Low-molecular-weight Organic Acids As a Phosphorus Fertilizer Alternative for Vegetable Production in Calcareous Soil Regions

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Introduction

While current applications of phosphorus (P) fertilizer have played a significant role in providing sufficient harvest demands for global food production, industrial agriculture has altered the P cycle by relying on mined phosphate rock (PR) as a non-renewable fertilizer resource (Cordell & White 2011). On the other hand, most soils in the U.S. contain enough native P for crop production (Jones et al. 2011). These soils may also contain low-molecular-weight organic acids (LMWOAs) in the rhizosphere that are used by plants and microorganisms for P-nutrient acquisition (Wang et al. 2008). Even so, high pH and high P fixation rates occur in arid soils with high concentrations of calcium carbonate (CaCO₃) parent material (Marschner 2002). The purpose of this study was to mimic LMWOAs commonly found in the soil rhizosphere for vegetable production. By examining their ability to solubilize native P from calcareous soils in semiarid and desert regions LMWOAs may render a possible alternative for P fertilizer applications in future crop production systems.

Materials & Methods

As a highly dependent P nutrient crop, S. melongena (eggplant) was used in a pot study within a complete randomized block design using two distinct soil types located in the Central Texas region. In order to determine nutrient availability and appropriate fertilizer applications, soil samples were analyzed prior to the study (Fig. 1 & Fig. 2). Soils included a Houston Black (Hb) series Vertisol and Tarpley (Tb) series Molisol for vegetable production. Each soil pot was treated individually with molar concentrations of oxalic or citric acid (0.1 mM kg⁻¹, 100 mM kg⁻¹). Controls received the recommended triple superphosphate (TSP) (Ca₃(PO₄)₂) application from soil analysis results. Equal parts of urea (N) [CONH₂] fertilizer was applied to all soil pots. During the growing period blooms were recorded for each treatment (Fig. 3 & Fig. 4). Fruit was harvested and measured to determine yield based on weight (g). P nutrient availability from soil samples of each pot was measured using a spectrophotometer (mg/kg). Two-repeated-measures factorial MANOVA further determined statistical significance between treatments in each soil for P nutrient availability and fruit production effects over time, p < 0.05.

Results

Fruit harvest totals (g) at the end of nine weeks for Houston Black soil showed citric acid 100 mM kg⁻¹ as the most effective for yield, while TSP treatment yielded best for Tarpley soil (Fig. 5; Fig. 7; Fig. 9). MANOVA results for fruit yield (g) indicate harvest [Wilks’ Λ = 0.333, F(2, 129) = 133.34, p = 0.000], harvest*soil class [Wilks’ Λ = 0.555, F(2, 129) = 51.80, p = 0.000], harvest*treatment [Wilks’ Λ = 0.826, F(6, 258) = 3.244, p = 0.002], and harvest*soil class*treatment [Wilks’ Λ = 0.800, F(6, 258) = 3.795, p = 0.000] significantly affected yield over time (Table 1). Soil test totals (mg/kg⁻¹) for treatments revealed that TSP treatment provided the most P-nutrient availability for both soils (Fig. 6; Fig. 8; Fig. 10). MANOVA results indicate that soil test [Wilks’ Λ = 0.844, F(2, 129) = 12.838, p = 0.000], soil test*soil class [Wilks’ Λ = 0.846, F(2, 129) = 11.733, p = 0.000], soil test*treatment [Wilks’ Λ = 0.725, F(6, 258) = 5.368, p = 0.000], and interaction between soil test*soil class*treatment [Wilks’ Λ = 0.626, F(6, 258) = 8.507, p = 0.000] significantly affected soil test results over time (Table 2).

Discussion

Total yield comparisons between LMWOA treatments and TSP treatment over time showed no significant differences in yield for Houston Black soils, demonstrating promising results for LMWOAs as a P fertilizer substitute in production (Table 3). This was likely due to relatively high CaCO₃ and Ca₃(CO₃)₂ mineral content, which easily reacted with LMWOAs to render soluble P nutrients through dissolution and ion exchange of existing calcium phosphate compounds as shown in a study by Jones and Darrah (1994). Similar P-test results over time showed no significant difference between treatments for Houston Black soil (Table 4), which correlate to a study by Khadem et al. (2010) in which all concentrations of citric and oxalic were effective while oxalic acid provided the most P from soil tests. As for Tarpley soil, results signify LMWOAs as a relatively weak P substitute, possibly due to buffering capacity of the soil and a negative reaction from excess iron release for oxalic 100 mM kg⁻¹ treatment. According to Marschner (2002), pH of calcareous soils is dependent on the presence of CaCO₃ buffer soils ranging between 7.5-8.5 pH. Nevertheless, acquiring native P from soil using LMWOAs is a method that merits further investigation as many recent studies using LMWOAs have shown to have a corrosive effect on P uptake by plants (Strom et al. 2002; Allan et al. 2003; Jones et al. 2011) but research on sole LMWOA use in crop production is scarce.

References


