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Watermelon Phosphorus Requirements in Soils with Low Mehlich-I-extractablePhosphorus

George J. Hochmuth[1], Ed A. Hanlon[2], and John Cornell[3]
Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL 32611

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Abstract. **Watermelon *[Citrullus lanatus* (Thunb.) Matsum. & Nakai] was grown at two sites differing slightly in Mehlich-I (double-acid) -extractable P (6 and 10 mg·kg^{-1}soil). Early and total yields responded positively to P rate; however, maximum yields were obtained with small amounts of P fertilizer. The linear-plateau critical P fertilizer rates were 26 and 27 kg·ha^{-1} at sites 1 and 2, respectively. These critical rates were lower than those currently used for recommending P fertilizer on soils that have very low P. Phosphorus concentrations of most-recently matured leaves at early fruit set were 2.5 and 2.8 g·kg^{-1} at sites 1 and 2, respectively, with 0 P, and 4.4 and 4.8 g·kg^{-1} with the 25-kg P/ha treatment.**

Watermelon is a moderately costly crop to produce. Production and marketing costs in Florida range from $3360 to $5680 per hectare, depending on production area, fertilizer costs make up ≈ 10% to 15% of the costs (Smith and Taylor, 1991). Average amounts of nutrients applied by watermelon growers are (inkg·ha^{-1}) 180N-65P-195K (Agricultural Statistics Board, 199 1). These observations indicate that growers may be overfertilizing watermelons. The Univ. of Florida recommends 80 kg P/ha for soils with very low P (Kidder et al., 1989). However, many soils used by watermelon growers have medium or high P, in which case no additional P would be recommended (Extension Soil Testing Laboratory, unpublished data). Yet, growers still apply an average of 65 kg P/ha.

Soil testing is recommended to predict the response of watermelon yield to added P fertilizer. However, little research has been conducted on the correlation of soil tests to watermelon response or the calibration of soil tests for fertilization recommendations. Previous research on sandy soils showed that nonmulched watermelon yield responded to P rates up to 80 kg·ha^{-1} atone site and up to 120 kg.ha^{-1} at another site when soil at both sites had low water-soluble P (Locascio et al., 1968). In another study on a sandy soil, nonmulched watermelon yield also responded to P rates up to 120 kg·ha^{-1} (Elmstrom et al., 1973).

Early watermelon yield in a 1969 test did not correlate with ammonium acetate-extractable P, but total yield did *(r* = 0.35, $P \leq 0.01$) (Elmstrom et al., 1971). Results were different in a similar study in 1970 when early yield correlated (r = 0.38, $P \leq 0.01$) with extractable P, but total yield did not (Elmstrom et al., 1971). Early ammonium acetate-extractable soil test values for the two studies would have been interpreted as medium for vegetables (Montelaro, 1970) and high for agronomic crops (Jones et al., 1974, NeSmith et al., 1972).

Soil test extracting solution for Florida was switched to the Mehlich-I (Mehlich, 1953) or double-acid solution (0.05 M HC1 + 0.0125 M H_2SO_4) in 1978. Watermelon yields did not respond to P fertilizer rates ranging from 0 to 100 kg·ha^{-1} in sandy soils with >25 m Mehlich-I-extractable P (MP)/kg in four studies and in soils with 6 mg·kg^{-1} in one study (Hochmuth and Hardon, 1989a).

All but one of the recent research studies cited above were conducted on soils containing appreciable amounts of P. The objectives of our studies were to evaluate watermelon response to P fertilizer in soils with very low MP.

The experiments were conducted at two sites on a commercial watermelon farm near MacClenny, Fla. (Baker County, northeastern Florida), during 1989. The soil at both sites was a Pelham series Ultisol (Arenic Paleaquults, loamy, siliceous, thermic). Soil analyses, using MP (Mehlich, 1953) for both sites, provided the following concentrations (in mg·kg^{-1}): site 1, 5.6P–9.2K–34.8Mg–202Ca–0.3 Zn-0.lCU–1.l Mn; site 2, 10.2P–22K–122Mg-645Ca4.8Zn-0.3 Cu-2.9Mn. These MP indexes represent an average of 20 samples. The soil pH (2 water: 1 soil) was 5.6 at site 1 and 5.8 at site 2. Before the experiment, site 1 was a newly cleared pine *(Pinus* spp. L.) forest and site 2 was an established bahiagrass *(Paspalum notatum* L.) pasture. For both sites, the MP soil test indexes for P were interpreted as very low, and large responses to P fertilizer were expected (Kidder et al., 1989). Recommended P fertilization rate for these sites was 80 kg P/ha (Kidder et al., 1989).

