number of pounds applied. Estimated[6] maximum fresh market tomato yields would have been obtained with 1278, 1251, and 1126 lb. broadcast K/A in combination with 0, 75, and 150 lb. sidedress K/A respectively. Estimated maximum processing tomato yields would have been obtained with 1300, 1273, and 1244 lb. broadcast K/A in combination with 0, 75, and 150 lb. sidedress K/A respectively.

Figures 4 and 5 illustrate the various combinations of broadcast and sidedress K estimated to be required for

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[6] by $\partial y/\partial Ka = 0$.

Table 10. Multiple regression equations relating C1327 tomato yields to applied K.

Yield Class[a]	Constant	Applied K Variables				R^2	sy.x
		K_{A68}[b]	K_{A68}^2	K_{S68}[c]	$K_{A68} \times K_{S68}$		
Crate	8.386	+0.20515	-0.000074	+0.17834	-0.0000534	.863**	21.7
Carton	28.789	+0.22549	-0.000083	+0.14316	-0.0000087	.871**	23.4
No. 2	38.483	+0.09020	-0.000046	+0.08760	-0.0000870	.482**	15.2
Mkt. FM	75.658	+0.52084	-0.000204	+0.40913	-0.0001492	.963**	35.6
Mkt. Proc.	73.630	+0.52854	-0.000203	+0.40486	-0.0001527	.931**	36.0

[a] Crate = No. 1 fruit 2 1/8" to 2 5/8" diameter. Carton = No. 1 fruit greater than 2 5/8" diameter. Mkt. FM = Marketable fresh market fruit including No. 1 fruit greater than 2 1/8" diameter and No. 2 fruit greater than 2 3/8" diameter. Mkt. Proc. = marketable processing fruit including all sizes of No. 1 and No. 2 grade fruit

[b] K_{A68} = lb. of K applied broadcast/A in 1968.

[c] K_{S68} = lb. of K applied sidedressed/A in 1968.

** Significant at the .01 level.

Table 11. Pounds per acre increase in marketable C1327 fresh market tomatoes for each lb./A broadcast and sidedress K applied.

Average Lb./A Broadcast K	Lb./A Sidedress K					
	0		75		150	
	Est.[a]	Actual[b]	Est.	Actual	Est.	Actual
0	0	0	40.9	94.4	40.9	48.0
134	49.4	62.6	45.9	63.9	43.9	48.5
514	41.6	47.4	40.9	40.4	39.8	43.5
738	37.1	38.7	36.7	41.2	35.9	35.5
1141	28.8	31.0	28.9	30.5	28.3	30.0
1529	20.9	21.6	21.1	22.5	20.7	21.7

[a] Estimated from equation in Table 10. Intercept = 7566 lb./A.

[b] Actual average yield with no fertilizer K = 5566 lb./A.

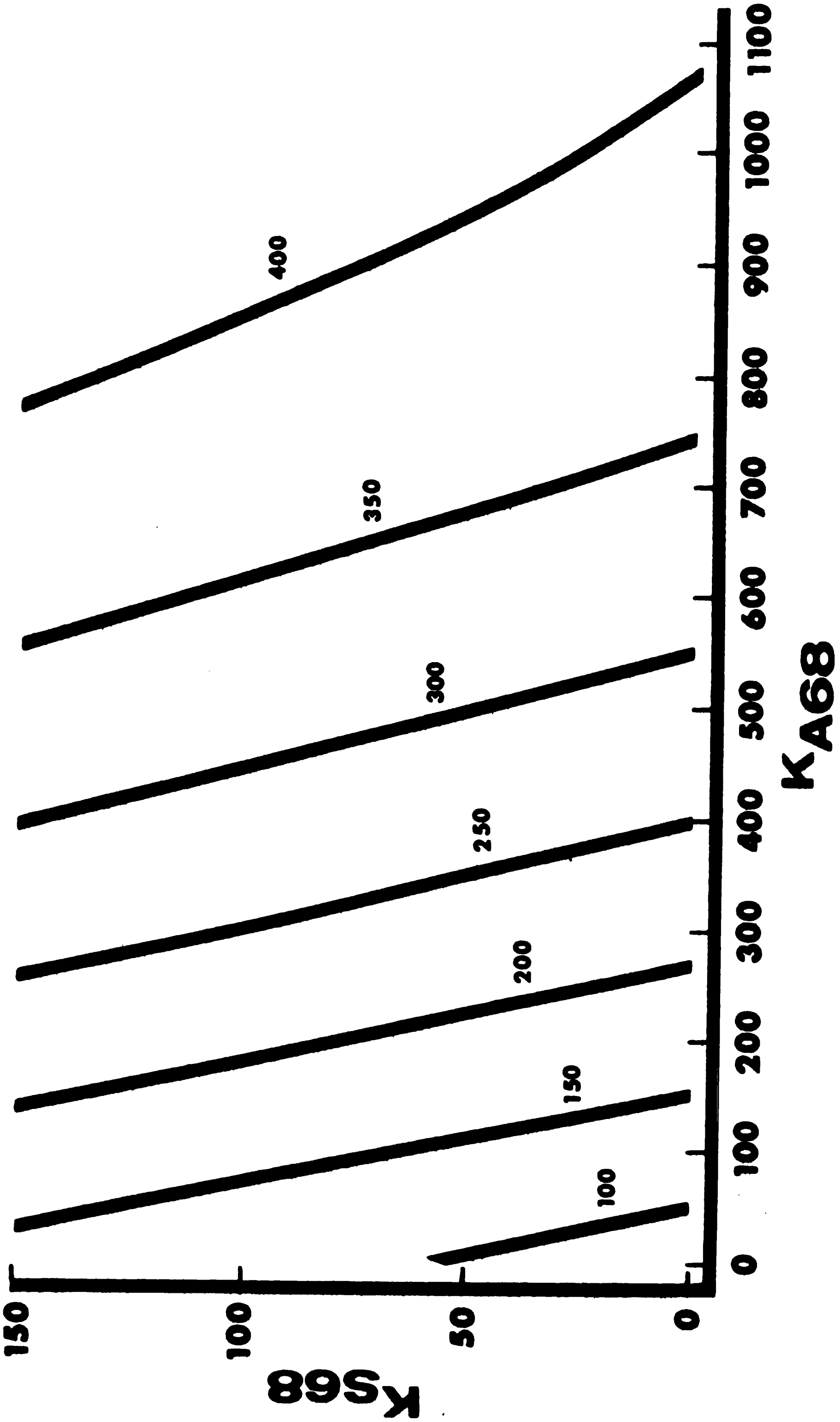
Table 12. Pounds per acre increase in marketable C1327 processing tomatoes for each lb./A broadcast and sidedress K applied.

Average Lb./A Broadcast K	Lb./A Sidedress K					
	0		75		150	
	Est.[a]	Actual[b]	Est.	Actual	Est.	Actual
0	0	0	40.5	88.6	40.5	47.1
134	50.1	61.5	46.0	62.6	44.0	47.7
514	56.8	46.9	41.2	39.8	40.3	43.5
738	37.9	38.6	37.1	40.9	36.4	35.7
1141	29.7	32.5	29.3	31.8	28.9	30.4
1529	21.8	22.0	21.6	22.7	21.4	22.3

[a] Estimated from equation in Table 10. Intercept = 7363 lb./A.

[b] Actual average yield with no fertilizer K = 5663 lb./A.

Figure 4. Various lb./A combinations of broadcast (K_{A68}) and sidedress (K_{S68}) K estimated to be required to produce selected yield levels (100-400 cwt/A) of marketable C1327 fresh market tomatoes.



K$_{S68}$
K$_{A68}$
0
50
100
150
0
100
200
300
400
500
600
700
800
900
1000
1100
100
150
200
250
300
350
400

Figure 4

Figure 5. Various lb./A combinations of broadcast (K_{A68}) and sidedress (K_{S68}) K estimated to be required to produce selected yield levels (5-20 T/A) of marketable C1327 processing tomatoes.

