Tomato Responses to Preplant-incorporated or Fertigated Phosphorus on Soils Varying in Mehlich-1 Extractable Phosphorus

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Abstract. Experiments were conducted to evaluate the yield response of tomato (Lycopersicon esculentum Mill.) to P, either preplant-incorporated or injected through the drip irrigation system, on soils with low, high, or very high soil P content. Fertilization through the drip irrigation system (fertigation) was more efficient than preplant incorporation of P for soil that tested low in P (9 mg·kg⁻¹ Mehlich-1 P). On soil testing low in P, marketable yield response to preplant soil P application rates (0 to 100 kg·ha⁻¹) was maximum at 61 kg·ha⁻¹ P according to the linear-plateau model, but 37 kg·ha⁻¹ P according to the quadratic-plateau model. The lower value is about one-half the P recommended by Univ. of Florida for low-P soils. On soil testing high in P (48 mg·kg⁻¹ Mehlich-1 P) the linear-plateau model predicted a maximum yield of 72.8 t·ha⁻¹ with 25 kg·ha⁻¹ P. The Univ. of Florida recommended no P for that soil. On soil testing very high in P (85 mg·kg⁻¹ Mehlich-1 P), there was no yield improvement with P fertilization.

Support zero P application, growers still apply P to high-P soils. Although soils might contain large amounts of P, the availability of P to plants depends on soil-fertilizer chemical reactions. Phosphorus reacts chemically in soils with Ca⁺, Mg⁺, Al⁺, Fe⁺, and Mn⁺ to form compounds less available to plants (Burt et al., 1995). Therefore, P near the roots must be continually replenished or dissolved from these less available P fractions to support plant growth (Mikkelsen, 1989). A calibrated soil test should be able to predict relative availability of P to plants from the soil during the season.

Because of the low mobility of P in the soil, P fertilizer should be placed near the roots, using the most efficient methods of application. Banding the fertilizer in a concentrated zone near the plant roots should be more efficient than broadcasting (Barber and Kovar, 1985; Kovar and Barber, 1987; Randall and Hoeft, 1988). Although band placement of P is theoretically more efficient than broadcast application, experiments comparing band placement vs. broadcasting have occasionally given conflicting results (Lorenz and Vittum, 1980). In Israel, no difference was found between broadcast or drip irrigation injection of P for corn grown on a sandy soil (Bar-Yosef et al., 1995).

With P fertigation, only a small fraction of the root zone is exposed to P. Mikkelsen (1989) documented that nutrient application through drip irrigation was comparable with application in an adjustable fertilizer band, where the nutrient applications can be exactly timed to meet plant needs during critical growth stages. Fertilization of P through a drip irrigation system has not been widely recommended; however, some reports indicate that this procedure can stimulate plant growth and yield (Mikkelsen, 1989; Rolston et al., 1981). These benefits are probably due to a “band-like” application of P by drip irrigation; nutrients are not widely mixed, avoiding P fixation (Hochmuth and Smajstrla, 1997; Mikkelsen, 1989; Rolston et al., 1981).

About 30% of the Florida tomato crop is grown with drip irrigation. Tomatoes are grown on polyethylene-mulched beds, and drip irrigation can improve production by efficiently applying both water and nutrients under the mulch (Smajstrla et al., 1995). Drip fertigation with N and K is a common practice in this system (Locascio et al., 1996). However, fertigation with P has not been widely used, mainly because emitters can be plugged by the formation of insoluble P precipitates with the calcium in the irrigation water, and because of the generally assumed restricted movement of P in the root zone (Rauschkolb et al., 1976). Use of acidic fertilizer sources such as phosphoric acid (H₃PO₄) and urea phosphate should minimize formation of insoluble P salts (Mikkelsen, 1989). More recently, the use of monopotassium phosphate-MKP (KH₂PO₄) in fertigation has been reported to be beneficial (Ankori, 1995; Csiszynsky, 1996).

The objectives of this trial were to evaluate the yield response of tomato to P fertilization of soils testing low, high, or very high in P. In addition, the yield responses to the method of applying P, preplant-incorporated or injected through the drip irrigation system as monopotassium phosphate, were evaluated.

Materials and Methods

Three experiments were carried out in fields with soils containing three different concentrations of Mehlich-1 P (low, high, and very high) at the Univ. of Florida Horticultural Research Unit at Gainesville, Fla., during Spring 1997. The ESTL, using the Mehlich-1 extractant (Hanlon et al., 1994), evaluated the chemical properties of the soil samples. The soil in the high-P field used in this experiment was classified as Pelham sand (sandy, siliceous, thermic arenic Paleaquolls). The soils in the low-P and very-high-P fields were classified as Pomona sand (sandy, siliceous, thermic ultic Alaquolls) (Harris, personal communication; Thomas et al., 1984).