Fertilizer materials were ammonium nitrate, triple superphosphate, potassium chloride, potassium magnesium sulfate, and a commercial micronutrient mix. Nutrients were applied at (in kg·ha^{-1}) 134N–112K–34Mg–4Cu–10Mn-lB-3Zn. Phosphorus fertilizer was added according to treatment at 0, 25,50, 75, or 100kg·ha^{-1}. Rates were calculated based on 3700 m of crop/ha (with rows on 2.74-m centers) to conform to standardized fertilizer application rates (Kidder et al., 1989).

Both sites were prepared for planting by disking 25 cm deep to incorporate surface plant residue. Sites for watermelon rows were marked at 2.74-m intervals, and fertilizer was spread evenly by hand over a 1-m-wide area centered on the row mark. Fertilizer was incorporated in the bed area by rototilling. Soil was bedded to a final bed height of 10 cm, pressed, and covered with black polyethylene mulch. Drip irrigation tubing was positioned near the center of the bed just before mulching. Irrigation tubing had emitters spaced 30 cm apart with a flow rate of 62 ml·m^{-1}·min^{-1}.

Experimental units consisted of one 12.2-m-long row of watermelons with a 3-m nonfertilized area between plots down the row. 'Royal Jubilee' watermelon seeds were planted mechanically through the mulch on 11 Mar. 1989 at site 1 and on 20 Mar. 1989 at site 2. Watermelon plants were spaced 0.9 m down the row. Watermelon crop culture (weed and pest control) was similar to that in the commercial portion of the field. Watermelons were irrigated via drip tubes to maintain soil water potential at –12 kPa, as measured with tensiometers with ceramic tips at the 15-cm depth. Most-recently matured whole watermelon leaves (plus petiole) were sampled on 30 Apr. and 8 May at site 1 and on 22 Apr. and 30 Apr. at site 2. These dates were during the early fruit-setting period at both sites. Leaves were dried at 60C for 2 days, ground, dry-ashed, and analyzed for P by plasma emission spectroscopy (Donahue and Aho, 1992; Jones and Case, 1990).

Watermelons were harvested on 14, 19, and 23 June at site 1, and on 16, 19,23, and 26 June at site 2. Fruit weighing >4.5 kg were considered marketable.

The experiment was designed as a randomized complete block with four replications. Data were tested by analysis of variance and regression techniques using SAS software for ANOVA, GLM, and NLIN procedures (SAS Institute, Cary, N.C.). Watermelon yield response was plotted against P fertilizer to determine critical P fertilizer rates using quadratic-plateau (Cerrato and Blackmer, 1990), linear-plateau (Dahnke and Olson, 1990; Nelson and Anderson, 1977), simple quadratic (SAS, 1982), and logistic (Ratkowsky, 1990) models.

Yield. In both experiments, average early and total fruit yields with O kg P/ha were less *(P< 0.05)* than those for all other P treatments (Table 1). There was no early yield from plants receiving no P at site 1, and very few fruit were harvested from plants with the same treatment at site 2. Phosphorus need for early watermelon yields was satisfied by adding a small

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[1]Associate Professor, Horticultural Sciences Dept.
[2]Associate Professor, Dept. of Soil and Water Science.
[3]Professor, Dept. of Statistics.

Table 1. Early and total marketable watermelon yield and average fruit weight at two sites in Florida by P rate in 1989.

P rate (kg·ha⁻¹)	Early (first two harvests) Avg fruit wt (kg/fruit)	Early (first two harvests) Marketable yield (t·ha⁻¹)	Total season[z] Avg fruit wt (kg/fruit)	Total season[z] Marketable yield (t·ha⁻¹)
Site 1[y]				
o	0.0	0.0	2.2	0.7
25	10.4	23.9	10.2	37.8
50	11.0	23.1	10.1	35.8
75	11.0	28.7	10.2	39.4
100	10.6	28.0	10.1	44.5
Regression	L** Q**	L**Q*	L**Q**	L** Q**
Contrasts				
O vs. fertilizer	**	**	**	**
25 *VS.* 50,75, 100	NS	NS	NS	NS
Site 2[y]				
o	2.4	2.2	9.2	26.7
25	11.2	31.2	10.6	66.0
50	11.3	27.5	10.5	66.5
75	10.7	18.0	9.7	70.5
100	11.4	34.4	10.4	73.5
Regression	L** Q**	L*	NS	L**Q*
Contrasts				
O vs. fertilizer	**	**	NS	**
25 *VS.* 50,75, 100	NS	NS	NS	NS

[z]Total season yield was from three harvests at site 1 and four harvests at site 2.
[y]Prefertilization Mehlich-I index was 6 mg P/kg at site 1 and 10 mg P/kg at site 2.
"*"'Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively; L = linear, Q = quadratic.

amount of P, since rates >25 kg·ha⁻¹ did not increase yields significantly $(P > 0.10)$.