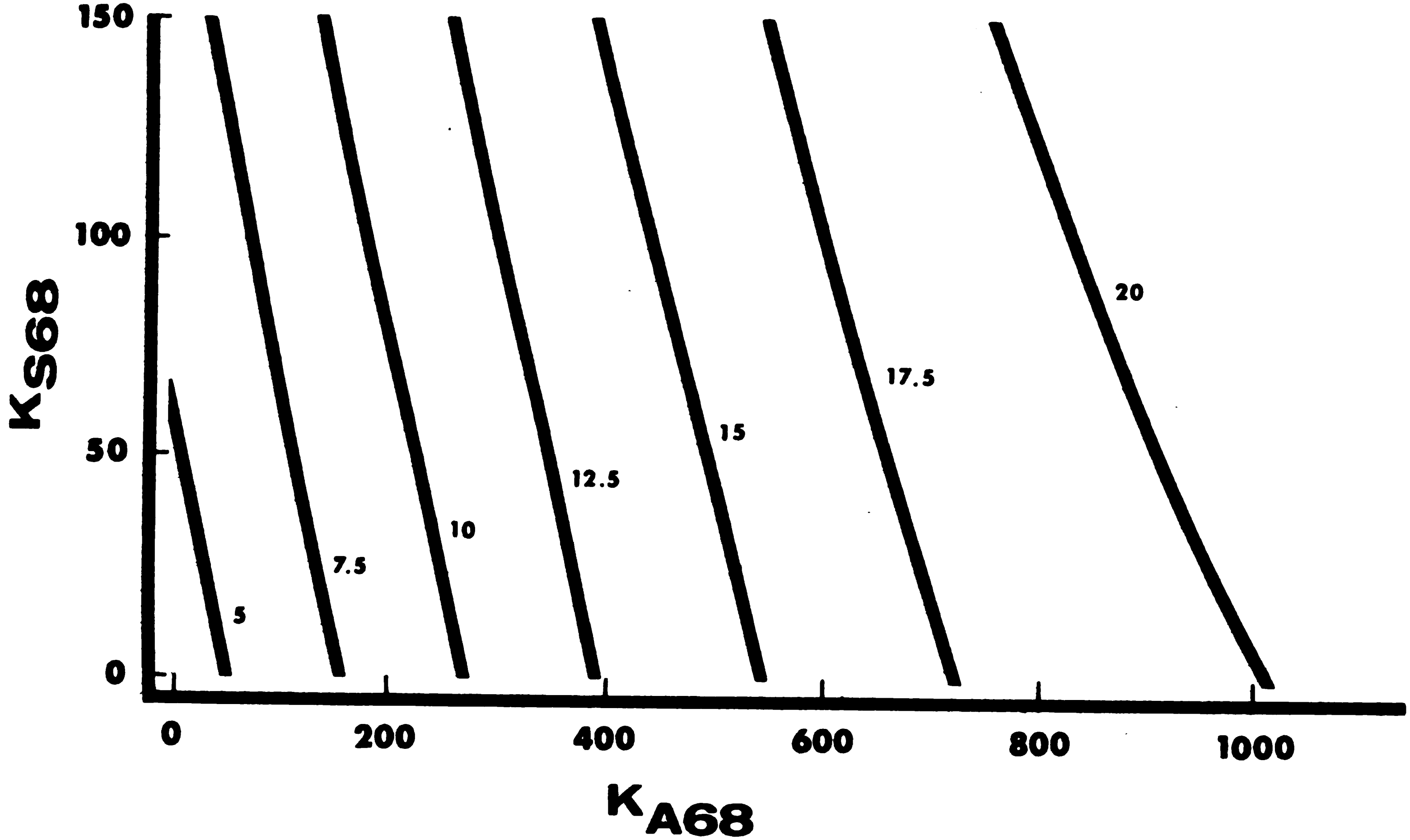


Figure 5

selected yield levels of fresh market and processing tomatoes[7]. For example, 30,000 lb./A fresh market tomatoes could be produced with either 550, 465, or 410 lb./A of broadcast K in combination with either 0, 75; or 150 lb./A of sidedress K respectively. An estimated maximum fresh market yield of 44,000 lb./A would be obtained with 1126 and 150 lb./A broadcast and sidedress K respectively. The estimated maximum processing market yield of 22.45 T/A would be obtained with 1244 and 150 lb./A broadcast and sidedress K respectively.

Yield results showed that the response to sidedress potassium was greatest at the low rates of broadcast potassium. A greater portion of the plants' total needs could be supplied by late applications of heavier rates of sidedress K, which would reduce fixation and increase availability during heavy fruit development.

Plant Analysis

Spectrographic Analysis

The values obtained from spectrographic determination of 10 nutrient elements in tomato petioles at three sampling dates are shown in Table 13. At the time of first fruit set, July 1, no significant treatment differences were evident. Analysis of samples collected during midseason fruit set, July 22, showed a significant

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7 Estimates derived from isoquant equations.

Table 13. Nutrient composition (dry wt basis) of petioles from C1327 tomatoes grown on a Genesee sandy clay loam soil with up to 1742 lb./A K.

Sample Time	Average Lb./A K_{A68}	Per Cent[a]				ppm[a]					
		P	Na	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
July 1	0	.65	.19	3.15	1.90	109	141	15	29	46	178
	134	.62	.19	3.03	1.54	97	102	15	29	43	150
	514	.77	.17	3.01	2.26	97	106	14	31	44	126
	738	.64	.13	2.71	1.18	87	154	14	30	39	118
	1141	.68	.17	3.05	2.82	112	127	16	32	48	145
	1529	.63	.13	3.08	1.83	116	151	17	32	51	158
	sy.x	.10	.02	0.12	0.64	7	21	1	1	3	9
July 22	0	.54	.43	3.06	2.82	152	105	15	31	47	238
	134	.51	.44	2.99	1.34	139	104	15	33	53	254
	514	.46	.48	2.99	1.27	139	81	14	32	57	221
	738	.54	.28	2.97	1.77	145	85	12	31	56	169
	1141	.54	.30	2.71	0.96	120	95	15	34	54	205
	1529	.53	.18	2.77	0.89	125	85	14	32	50	147
	sy.x	.06	.07	0.10	0.40	7	13	1	1	5	25
August 13	0	.42	.30	3.39	1.38	477	283	39	69	52	294
	134	.43	.46	3.96	0.77	407	318	87	68	62	469
	514	.44	.27	5.72	0.90	554	237	101	85	80	414
	738	.32	.21	5.63	1.51	566	305	101	63	84	474
	1141	.36	.22	5.72	0.84	566	271	125	78	83	451
	1529	.37	.14	5.66	1.21	637	245	90	70	80	335
	sy.x	.04	.04	0.37	0.26	45	38	18	7	6	64

[a] Average of 40 plots. Petioles from first fully developed leaves.

reduction in Mg and Mn with high rates of applied K. Samples collected during late season fruit set showed a significant reduction in Na and significant increases in Ca and Mn with high rates of applied K.

There is no evidence of either critically deficient or toxic levels of any nutrient in the tested samples. Lucas and Wittwer (1963) found that an increase in K was associated with a decrease in Na and Mg and noted that foliar symptoms of magnesium deficiency were associated with 0.3% mg in dry tomato petioles. MacLean et al. (1968) reported a general decline of P and a slight increase of B in dry weight analysis of greenhouse tomato leaves toward the end of the growing season. Wall (1940) stated that per cent Ca in dry tomato leaf tissue fluctuated throughout the season with up to 350 lb. K/A.

Even though Mn was depressed in the midseason sample with high K applications, the Mn:Fe ratio of 1:1 suggested by Ouelette (1951) was not maintained. A greater imbalance between Mn and Fe is evident in the late petiole samples, indicating the importance of sampling time in relation to tissue nutrient levels.

Treatment differences and changes in plant nutrient status throughout the season might be attributed to dilution with increased plant growth, mobilization to new vegetative growing areas, and translocation to developing fruit.