The low-P soil (9 mg·kg⁻¹ Mehlich-1 soil test P index) was low in K (23 mg·kg⁻¹), and Ca (98 mg·kg⁻¹), and high in Mg (49 mg·kg⁻¹). The soil classified initially as high in P (48 mg·kg⁻¹) was high in Ca (552 mg·kg⁻¹) and Mg (70 mg·kg⁻¹) and low in K (27 mg·kg⁻¹). This high-P field was reclassified as very high in P after liming (61 mg·kg⁻¹). This increase in extractable P was probably due to the effects of lime on P release from insoluble P salts present in the soil matrix, as Al, Fe, and Mn phosphates. Although this soil, after liming,
was 1 index unit inside the very high classification, it will henceforth still be referred to as high-P soil. The soil classified as very high in P (85 mg kg\(^{-1}\)) was also high in most of the other nutrients.

The low-P and high-P fields received 4.5 and 2 t ha\(^{-1}\) of dolomite lime, respectively, 45 d before planting. But even after liming, at 56 d after planting, the pH of the low-P field was still low (4.9). Liquid K\(_2\)CO\(_3\) (0N–0P–24K) was applied in that field once a week for 3 weeks at 2.5 L·ha\(^{-1}\). Injection of K\(_2\)CO\(_3\) through the drip lines once per week for the two factorial experiments conducted in the high- and low-P soils with treatments replicated four times. The treatments were defined by a factorial combination of four P rates (25, 50, 75, and 100 kg·ha\(^{-1}\)), and two methods of P application [preplant-incorporated or injected (fertigated)] during the season through the drip irrigation system. On the field with soil very high in P, only the four rates of preplant P were used in a randomized complete-block design. A check treatment with zero P was included in all three experiments.

Nitrogen (N), potassium (K), and lime were applied as recommended by the ESTL. Potassium fertilizer requirements were determined by the Mehlich-1 soil test made before soil preparation. Total seasonal amount of K applied to maintain soil pH from 4.9 to 5.4.

Randomized complete-block designs were used for the two factorial experiments conducted in the high- and low-P soils with treatments replicated four times. The treatments were defined by a factorial combination of four P rates (25, 50, 75, and 100 kg·ha\(^{-1}\)), and two methods of P application [preplant-incorporated or injected (fertigated)] during the season through the drip irrigation system. On the field with soil very high in P, only the four rates of preplant P were used in a randomized complete-block design. A check treatment with zero P was included in all three experiments.

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and only the center 16 plants were harvested.

On 20 Nov. 1996 (before liming), on 10 Feb. 1997 (after liming and soil preparation but prior to fertilization), and on 13 June 1997 (after the second harvest), soil samples were taken from the bed to a depth of 0.15 m. To investigate P movement in the soil, additional sets of samples were taken to a depth of 0.20 m in 0.05-m increments on 14 Jun. 1997 (after the second harvest). These were taken at 0, 0.05, 0.10, 0.15, and 0.20 m from the emitter, both parallel with (data not shown) and perpendicular to the drip irrigation line. Samples of 10 recently matured leaves from shoots were taken for nutrient concentration determinations on 22 Apr. (when the first flower clusters appeared), on 13 May, and on 13 June, which were 35, 56, and 88 d after planting, respectively. Leaves were dried, ground, and digested in sulfuric acid/hydrogen peroxide, and analyzed for N by rapid-flow colorimetry and for P, K, and micronutrients by plasma emission spectroscopy (Hanlon et al., 1994).

Tomatoes were harvested three times from the fields with soils testing very high and high in P, and four times from the field with soil low in P. Fruits were harvested at the mature-green stage and graded into marketable and cull (undersized and misshapen) categories using a mechanical fruit sizer. Marketable fruits were further graded into size categories of extra-large, large, and medium (>70, 63.5 to 70, and 57 to 63.5 mm diameter, respectively) according to the Florida Tomato Marketing Order (Florida Tomato Committee, 1997). Fifteen fruits from the second harvest were chosen at random to evaluate postharvest fruit quality parameters. Soluble solids (*Brix), pH, and titratable acidity were evaluated after fruits had fully ripened in a ripening room in the dark at 20 °C. Soluble solids concentrations were measured using a digital refractometer ABBE type (model MARK II, Cambridge Instruments, Buffalo, N.Y.). The pH of the fruit juice was then determined. Titratable acidity was determined using 6 g of tomato juice centrifuged at 17.6 kg pressure (17,600 g) for 15 min and mixed with 50 mL of distilled water. Each sample was titrated with 0.1 N NaOH to pH 8.2 (end point) with an automatic titrimeter. The titratable acidity was calculated using the following equation:

\[
\text{% Acid} = \text{mL} \times 0.1 \times \text{NaOH} 
\]

Yield data were analyzed by analysis of variance using the SAS GLM procedure (SAS Institute, 1995). There were unequal numbers of plants per plot due to the low occurrence of bacterial wilt. A covariance analysis was performed to minimize the effects of this inequality (different numbers of plants per plot). The number of plants per hectare was incorporated in the regression models. Orthogonal contrasts were made between treatments, including preplant P vs. zero P, fertigated P vs. zero P, 25 kg·ha⁻¹ P vs. zero P, and soil applied P vs. fertigated P. Regression lines were fitted to data by linear and nonlinear least square procedures.