Total yield also responded little to P rates >25 kg·ha⁻¹. At both sites, the contrast of average yield at 0 P vs. the average yield at all other P rates was significant $(P \leq 0.01)$. However, there was no significant effect of P rate on total yield for P rates ≥25 kg·ha⁻¹ at either site. Regression techniques were used to determine critical P rates for each site. Although a quadratic regression equation for P rates O through 100 kg·ha⁻¹ explained 75% of the total variation in the data, a more realistic fitted model that gave a higher accounting of the total variation $(r^2 = 0.86)$ was a linear-plateau model (Dahnke and Olson, 1990; Nelson and Anderson, 1977) for the data from site 1. A quadratic-plateau model (not shown) did not improve the interpretation.

A simple quadratic relationship $(r^2 = 0.65$ for total yield) was found at site 2 also, but the data were described better by a linear-plateau model $(r^2 = 0.72$ for total yield). A quadratic-plateau model was not better than the linear-plateau model. The linear-plateau critical values for sites 1 and 2 were 26 and 27 kg P/ha, respectively. Estimated quadratic regression maxima for total watermelon yields from the two sites were 77 and 75 kg P/ha, respectively.

Because the linear-plateau critical P rates were similar at both sites, relative yields were calculated with the highest yield across sites set at 100% (Fig. 1). Quadratic and linear-plateau regressions were performed on the relative yield data over both sites. Watermelon yields were excellent at both sites (Florida state average yield is 19 t·ha⁻¹). The maximum for the quadratic regression was 75 kg P/ha, while the critical vALue for the linear-plateau method was 26 kg P/ha. The linear-plateau model was relative yield = 16.25 + 2.37 P for P rate ≤ 26.4 kg·ha⁻¹ and relative yield = 78.8% for P rate >26.4 kg·ha⁻¹. For comparison, a logistic model was fitted $(r^2 = 0.77)$ and resulted in relative yield = 81.65 (1 + $4.23e^{-0.73 \cdot \sqrt{P}})^{-1}$. This model predicted that 95% of the relative yield at 100 kg P/ha could be achieved at 35 kg P/ha.

Tissue analysis. Results of the tissue analysis from two sample dates at both sites (Table 2) support yield findings (Fig. 1) that the fiRst P addition (25 kg·ha⁻¹) provided sufficient P for watermelon growth. Hochmuth et al. (1991) reported a sufficiency range for watermelon at early fruit setting of 2.5 to 5.0 g P/kg of tissue. Plant leaves from the control (O P) treatment at site 1 were deficient in P, while leaves of plants from the control treatment at site 2 were at the low end of the sufficiency range.

In watermelon production, underfertilization directly affects yield and quality (Bradley and Fleming, 1959; Elmstrom et al., 1973; Sundstrom and Carter, 1983). Thus, fertilization recommendations must be as accurate as possible to prevent loss of quality and avoid the environmental hazards of overfertilization. The current Univ. of Florida recommended P fertilization rate for soil with very low P (O to 10 mg·kg⁻¹ soil, using MP) (Hanlon et al., 1990) is 80 kg·ha⁻¹ (Hochmuth and Hanlon, 1989b Kidder et al., 1989). This recommended value closely agrees with the quadratic maxima P values of 77 and 75 kg·ha⁻¹ for sites 1 and 2, respectively. This recommendation, however, is nearly three times higher than the P need predicted by the linear-plateau critical values of 26 and 27 kg·ha⁻¹. Our results indicated that, for these two sites, the Univ. of Florida P recommendation is above that actually needed for high yields. Based on these experiments, reducing P fertilization rate to 40 kg·ha⁻¹ would prevent underfertilization, maximize yield and quality, and be more environmentally appropriate. Selecting 40 kg·ha⁻¹ as a target fertilizer rate for low-P soils would reduce the current fertilization rate by one-half. The rate still would be slightly above the linear-plateau critical P rate, thus providing a degree of safety against underfertilization.

In earlier work, Locascio et al. (1968) reported yield increases on soils low in Cu and P described by a quadratic regression, with P rates banded from 0 to 235 kg·ha⁻¹. Watermelon yield responded little at P rates >120 kg·ha⁻¹ at. Immokalee, Fla., in 1965 or 58 kg·ha⁻¹ in 1966. At the Gainesville, Fla., site, little response to P rates >80 and 40 kg·ha⁻¹ were reported for 1966 or 1967, respectively. Preplant soil test showed that the soils were low in P and acidic. Both sites previously were