Values obtained from spectrographic determination of

10 nutrient elements in marketable tomato fruit and root samples are presented in Table 14. Potassium treatments had no significant influence on the nutrient composition of fruit or root tissues. Levels of P, Na, Fe, Cu, and B were similar and levels of Ca, Mg, Mn, Zn, and Al were lower in fruit tissue than petiole tissue. Levels of Na, Cu, B, and Zn were similar and levels of P, Ca, Mg, and Mn were lower in root tissue than petiole tissue. The high values obtained for Fe and Al in root tissue appeared to be soil contamination.

Sidedress treatments of K, Ca, and Mg did not contribute significantly to the nutrient element status of the tomato plants determined with spectrographic methods.

Potassium Determination

Potassium composition values from C1327 tomato petioles on three sampling dates, marketable fruits on the last harvest, and roots immediately after harvest are presented in Table 15.

Sidedress Ca and Mg treatments did not contribute significantly to differences obtained in tissue K. As seen in Table 16, a large portion of the variation in K composition may be attributed to the effect of treatment rates of broadcast (K_{A68}) and sidedress (K_{S68}) K. Petiole K composition during first fruit set, July 1, was related significantly only to broadcast K because the sidedress treatments were not applied until the day after this

Table 14. Nutrient composition (dry wt basis) of fruit and root tissue from C1327 tomatoes grown on a Genesee sandy clay loam soil with up to 1742 lb./A K.

Average Lb./A K_{A68}	Per Cent				ppm					
	P	Na	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
				Fruit Tissue[a]						
0	.67	.23	.29	.15	39	99	18	23	28	65
134	.56	.31	.29	.09	38	71	16	23	27	43
514	.58	.19	.29	.11	40	76	17	25	29	57
738	.62	.11	.32	.14	36	66	14	24	23	55
1141	.54	.12	.22	.11	37	61	13	24	26	51
1529	.58	.09	.31	.30	45	89	18	23	21	66
sy.x	.06	.03	.03	.05	3	6	2	1	3	11
				Root Tissue[b]						
0	.31	.33	1.81	.43	73	1075	21	22	66	837
134	.41	.32	1.92	.53	105	1179	29	29	72	1122
514	.31	.23	2.10	.39	81	1165	26	24	64	901
738	.35	.15	1.88	.41	81	1179	27	23	62	893
1141	.33	.12	1.80	.33	81	1179	25	23	59	934
1529	.31	.13	2.03	.42	80	1072	25	23	63	756
sy.x	.04	.02	0.11	.09	10	43	2	2	5	110

[a] Average of 40 plots.

[b] Average of 4 plots.

Table 15. Potassium composition of C1327 tomato petiole, fruit and root tissue.

Average Lb./A K_{A68}	% K[a]				
	Petiole				
	July 1	July 22	Aug. 13	Fruit	Root
0	3.22	1.65	0.89	2.72	0.46
134	4.97	3.41	0.90	2.77	0.58
514	6.81	5.41	1.21	4.45	0.91
738	7.72	6.53	1.62	4.88	1.15
1142	7.35	7.14	1.55	5.16	1.23
1529	7.60	7.42	1.80	5.65	1.46
Mean	6.28	5.26	1.33	4.27	0.96

[a] Average of 40 plots for petiole and fruit samples. Average of 4 plots for root samples.

sampling. The first sidedress K application significantly increased midseason petiole K composition, especially at the low rates of broadcast K. The second sidedress K application on July 24 did not contribute to late season petiole K composition but did significantly increase the per cent K in fruit tissue, especially at the low rates of broadcast K.

The relationship between per cent K in root tissue and broadcast K applications suggests that the roots are active in K uptake late in the growing season. Lack of differences in root uptake with sidedress K treatments indicates that this source of K had been exhausted, or that the active absorption sites were beyond the sidedress band area or depth.

Table 16. Regression equations relating K concentration in C1327 tomato petioles at three sampling dates, fruit and roots in 1968 to applied K.

% K	Constant	Applied K Variables				R^2	Sy.x
		K_{A68} [a]	K_{A68}^2	K_{S68} [b]	$K_{A68} \times K_{S68}$		
July 1	3.607	+0.007854	-0.00000354			.951**	0.38
July 22	1.620	+0.008808	-0.00000324	+0.004677	-0.00000476	.972**	0.37
Aug. 13	0.841	+0.001021	-0.00000027			.727**	0.21
Fruit	2.677	+0.003618	-0.00000120	+0.005340	-0.00000344	.927**	0.27
Root	0.542	+0.000624				.542**	0.34

[a] K_{A68} = lb. of K applied broadcast/A in 1968.
[b] K_{S68} = lb. of K applied sidedress/A in 1968.
** Significant at the .01 level.

Table 17 shows the tissue K composition values one could expect with 1300 lb. broadcast K/A and sidedress K rates which maximized marketable yields. Lower applications, and consequently lower composition values, would result in yield reductions.

Table 17. Per cent K in C1327 tomato tissues with 1300 lb./A broadcast K and rates of sidedress K required for maximum marketable yields.

% K[a]	Lb./A Sidedress K		
	0	75	150
July 1 Petiole	7.83	7.83	7.83
July 22 Petiole	7.59	7.48	7.38
Aug. 13 Petiole	1.71	1.71	1.71
Fruit	5.35	5.41	5.48
Root	1.35	1.35	1.35

[a] Estimated from equations in Table 16.

The overall relationships between petiole K composition, K application rates, and time are illustrated in Figure 6. Time was based on number of days after first nutrient sampling corresponding to first fruit set.