Results and Discussion

Field with soil testing very high in P. Application of P (0 to 100 kg·ha⁻¹) had no significant effect on fruit production in the very-high-P field. Average yields were 64.6 t·ha⁻¹ of extra-large and 88.2 t·ha⁻¹ of marketable fruits. Average fruit weight decreased significantly from 216 to 204 g per fruit as P application increased from 0 to 100 kg·ha⁻¹. Soils in Florida testing above 30 mg·kg⁻¹ Mehlich-1 P are not expected to respond to P fertilization (Hochmuth and Hanlon, 1995). These results were similar to the those reported by Rhue and Everett (1987) and Shuler and Hochmuth (1996) for Florida sandy soils testing very high in P. Yield of millet was not affected by P fertilization of soils in Colorado and Ne-
Field with soil testing high in P. There was no interaction of P rate and application method effects for fruit yield and P concentration in tomato leaves. P application method (preplant or fertigation) did not affect extra-large or total marketable yields, or fruit weight (Table 2). Fertilization method had no effect on tomato yield because all plants received ample P under either application method (Table 3).

Rate of P application did not affect yield of extra-large fruits (average = 45.6 t·ha⁻¹), total marketable yield (average = 74.6 t·ha⁻¹), or fruit weight (average = 193 g), although plants without P had lower yields than those with P (Table 2). Contrast between the check (zero P) and the 25 kg·ha⁻¹ P rate was significant at the 5% level for extra-large and total marketable yield, and for average fruit weight. There was a slight beneficial effect on yield of applying P but no more than 25 kg·ha⁻¹ P was required. A linear-plateau model (Dahnke, 1993; Dahnke and Olson, 1990) was fitted to total marketable yields using the NLIN SAS procedure (Fig. 1). Although P fertilization was not recommended for this soil, the linear-plateau model predicted maximum total marketable yield of 75.4 t·ha⁻¹ with 25 kg·ha⁻¹ P ($r^2 = 0.55$).

Neither rate nor method of application affected P concentrations in leaves at the first flower cluster stage (Table 3). These concentrations were higher than the reported sufficiency values (2 to 4 g·kg⁻¹ at flowering stage) for tomato growing in the open field in Florida (Hochmuth et al., 1996). Method of P application did not affect leaf P concentration 65 d after planting, but application of P at rates greater than 25 kg·ha⁻¹ increased it (Table 3). However, all leaf P concentrations were in the sufficiency range (Burt et al., 1995; Hochmuth et al., 1996; Reisenauer, 1983). Leaf P concentrations at second harvest were greater with fertigated than with preplant P (Table 3), although both concentrations were within sufficiency ranges (Burt et al., 1995; Hochmuth et al., 1996; Reisenauer, 1983). Application of P above 25 kg·ha⁻¹ increased leaf P concentration at second harvest, and the concentrations with zero or 25 kg·ha⁻¹ were near deficiency (Burt et al., 1995; Hochmuth et al., 1996; Reisenauer, 1983). This late-season deficiency in P probably was associated with the slight reductions in yield with less than 25 kg·ha⁻¹ P. Leaf macronutrient concentrations were sufficient for N, Ca, and Mg (data not presented).

Neither rate or application method used affected the pH, soluble solids, or titratable acidity of tomato fruits, with grand means of 4.5, 3.8 °Brix, and 0.94%, respectively.

Field with soil testing low in P. The interactions between application methods and P rates for extra-large, medium-plus-large, and total marketable yield were significant for tomato from the low-P field (Table 4). When P was preplant-incorporated, the effects of P fertilization on extra-large, medium-plus-large, and total marketable yields were linear. There was a linear relationship between yield of medium-plus-large fruits and increasing fertigated P rates, and a quadratic effect of P.

![Fig. 2. Effect of preplant P application rates (soil applied) on marketable fruit yield for soil testing low in P. P is the P rate and NP is the actual number of plants used to estimate the predicted yield.](image-url)

![Fig. 3. Effect of fertigated P application rates on marketable fruit yield for soil testing low in P. P is the P rate and NP is the actual number of plants used to estimate the predicted yield.](image-url)
rate for extra-large and total marketable yield. Average fruit weight (165 g/fruit) was not affected by P application method or P rate (data not presented).