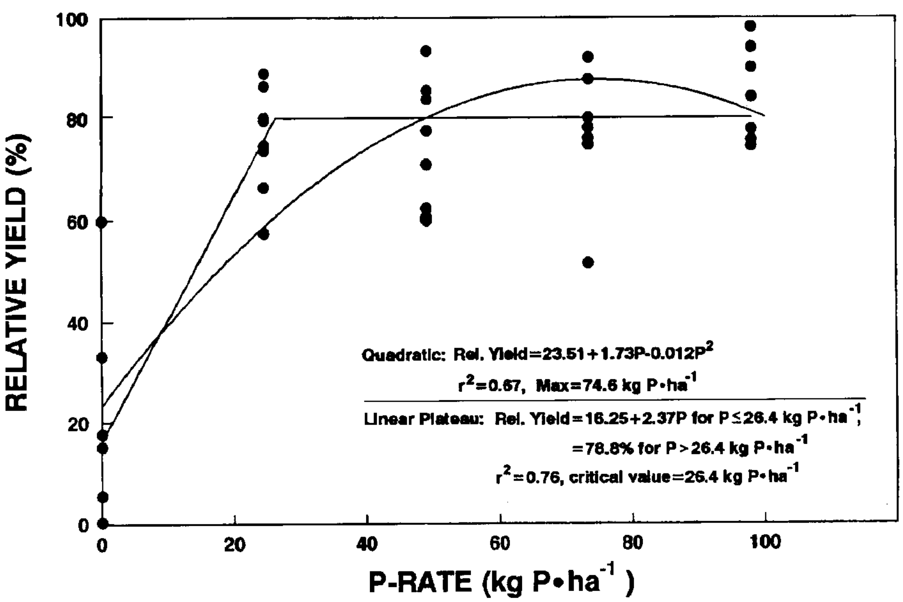

Fig. 1. Phosphorus fertilization rate vs. percent relative watermelon yield for both Baker County, Fla., locations with quadratic and linear-plateau regressions.

Table 2. Tissue P concentrations for watermelon leaves at two sites in Florida in 1989.

P rate (kg·ha^{-1})	Leaf P concn (g·kg^{-1} dry wt) Site 1[z] 30 Apr.	Site 1[z] 8 May	Site 2[z] 22 Apr.	Site 2[z] 30 Apr.
0	2.5	2.1	2.8	3.0
25	4.4	3.8	4.8	4.6
50	4.8	4.2	4.4	4.3
75	4.9	4.7	5.4	5.1
100	5.0	4.9	5.4	4.9
Regression	L**Q**	L**Q**	L*	L*

[z]Prefertilization Mehlich-I index was 6 mg P/kg at site 1 and 10 mg P/kg at site 2.
"*"Significant at $P \leq 0.05$ or 0.01, respectively L = linear, Q = quadratic.

noncultivated, and differences in soil Cu were thought to be responsible for the wide range of responses at the Immokalee site in 1965 and 1966. Both years of research at the Gainesville site produced yield responses to P rates similar to those reported in this paper.

In other work, Hochmuth and Hanlon (1989a) reported on five experiments in northern and central Florida. One site was (MP) very low, one was medium, and three were high (Hanlon et al., 1990). Phosphorus treatments ranged from 0 to 190 kg·ha^{-1}. None of the five locations responded to P. Using the proposed 40 kg·ha^{-1} rate still would have resulted in overfertilization at two of these sites, but would have reduced the excess amount by a factor of 0.5. Lowering the recommended P fertilization rate would save fertilizer, reduce fertilizer application costs, and minimize environmental risks due to P runoff. There would have been no negative effects on watermelon yield or fruit quality. Reducing P fertilization rate by a factor of 0.5 on low-P soils would save an estimated $60/ha in fertilizer materials and application costs.

Results of the two experiments reported here provide supporting evidence that the current recommended P fertilization rate for Florida watermelon on soils with very low P, according to the MP soil test, maybe too high. Reducing the current recommendation to 40 kg·ha^{-1} seems to fit the data reported here and similar data for mulched watermelons found in the literature. Responses here were not as great as those in early work with nonmulched watermelons (Locascio et al., 1968; Elmstrom et al., 1973). Reasons for differences in responses are unknown, but different cultural practices (mulching in the present study) could have played a role.

These studies also indicated that using the quadratic regression equation alone to describe the relationship between yield and P fertilizer rate may result in an overestimation of needed fertilizer. Similar conclusions were reported for corn *(Zea mays* L.) response to N (Cerrato and Blackmer, 1990). Using data from all P treatments, a quadratic maximum was predicted at 75 kg·ha^{-1}; however, separate analysis of P treatments from 25 to 100 kg·ha^{-1} showed no relationship of yield to P rate. Simultaneous use of both simple quadratic and linear-plateau (or quadratic-plateau and logistic) regressions sets upper and lower bounds on the response to fertilizer and helps determine a recommendation that is both environmentally and economically appropriate.

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