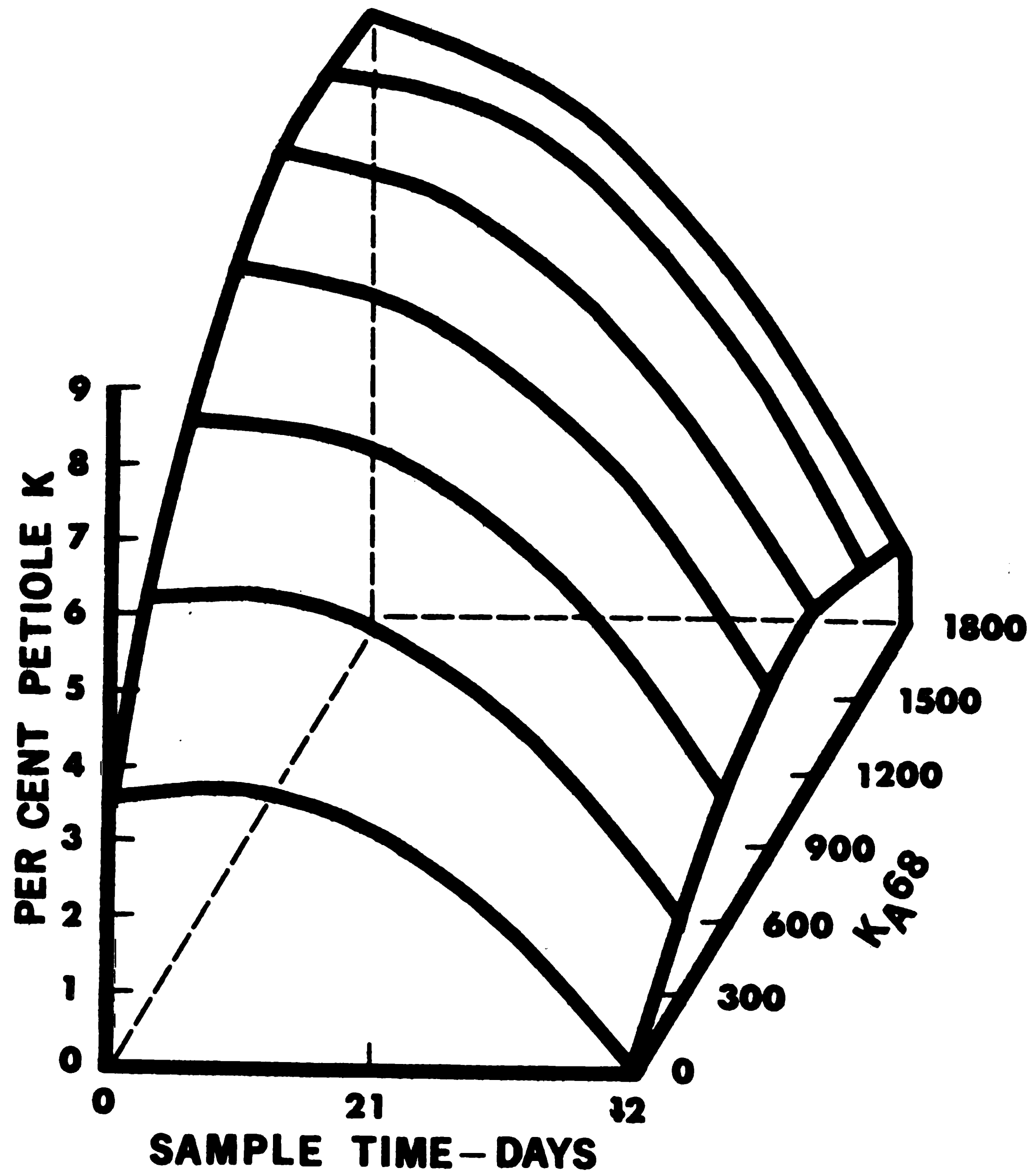
Chlorophyll Determination

During midseason, plants growing in low K plots showed distinctly darker leaf color in comparison to high K plots. Determinations showed significantly more chlorophyll in the fresh leaf tissue of low K plots as shown in Table 18. However, no significant differences were obtained when chlorophyll was expressed on a per cent

Figure 6. Relation of petiole per cent K to broadcast K applications and time of sampling.

$$\% K = 3.47 + 0.00675 K_{A68} - 0.00000235 K_{A68}^{2} + 0.052345 T - 0.00331 T^{2} - 0.000046 K_{A68} \times T$$

$$R^{2} = .933^{**} \quad sy.x = 0.7$$



PER CENT PETIOLE K
9
8
7
6
5
4
3
2
1
0
0
21
32
SAMPLE TIME–DAYS
1800
1500
1200
900
600
300
0
KA68

Figure 6

Table 18. Effect of K applications on total chlorophyll content and per cent dry wt of C1327 tomato leaves.

Average K_{A68}	Mg/100 g Tissue[a]		Per Cent Dry wt
	Fresh wt	Dry wt	
0	6.08	0.38	15.97
134	5.50	0.40	13.93
514	4.84	0.34	14.08
738	4.90	0.34	14.65
1142	4.76	0.35	13.80
1529	5.06	0.37	13.52
Sig.[b]	**	n.s.	**
$s_{\bar{x}}$	0.23	0.02	0.07

[a] Average of 4 plots.

[b] n.s. = no significant difference. ** = significant at the .01 level. Based on analysis of variance.

Table 19. Effect of K applications on respiration of C1327 tomato leaf tissue.

Average K_{A68}	Ml CO_2/Kg/24 hr[a]	
	Fresh wt	Dry wt
0	256	16.4
134	228	17.1
514	205	14.6
738	206	13.4
1142	209	15.3
1529	222	15.9
Sig.[b]	**	n.s.
$s_{\bar{x}}$	9.6	1.36

[a] Average of 4 plots.

[b] n.s. = no significant difference. ** = significant at the .01 level. Based on analysis of variance.

dry weight basis. Per cent dry weight of leaves decreased from 15.97 to 13.52 with increasing K applications.

Respiration Determination

Respiration data shown in Table 19 followed the same pattern obtained for chlorophyll. Significant treatment differences were obtained when CO_2 evolution from plant leaves was quantified on a fresh weight basis, but disappeared when quantified on a dry weight basis because of the decrease in dry weight with increasing K.

Tomato petiole analysis showed no evidence of problems other than an available and adequate supply of K for plant growth and development. Potassium deficiency symptoms which occurred late in the season were similar to results obtained by Wilcox (1964). However, there was no excessive fruit drop on low K plots. Yield responses were obtained when midseason plant composition was much higher than 2.3% K. In fact, maximum yield required midseason petiole K composition of approximately 7.5%.

Lawton and Cook (1954) reported that the critical K concentration of tomato petioles was between 0.75 and 1.50 per cent of dry weight. Sampling time in relation to fruit development becomes important in determining critical K concentrations. Even under conditions of high K fixation, early petiole K levels were maintained above 1.5% with no added K fertilizer. However, at the time of heavy fruit load, 825 lb./A K was required to maintain a composition value of 1.5% K.

Season average 3.07% K reported by Moore, Kattan and Fleming (1958) with no fertility effects on tomato production and quality was lower than the season average 4.29% K obtained in this experiment. A sufficient concentration of 4.78% K obtained at the beginning of tomato fruit set by Cannell, Bingham, Lingle and Garber (1963) would not be sufficient on this Genesee sandy clay loam soil.

The late season response to sidedress K was in agreement with the results of Ward (1969) where healthy tomato plants responded to a moderate application of KNO_3 by absorbing almost all of it. Tissue, fruit, root, and yield analyses all indicated that the late sidedress potassium was completely absorbed, thereby increasing yield. Thus, further studies should be concerned with rates, application times, and materials.

Although fruit samples were collected at the end of the harvest season, they should represent treatment conditions. According to Ward (1967), the per cent composition of normal mature fruit may remain relatively constant throughout the entire production period. He also reported absorption of K to the end of growth, therefore, there is a physiological reason for supplying the late season K needs of the tomato plant. Under the conditions of this experiment, a total tomato yield of 35 T/A removed 187 lb. K/A in the fruit.

Fruit Quality

The influence of applied K and subsequent K composition of fruit tissue on fruit quality measurements is shown in Table 20. Average rates of K fertilization up to 1142 lb./A significantly increased the per cent citric acid. Though not significant by analysis of variance, pH and color index show some tendency to increase, and per cent sucrose to decrease, as applied K and subsequent fruit composition K increased. Tomato fruits contain the two principal organic acids, citric and maleic, but pronounced changes in titratable acidity are primarily associated with changes in citric acid. Results obtained in this experiment with regard to the increase in citric acid in whole ripe tomato fruit associated with high soil K agree with the results reported by Davies (1964).

Table 20. Influence of applied K and subsequent K composition of fruit tissue on quality measurements of marketable ripe C1327 tomato fruit.

Lb./A K_{A68} [a]	% K Fruit	pH	% Citric Acid	% Sucrose	Color Index
0	2.72	4.50	7.83	5.46	29.5
134	2.77	4.59	6.90	5.14	32.1
514	4.45	4.67	7.91	4.82	34.0
738	4.88	4.58	8.83	4.98	30.8
1142	5.16	4.77	9.52	5.30	33.6
1529	5.65	4.72	7.47	4.85	33.6
Sig.[b]	**	n.s.	**	n.s.	n.s.
$s_{\bar{x}}$	0.20	0.29	0.42	0.20	1.93

[a] Average of 40 plots.

[b] n.s. = no significant difference. ** = significant at the .01 level.

Ranges in tomato fruit pH of 3.95 to 4.80 and titratable acidity of 3.7 to 12.3 per cent citric acid have been reported by Thompson, Lower, and Hepler (1964). According to Lower and Thompson (1967), changes of .084 pH and 0.15% citric acid are considered to be economically significant. Samples above 4.5 pH and below 5.5% citric acid are undesirable for processing tomatoes because of increased processing times and temperatures required to prevent spoilage. Although pH values obtained in this study were above the desirable level for processing, they could prove beneficial in mechanical harvest situations. A loss in acidity during tomato fruit ripening, demonstrated by Thompson, Lower, and Hepler (1964), could result in the need for high levels of acidity when a large volume of fruit are left on the vine to mature for once over harvest. Undoubtedly, the pH values are high in this study because the fruit were hand harvested throughout the season.