Plants with preplant fertilization had higher leaf P concentration than did those under fertigation at flowering and fruiting stages, but the reverse was true at harvesting time (Table 3). Fertilization with P increased leaf P concentrations in all three growth stages. Although concentrations at first flowering and at 65 d after planting were increased by P fertilization, all values were within published sufficiency ranges. Leaf P at the second harvest had fallen to a deficient concentration with zero P and to near deficiency with 25 kg·ha⁻¹ P.

A preplant application of 72 kg·ha⁻¹ P was recommended by Univ. of Florida (Hochmuth and Hanlon, 1995) for producing tomatoes in a low-P soil (10 to 15 mg·kg⁻¹ Mehlich-1 P). This amount is slightly greater than the maximum preplant P response value obtained by linear-plateau fitting (61 kg·ha⁻¹) for total marketable yield of 71 t·ha⁻¹ (Fig. 2). The recommended P rate is considerably less than the preplant P requirement predicted by the quadratic-plateau model (142 kg·ha⁻¹) for a maximum marketable yield of 79 t·ha⁻¹. Cerrato and Blackmer (1990), and Hochmuth et al. (1993a) observed that quadratic models tend to overpredict responses to fertilization for other crops and nutrients.

The quadratic regression model and a quadratic-plateau model (linear-plateau was not significant) were applied to the total marketable yield in fertigated plots (Fig. 3). The P rate for maximum marketable yield was 68.3 kg·ha⁻¹ for the quadratic regression, and 36.6 kg·ha⁻¹ for the quadratic-plateau model, with maximum yields of 68.9 and 64.3 t·ha⁻¹, respectively. An unexpected decrease in yield of extra large fruits was observed when the highest rate (100 kg·ha⁻¹) of P was applied. Fertigation with P had no effect on yield of extra-large fruits for either plateau model. The quadratic regression model predicted 55.6 kg·ha⁻¹ of fertigated P for maximum extra-large yield of 36.1 t·ha⁻¹ (Fig. 4). The optimum fertigated P rate (37 kg·ha⁻¹) to maximize total marketable yield was smaller than those values predicted for preplant P (61, or 142 kg·ha⁻¹ P), indicating that P was more efficiently used following fertigation than following preplant soil incorporation. This increased efficiency in P utilization with fertigation was not observed for the tomatoes grown on the soil testing high in P. Effectiveness of fertigated P might differ with relative soil test P levels, as shown by Peterson et al. (1981) with wheat. In the wheat study, banding was three times as effective as broadcasting on low-P soils, but the methods of placement were equally effective when soil P was in the medium range.

Neither the P fertilization rate nor the method of P application affected any of the following fruit quality parameters on low-P soil: pH, soluble solids, or titratable acidity with overall averages of 4.5, 3.9 °Brix, and 1.1%, respectively.

Phosphorus movement away from the emitters was greater than 20 cm in depth and 10 to...
15 cm in width (Fig. 5), sufficient to supply P to most of the root zone. Without added fertilizer, this soil contained 9 mg kg⁻¹ Mehlich-1 P, and by the end of the season, concentrations >60 mg kg⁻¹ P (very high) were found 20 cm under the drip tube emitter and up to 10 cm laterally from the emitter. Using several P fertilizer sources on sprinkler-irrigated sandy soils near Patterson, Wash., Lauer (1988) measured P movement to a depth of 10 cm. Our results showed that fertigation with acidic P fertilizers such as MKP can be used to place P in the root zone in these sandy soils.

In summary, the Univ. of Florida Extension Service, in 1997, recommended 72 kg ha⁻¹ preplant-incorporated P for tomatoes to be grown on soil testing low in P, which is greater than the P rate predicted by the linear-plateau model (61 kg ha⁻¹) to maximize marketable yield. University of Florida also recommended no P application for tomato production on very high and high-P soils. Results of these experiments showed no response on soil testing very high and high-P soils. The linear-plateau model predicted a high in P. However, there was a slight benefit. Most showed no response on soil testing very high and high-P soils. Results of these experiments showed no response on soil testing very high in P. However, there was a slight beneficial effect of a small amount of P on the high-P soil. The linear-plateau model predicted a maximum total marketable yield of 75.8 t ha⁻¹ on high-P soil with a P application of 25 kg ha⁻¹. A slight change in the Mehlich-1 P calibration might be warranted and more research is justified with soils in the range of 50 to 70 mg kg⁻¹ Mehlich-1 P.

Our results also documented greater P fertilization efficiency with fertigation than with a broadcast preplant application of P to the soil. The Univ. of Florida recommendation of 72 kg ha⁻¹ P was adequate for greatest yields when the P was broadcast and incorporated in the low-P soil. However, only one-half that amount of P was needed to achieve maximum yield when the P was applied by fertigation.

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