Color index values for all treatments were above the grade A minimum of 27 reported by Robinson, Ransford, and Hand (1951) based on their standard equation involving the aL:bL ratio.

Subplot applications of K, Ca, and Mg did not significantly alter fruit quality measurements.

Heinz 1350 fruit harvested in 1967 appeared to have many fruits with symptoms of blotchy ripening associated with low K levels. However, no specific data were collected in regard to blotchy fruit and they were bulked with the cull grade fruit. During the same season, C1327 tomatoes grown on the same soil type in other experimental plots showed more severe symptoms of blotchy ripening than H1350. Therefore, C1327 tomatoes were grown in the K plots in 1968 and separate weights for blotchy fruit were obtained while grading plot yields. The nonsignificant difference in color index reported in Table 20 indicates the reliability of the data in grading blotchy fruit.

Variations in the symptoms of blotchy fruit are illustrated in Figure 7. Fruit on the left exhibit extreme symptoms and breakdown with subsequent secondary fungal infection. Internal fruit symptoms are illustrated in Figure 8. In some cases, external symptoms were so mild that fruit had to be examined internally in order to grade the fruits accurately.

Symptoms of blotchy ripening shown in the two figures corresponded to the descriptions provided by Minges and Sadik (1964) and Sadik and Minges (1966). The fruit did not develop red color in areas which were irregular in shape and size. These discolored areas were either green, yellow or grayish-brown and were hard textured at fruit maturity. Brown tissue surrounding the vascular bundles, which results from lignification of parenchyma cell walls, was evident. The symptoms of blotchy ripening were not restricted to the stem-end of fruit in severe cases.

Figure 7. External fruit symptoms of blotchy ripening.

Figure 8. Internal fruit symptoms of blotchy ripening.

Figure 7

Figure 8

Table 21 shows the influence of K on the per cent of total tomato yields exhibiting symptoms of blotchy ripening. Blotchy fruit, as a per cent of the total yield, decreased quadratically with increasing K and is summarized in Equation 7.

$$\% \text{ Blotch} = 62.07 - 0.0465\ K_{A68} + 0.0000144\ K_{A68}^{2} \qquad (7)$$
$$R^2 = .882^{**} \quad sy.x = 5.3$$

The per cent of the total yield graded as blotchy fruit ranged from 84.7% with low K to 15.1% with high K.

Table 21. Influence of applied K on the proportion of total tomato yields showing symptoms of blotchy ripening.

Lb./A K_{A68}	Per Cent of Total Yield[a]	
	Marketable	Blotchy
0	24	63
134	30	59
514	45	44
738	58	32
1142	60	29
1529	60	28

[a] Average of 40 plots.

Additional strong evidence of the influence of K on blotchy ripening is provided by adding the proportions of marketable and blotchy fruit shown in Table 21. Regardless of the broadcast K application rate, between 87 and 90 per cent of the total yields can be accounted for by the summation. These data could not complement each other so closely without suggesting a direct affect of K on blotchy ripening. Futhermore, sidedress applications of K, Ca and Mg did not significantly affect the quantity of blotchy fruit.

The relationships between per cent blotchy ripening and per cent K in midseason petiole (K_{J22}) and fruit (K_F) are summarized in Equations 8 and 9.

$$\% \text{ Blotch} = 77.02 - 6.62 K_{J22} \qquad r = .908^{**} \quad sy.x = 4.9 \tag{8}$$

$$\% \text{ Blotch} = 105.26 - 14.16 K_F \qquad r = .906^{**} \quad sy.x = 6.3 \tag{9}$$

Blotchy ripening due to K deficiency would theoretically be eliminated if a midseason petiole content of 11.63% K and fruit content of 7.3% K were obtainable. Such levels have been reported in healthy crops of greenhouse tomatoes by Lucas and Wittwer (1963).

The relationships between K and blotchy ripening obtained in this field trial agree with results reported in greenhouse studies. Hobson (1963) reported up to 12 times as many severely blotchy fruit in low K plots as in high K plots. He found that the activity of pectic enzymes was lower in blotchy tissue and closely associated with fruit ripening and ripening disorders.

Ozbun et al. (1967) induced the formation of white tissue in young tomato fruits by low K levels in sand culture. Chemical analysis of plant tissue K was correlated significantly (r = -.97) with white tissue ratings of the fruit. Their data indicated a significant reduction in white tissue if petiole K could be maintained above 1.52%. They hypothesized that K is involved in the synthesis of lycopene (red pigment) through either a direct regulation of pyruvic kinase activity or through an effect on chromoplast development and structure.

The field results obtained differ from the previous report on early initiation of blotchy ripening by Sadik and Minges (1966). Even though chemical plant analysis showed no evidence of K deficiency during either first fruit set or three weeks after first fruit set, an appreciable quantity of early harvested fruits showed symptoms of blotchy ripening. With ^{14}C labelled glucose, McCollum and Skok (1960) showed a rapid movement of the products of photosynthesis into very young green fruit and lack of movement into mature green fruit. Activity again increased at the turning stage and decreased after pigment formation. These results suggest two periods during fruit development in which K could be critical. Low K during early fruit development with subsequent altered metabolism and lignification could influence fruit development. The effect of K on lycopene synthesis would appear to take place at the mature green stage when the influx of photosynthates occurs prior to pigment formation. Possibly this could result from either alteration of metabolism or the formation of a physical barrier prior to maturity.

Soil Analysis

Figure 9 illustrates the change in soil test K with K treatments ranging from 0 to 1742 lb./A. With no K treatment the soil test remained unchanged, and tomato fruits removed an average 46 lb. K/A. Soil test changes of up to 280 lb. K/A were obtained. The three plots receiving 900-1200 lb. K_{A68}/A showing the greatest increase in soil test K (above the line in Figure 9) were sandy soils with lower fixation capacity than others in this group. Had they fixed applied K to the same extent as other plots the curve probably would not have reflexed downward but would have continued to rise. Also, the heavy vine growth accompanying 1742 lb. of fertilizer K/A may have contributed to the apparent decline in soil test indicated by the regression curve.

Average soil test K before treatment and after cropping are shown in Table 22. Soil test K after cropping ranged from 73 to 474 lb./A for individual plots and was significantly correlated (r = .942**) with expected soil test values.

Percentage K fixation in the soil appeared to be essentially constant at 75%. This value was arrived at by adjusting post harvest soil test K for estimated crop removal and K applied. Crop removal estimates were based on yields and K concentrations found in the fruits. Potassium removed in the vines was estimated to be

Figure 9. Effect of K fertilization on the difference between soil test K prior to treatment and after cropping.

$$K\ Change = 0.8421 - 0.173K_{A68} + 0.000551K_{A68}^2 - 0.00000021\ K_{A68}^3$$

$$R^2 = .871^{**} \quad sy.x = 44.6$$

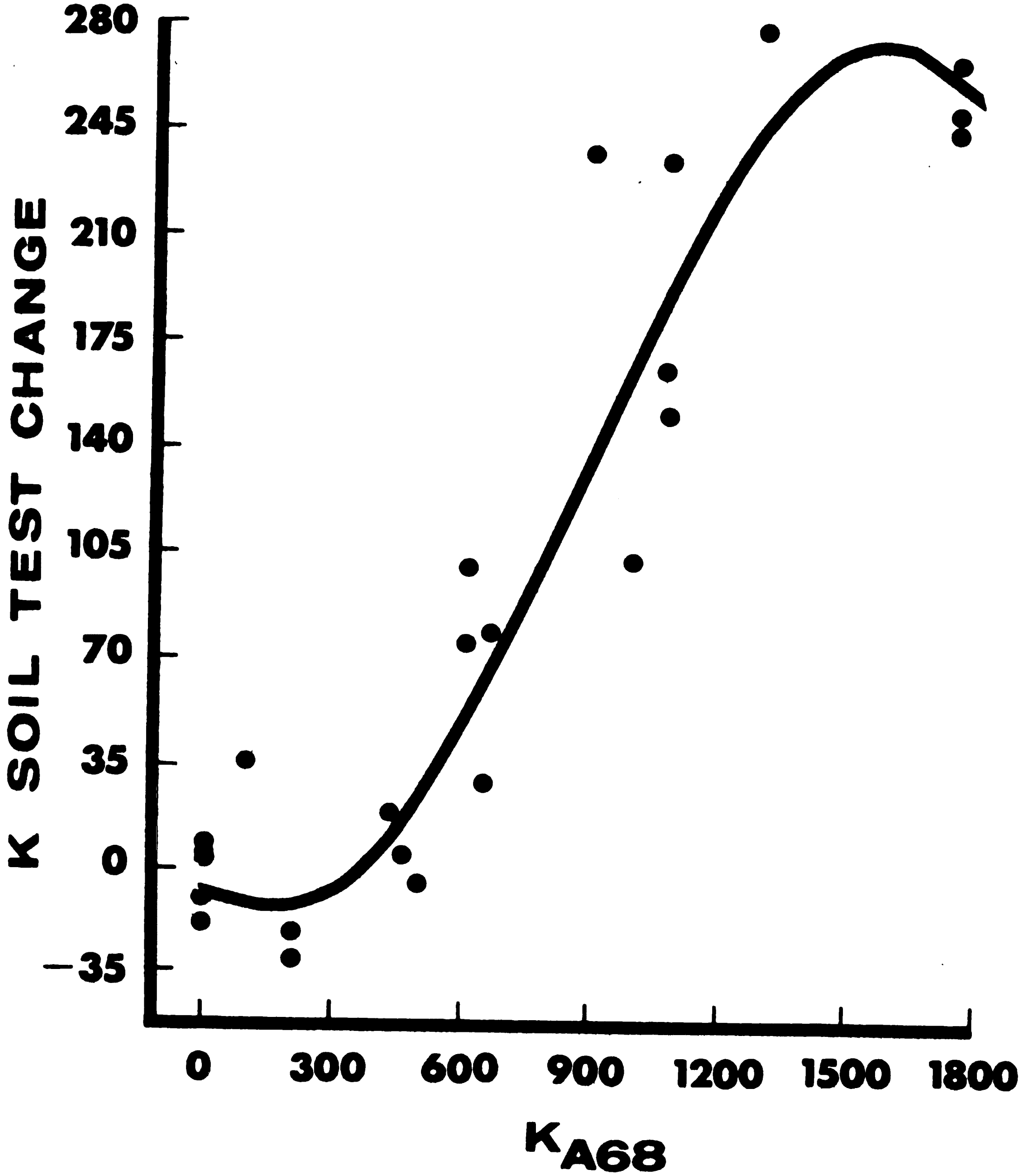

280
245
210
175
140
105
70
35
0
−35
K SOIL TEST CHANGE
0
300
600
900
1200
1500
1800
K_{A68}

Figure 9

equivalent to one third that removed by the fruit. Crop removal K was thus 1.33 ((K conc. in the fruit)(fruit yield)).

Table 22. Average K application rates, soil test K before treatment and after cropping, and expected range of soil test K.

Lb./A K_{A68}	Lb./A (pp2m) Soil Test K Fall 1967	Soil Test K Fall 1968	Expected Range of Soil Test K
0	90	91	100
134	113	106	101-150
514	126	148	151-225
738	123	200	226-300
1141	124	333	301-450
1529	133	403	450

Foliar and Sidedress Combination Applications

Sidedress K treatments of 0, 100, 200, and 400 lb./A in combination with foliar K treatments of 0, 3, 6, 9, and 12 lb./A did not satisfactorily meet the K requirements of C1327 tomato transplants on this Genesee sandy clay loam soil. Five weekly foliar treatments, resulting in a total of up to 60 lb. K/A, did not significantly affect yields and fruit quality or modify sidedress treatment effects. No plant injury was apparent even with the high 12-lb./A rate which was equivalent to 27.3 lb. KNO_3/A.

Single sidedress applications of up to 800 lb. KCl/A, equivalent to 400 lb. K/A, consistently increased marketable yields an average 9,200 lb./A, and decreased the quantity of blotchy fruit 10%. Highest average marketable yields of 27,600 lb./A with 39.8% of the fruit showing symptoms of blotchy ripening were obtained with 400 lb. sidedress K/A. The level of K in early and midseason petiole samples averaged 4.3 and 2.6 per cent respectively and did not differ with treatment. August tissue composition was increased significantly from 0.84 to 1.24 per cent K with the 400 lb./A treatment. However, the tissue K was not maintained above the 1.5% critical level. Potassium content of fruit tissue increased from 2.9 to 3.8 per cent with treatment.

Bukovac and Wittwer (1957) concluded that K was the most readily absorbed and the most highly mobile of the macronutrient elements studied with foliar application of radioactive isotopes. Their findings indicated that macronutrients could not be provided in sufficient quantities to supply the total plant needs. Learner (1952) reported no influence of 0.3% KCl weekly foliar sprays on total and No. 1 yields, maturity, and blotchiness of tomatoes.

Even with high broadcast rates of K, the results indicate a need for better methods of either supplying the late season K requirements of the tomato plant or overcoming the affect of K fixation by soil vermiculite. Noggle (1966) has shown that increasing the soil chloride content may reduce yields before salt concentration is sufficiently high to cause osmotic stress. Thus, repeated applications of extreme rates of KCl could cause additional problems with plant growth on this soil type. Possibly the yield reductions obtained with K rates above 1300 lb./A are a result of high soil chloride. Further response to K from KNO_3 was evidenced by increased yields from sidedress treatments at maximum broadcast levels.

The results of Winsor, Davies, and Long (1961) show a yield response and reduction in blotchy fruit with sprinkler application of K to greenhouse tomatoes. This remains a possibility for supplying the late season K requirements.

Welch and Scott (1961) found that plants grown with NH_4 forms of N required more K than those receiving N as NO_3. Increased applications of NH_4 to sub-soil samples reduced the uptake of nonexchangeable K by greenhouse grown corn plants due to the blocking effect of NH_4^+ on the release of K^+ from soil particles. If NH_4 was fixed by the soil, which can happen with vermiculitic clay, it would be unavailable for nitrification and the blocking effect on K release would persist. They indicated that adding NH_4 as $(NH_4)_2SO_4$ prior to K treatment blocked further fixation of added K. Based on their results and treatment levels, it would have required 2,000 lb. NH_4/A to block K fixation on the Marshall and Clarion soil types of Iowa.

Similar results were obtained with greenhouse corn plants grown on a Buxton silt loam by Bartlett and Simpson (1967). Approximately 1100 and 1300 lb. K/A were recovered if 320 and 540 lb. NH_4/A were applied as bicarbonate prior to an application of 1620 lb. K/A. Plant content of K and N were increased with treatment.

Barker, Maynard, and Lachman (1967) demonstrated the induction of tomato stem and leaf lesions with excessive NH_4 nutrition which caused soil K entrapment and K deficiency in greenhouse tomato plants.

Although the reports discussed offer an approach to overcoming the fixation of soil potassium, studies concerned with application material, rate, time, and influence on different vegetable crops and varieties under field conditions with this Genesee sandy clay loam soil should be undertaken.

Economic Implications

The estimated optimum levels of broadcast K in combination with varying levels of sidedress K are presented in Table 23 for various fertilizer and processing tomato prices. At a given crop price the optimum level of broadcast K would decline as the price of the fertilizer increases. Conversely, at a given fertilizer price, more could be profitably applied as crop prices increase. Optimum levels of broadcast K would decrease as sidedress K levels increase.

In Tables 24 and 25, a range of broadcast K levels are arrayed with corresponding fertilizer costs, estimated yields, and dollar returns over fertilizer costs at

Table 23. Optimum pounds per acre broadcast K in combination with sidedress K for marketable processing tomatoes under varying crop and fertilizer prices.*

$/lb. K K_{A68}	Prices in $/lb. for Mkt. Tomatoes			
	.015	.0175	.02	.0225
		0 lb./acre Sidedress K		
.04	1235	1244	1251	1257
.045	1227	1237	1245	1251
.05	1218	1230	1239	1246
		50 lb./acre Sidedress K		
.04	1216	1226	1232	1238
.045	1208	1218	1226	1232
.05	1200	1211	1220	1227
		100 lb./acre Sidedress K		
.04	1197	1207	1214	1219
.045	1189	1200	1208	1214
.05	1181	1192	1201	1208
		150 lb./acre Sidedress K		
.04	1178	1188	1195	1200
.045	1170	1181	1189	1195
.05	1162	1174	1183	1190

* Derived by equating the partial derivative, $\partial y/\partial k_a$, of the yield estimating equation, $Y = 73.63 + 0.52854\ K_{A68} - 0.002032\ K_{A68}^2 + 0.40486\ K_{S68} - 0.0001527\ K_{A68} \times K_{S68}$, with the inverse of the crop/price ratio, Pka/Py, where Pka = cost per lb. of K at the listed prices, and Py = the varying tomato prices.

Table 24. Dollar/acre return over fertilizer cost for C1327 marketable processing tomatoes with no sidedress K*.

Lb./A K_{A68}	Fert. Cost[a]	Lb./A Mkt. Y	Tomato Price $/Lb.[b]			
			.015	.0175	.02	.0225
0	11.82	7363	98.63	117.03	135.44	153.85
100	16.32	12445	110.36	201.47	232.58	263.69
200	20.82	17121	236.00	278.80	321.60	364.40
400	29.82	25253	348.98	412.11	475.24	538.37
600	38.82	31760	437.58	516.98	596.38	675.78
800	47.82	36641	501.80	593.40	685.00	776.60
1000	56.82	39897	541.64	641.38	741.12	840.86
1227	67.04	41623	557.30	661.36	765.42	869.48
1237	67.49	41650	557.26	661.39	765.51	869.64
1245	67.84	41670	557.21	661.38	765.56	869.74
1251	68.12	41682	557.11	661.32	765.52	869.75
1300[c]	70.32	41732	555.66	659.99	764.32	868.65
1400	74.82	41531	548.15	651.97	755.80	859.63
1600	83.82	39910	514.83	614.61	714.38	814.16
1800	92.82	36663	457.13	548.78	640.44	732.10

* Based on the equation $Y = 73.63 + 0.52854\ K_{A68} - 0.0002032\ K_{A68}^2 + 0.40486\ K_{S68} - 0.0001527\ K_{A68} \times K_{S68}$.

[a] Based on muriate of potash cost of $45.00/ton and ammonium nitrate cost of $78.00/ton.

[b] Tomato prices correspond to $30, $35, $40, and $45/ton respectively.

[c] Potassium application rate producing maximum yield.

Table 25. Dollar/acre return over fertilizer cost for C1327 marketable processing tomatoes with 150 lb./A sidedress K.*

Lb./A K_{A68}	Fert. Cost[a]	Lb./A Mkt. Y	Tomato Price $/Lb.[b]			
			.015	.0175	.02	.0225
0	26.55	13436	174.99	208.58	242.17	275.76
100	31.05	18289	243.29	289.01	334.73	380.45
200	35.55	22736	305.49	362.33	419.17	476.01
400	44.55	30410	411.60	487.63	563.65	639.68
600	53.55	36459	493.34	584.48	675.63	766.78
800	62.55	40882	560.68	662.89	765.09	867.30
1000	71.55	43679	583.64	692.83	802.03	911.23
1170	79.20	44779	592.49	704.43	816.38	928.33
1181	79.70	44810	592.45	704.48	816.50	928.53
1189	80.06	44829	592.38	704.45	816.52	928.59
1195	80.32	44843	592.32	704.43	816.51	928.65
1244[c]	82.53	44891	590.84	703.06	815.29	927.52
1400	89.55	44398	576.42	687.42	798.41	909.41
1600	98.55	42318	536.22	642.02	747.81	853.61
1800	107.55	38613	471.65	568.18	664.71	761.24

* Based on the equation $Y = 73.63 + 0.52854\ K_{A68} - 0.0002032\ K_{A68}^2 + 0.40486\ K_{S68} - 0.0001527\ K_{A68} \times K_{S68}$.

[a] Based on muriate of potash cost of $45.00/ton, ammonium nitrate cost of $78.00/ton and potassium nitrate cost of $97.50/ton.

[b] Tomato prices correspond to $30, $35, $40, and $45/ton respectively.

[c] Potassium application rate producing maximum yield.

varying processing tomato prices with 0 and 150 lb. sidedress K/A respectively. The optimum levels of broadcast K are underlined. In all cases, maximum net returns would be obtained at less than the level of broadcast K resulting in maximum yield. For example, the optimum levels with tomatoes at 2¼¢/lb. and K costing 4.5¢/lb. appear to be 1251 and 1195 lb. broadcast K/A with 0 and 150 lb. sidedress K/A respectively. Yields with these rates of fertilizer K were estimated at 41,682 and 44,843 lb./A worth $869.75 and $928.65 after the total fertilizer costs had been deducted.

Dollar per acre returns over fertilizer and package costs for selected fresh market yields are presented in Table 26. Fertilizer costs include the total for broadcast K, sidedress K and sidedress nitrogen which was required to balance all plots to 100 lb./A nitrogen.

Net value increased with increasing broadcast K, however, sidedress K did not contribute until maximum yield levels were achieved. A substitution rate of K_{S68} for K_{A68} of 2.97 was required before net value increased with sidedress K.

A maximum net value of $3,287.91 was estimated with 1225 and 150 lb./A broadcast and sidedress K respectively, with a total fertilizer cost of $81.68. The yield with these rates of fertilizer K was 44,200 lb./A fresh market tomatoes.

Table 26. Dollar/acre return over fertilizer and package costs for selected Marketable fresh market yields of C1327 tomatoes.

Lb./A K_{A68}	Lb./A K_{S68}	Sub. Rate[a]	Fert. Cost[b]	No. Units/Acre[c] Crate	Carton	No. 2	Gross Value[d]	Net Value[e]
				150 Cwt/Acre				
152	0		18.66	126	531	284	1066.84	1048.18
110	50	0.84	21.69	129	519	287	1063.58	1041.89
68	100	0.84	24.69	132	504	292	1059.43	1034.74
26	150	0.84	27.72	134	488	298	1054.37	1026.65
				200 Cwt/Acre				
267	0		23.84	193	722	329	1448.95	1425.11
222	50	0.90	26.73	195	711	331	1446.54	1419.81
178	100	0.88	29.64	198	699	335	1443.38	1413.74
134	150	0.88	32.58	201	685	339	1439.28	1406.70
				250 Cwt/Acre				
396	0		29.64	260	913	372	1832.28	1802.64
348	50	0.96	32.40	262	906	373	1830.93	1798.53
300	100	0.96	35.13	265	896	375	1828.58	1793.45
253	150	0.94	37.94	267	884	379	1825.39	1787.45
				300 Cwt/Acre				
548	0		36.48	328	1108	412	2217.70	2181.22
494	50	1.08	38.97	330	1103	411	2217.30	2178.33
441	100	1.06	41.48	333	1095	412	2215.91	2174.43
389	150	1.04	44.06	335	1085	415	2213.55	2169.49

Table 26 (cont'd)

Lb./A $K_A 68$	Lb./A $K_S 68$	Sub. Rate[a]	Fert. Cost[b]	No. Units/Acre[c] Crate	Carton	No. 2	Gross Value[d]	Net Value[e]
				350 Cwt/Acre				
742	0		45.21	399	1307	445	2606.87	2561.66
676	50	1.32	47.16	400	1304	444	2607.27	2560.11
612	100	1.28	49.17	402	1299	444	2606.53	2557.36
552	150	1.20	51.39	404	1292	446	2604.96	2553.57
				400 Cwt/Acre				
1073	0		60.11	476	1520	458	3008.28	2948.17
950	50	2.46	59.49	475	1518	461	3006.40	2946.91
854	100	1.92	60.06	475	1514	463	3004.95	2944.89
770	150	1.68	61.20	476	1508	466	3002.98	2941.78
	Maximum Cwt/Acre = 409, 420, 431 and 442 with 0, 50, 100, and 150 $K_S 68$							
1278	0		69.33	497	1575	438	3093.58	3024.25
1260	50		73.44	514	1630	435	3186.07	3112.63
1242	100		77.52	532	1687	431	3278.78	3201.26
1225	150		81.68	550	1737	430	3369.59	3287.91

[a] Pounds of broadcast K replaced by 1 pound sidedress K to produce equal yield.

[b] KCl = \$45.00/ton. NH_4NO_3 = \$78.00/ton. KNO_3 = \$97.50/ton.

[c] Crate = 33 lb. Carton = 11.5 lb. No. 2 Basket = 18 lb. Equations in Table 16.

[d] Based on average prices paid on Benton Harbor Market 1968 - Crate = \$3.34, Carton = \$1.14, and No. 2 Basket = \$1.12 less package costs of \$.85, \$.14 and \$.25 respectively.

[e] Net \$/acre after package and fertilizer costs.

SUMMARY AND CONCLUSIONS

The original purpose of this work was to study certain K responses of vegetable crops and to determine the economy of either attaining or maintaining sufficient levels of K to meet the plant demands at high production levels. The surprising results obtained from 1967 plantings of transplant and direct seeded H1350 tomatoes focused attention on the extremely high K fixation capacity of the Genesee sandy clay loam soil, on which the experiments were being conducted. It was realized that the results of fertility studies on this soil type, (located adjacent to the St. Joseph River on the Sodus Horticultural Experiment Station in Berrien County, Michigan) which contains 19% vermiculite, might not be directly applicable to soils on most southwestern Michigan commercial fruit and vegetable farms, but unusual conditions invited further investigation.

Attention was subsequently directed toward determining the means of providing optimum available K to meet the demands of profitable tomato production on the Genesee sandy clay loam soil, initially low in available K (70-126 lb./A).

The 1967 results obtained with transplant and direct seeded H1350 receiving six levels of broadcast K and four levels of sidedress N are summarized as follows:

1. Fixation averaged 92.1% of applied K with no significant treatment effects on soil Ca and Mg.

2. Potassium fixation linearly decreased an average 2.8% for each 100 lb./A increment of up to 500 lb. K applied.

3. Potassium applications ranging from 0 to 500 lb./A did not significantly affect early transplant yield and maturity.

4. Total marketable and No. 1 fruit for transplants increased an average 4282 and 3682 lb./A respectively with each 100 lb./A increment of applied K.

5. Most of the cull grade fruit showed symptoms of blotchy ripening and decreased from 48 to 22 per cent of the total yield as the application was increased to 500 lb. K/A.

6. Marketable yield response directly related to increased K fertilizer was primarily a result of increased fruit size and improved color-quality.

7. Early yields of direct seeded processing tomatoes were significantly increased by K treatments. Single harvest yield linearly increased an average 1.26 T/A with each 100 lb./A increment of applied K. No. 1 fruit increased 24%, No. 2 fruit decreased 14%, and

cull fruit decreased 10% with 500 lb./A applied K.

8. Late harvest fruit of direct seeded processing tomatoes lacked size and were extremely blotchy regardless of K treatment.

9. Available soil K was depleted much earlier with the higher plant population in direct seeded plots compared to transplant plots. This resulted in lower K composition values relative to plant and fruit development which accounts for the treatment influence on early yields in direct seeded tomatoes.

10. Nutrient status changes in the plants, other than K, were within previously reported ranges and may be attributed to dilution, mobilization, and translocation. Generally, tissue composition of Mg was decreased with increasing K but did not approach critical deficient levels.

11. Plant tissue K through midseason was highly correlated with yields and fertilizer K. Although the tissues tested high early in the growing season, the late season values averaged well below the 1.5% critical level, and were not maintained at early levels even at high rates of K application.

12. Maximum yield and quality, especially color, were not achieved even with 500 lb. K/A.

13. Sidedress N treatments did not consistently affect either transplant or direct seeded tomato yields, quality or nutrient composition.

The 1968 results obtained with transplant C1327 tomatoe plants indicate the following:

1. Sidedress treatments of 0, 31, and 62 lb. Ca/A and 90 lb. Mg/A did not significantly influence either yield, quality, or nutrient composition of petiole and fruit tissue.

2. Marketable tomato yields (fresh market and processing) were significantly increased with broadcast K, supplied as KCl, and levels of 73 and 146 lb./A of sidedress K supplied as KNO_3. Maximum fresh market yield of 44,000 lb./A was estimated with 1126 and 150 lb./A of broadcast and sidedress K respectively. Maximum processing market yield of 22.45 T/A was estimated with 1244 and 150 lb./A of broadcast and sidedress K respectively.

3. Sidedress K contributed more toward increased production at low than at high rates of broadcast K.

4. The fruit harvested during the first week decreased from 32 to 13 per cent of the total harvest indicating a delaying effect of K on fruit maturity.

5. No evidence of either critically deficient or toxic levels of any nutrient other than K were found with up to 1742 lb. K/A.

6. Levels of Ca, Mg, Mn, Zn, and Al were lower in fruit than in petiole tissue.

7. Levels of P, Ca, Mg and Mn were lower in root than in petiole tissue.

8. Potassium composition of plant tissues corresponding to maximum production with 1300 lb./A of broadcast K and 150 lb./A of sidedress K were: petiole at first fruit set, 7.83%; petiole at midseason, 7.38%; petiole prior to fruit pigmentation, 1.71%; fruit, 5.48%; and root, 1.35%.

9. Significant increases in root K composition provide evidence that the roots were active in K absorption through the end of the growing season.

10. A total tomato yield of 35 T/A removed 187 lb. K/A.

11. Average rates of K fertilization up to 1142 lb./A significantly increased citric acid concentration of marketable fruit and showed trends of increased pH, color index and decreased sucrose content. Although pH values obtained were above the desired processing level of 4.5, increased acidity could benefit mechanical

harvesting where ripe fruits remain on the vine for longer periods of time than when hand harvested.

12. On a fresh weight basis, plants in low K plots contained significantly more chlorophyll and showed higher respiration levels than plants in high K plots. The dry weight of plant tissue decreased from 15.97 to 13.52 per cent with increasing K, negating chlorophyll and respiration differences when quantified on a dry weight basis.

13. The total portion of the yield graded as showing blotchy ripening symptoms decreased from 84.7% with low K to 15.1% with high K. Minimum amounts of blotchy ripening were estimated to require a midseason petiole content of 11.63% K and fruit content exceeding 7.43% K.

14. Even though early and midseason petiole K averaged well above the 1.5% critical level, a considerable portion of the early fruits showed symptoms of blotchy ripening.

15. Soil test K after cropping ranged from 73 to 474 lb./A and was significantly correlated (r = .942**) with the expected soil test levels calculated from fixation values for each plot.

16. Sidedress K treatments of 0, 100, 200, and 400 lb./A in combination with foliar K treatments of 0, 3, 6, 9, and 12 lb./A did not satisfactorily meet the K requirements of C1327 tomato transplants.

17. Maximum returns of $928.65 and $3,287.91 above fertilizer costs were obtained for processing and fresh market tomatoes, respectively, with various K treatments and varying fertilizer costs and tomato prices.

The results obtained in all experiments conducted emphasize the importance of sampling time in relation to plant K composition and subsequent effects on yield and quality. Changes in K requirements may occur with different cultural systems and varieties.

Evidence is provided which suggests that a direct influence of K on blotchy ripening occurs at the time of pigment development. This effect may be either directly on metabolism or through the formation of a physical barrier in the plant system and would not be limited to tomatoes grown on this soil type.

Tomatoes can profitably be produced on this Genesee sandy clay loam soil with high levels of K nutrition. Production and net returns above fertilizer costs were higher than results with C1327 tomatoes grown on the upland sandy loam soils of the experiment station.

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