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RESEARCH PAPER

Evaluation of liquid phosphorus fertilizers and fulvic acids in a potato crop in an Andisol type soil

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Abstract

I. Bustos, M. Schoebitz, E. Zagal, and C. Muñoz. Evaluation of liquid phosphorus fertilizers and fulvic acids in a potato crop in an Andisol type soil. 2022. Int. J. Agric. Nat. Resour. 123-129. Andisols are soils derived from volcanic ash that are characterized by high concentrations of phosphorus (P). However, most of the P is not readily available for plant uptake due to the physical–chemical properties of the soils. The objective of this field study was to evaluate the effects of liquid P fertilizers on the plant growth and yield of a potato crop cultivated in Andisol type soil located in southern Chile. Ten treatments were applied pre- and/or postemergence, including orthophosphate- or ammonium polyphosphate-based fertilizers applied alone or in combination with fulvic acid and granular fertilizers; in addition, an unfertilized control (T0) was also included. Significant differences were found in terms of yield, total number of stems, and tuber size. The application of liquid fertilizers resulted in similar levels of foliar P content, while the number of stems was higher with the combined application of ammonium polyphosphate and fulvic acid. Furthermore, liquid P fertilizers increased crop yield (38%) and the proportion of large tubers (17%). The effects of orthophosphate and polyphosphate liquid fertilizers on potato were enhanced by the addition of fulvic acid to the soil.

Keywords: Fertilizers, humic substances, orthophosphate, phenological stages, polyphosphate, volcanic soil.

Introduction

Potato (*Solanum tuberosum* L.) production is economically important worldwide, reaching an average of 366 million metric tons in recent years, with an estimated planted area of 17 million hectares (2015–2018; FAO, 2020). These crops are highly responsive to soil fertilization, particularly fertilizers with phosphorus (P), due to its relatively short cropping cycle and high potential yield. Furthermore, the crop has a low root length density and a restricted capacity for P uptake in response to P fertilization.

Andisols develop from volcanic materials and contain high amounts of organic matter, which regulates several chemical reactions. However, these soils typically show low availability of calcium, magnesium, molybdenum, and P (Shoji

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et al., 1993). At the global level, potato cropping systems have been developed in Andisols with different levels of P availability. While analyzing Olsen-P levels from different experiments established in different potato production regions in Chile, Sandaña et al. (2018) found that, at an average pH value of 5.5, the topsoil layer (0–20 cm) had from low to medium P availability, ranging from 2 to 70 mg P kg^{-1} with a critical value of 33 mg P kg^{-1} in soils with high P fixation.

Low P availability in the soil affects photosynthesis and photoassimilation production in many different plant species by inducing photooxidative stress (Hernández & Munné-Bosch, 2015). In this sense, different strategies have been developed to increase P solubility in the soil, such as inoculation with phosphate-solubilizing bacteria that promote plant growth (Barra et al., 2019) or addition of humic substances (Mosa, 2012), which may improve plant physiological responses depending on the characteristics of the species and type of humic substances used. In fact, it has been described that humic substances promote plant growth and development by influencing metabolic activity and stimulating the production of phytohormones (Jindo et al., 2020).

Phosphates are classified as orthophosphates, polyphosphates, and organic phosphate. Polyphosphates and organic phosphate must first undergo a slow hydrolysis reaction, either abiotic and/or biotic, to release orthophosphates for absorption by plant roots. However, a complete understanding of the physiological response of potato plants to the application of liquid P fertilizers remains unknown. Therefore, the objective of this field study was to evaluate the effects of liquid P fertilizers on the plant growth and yield of a potato crop cultivated in Andisol type soil in southern Chile.

Materials and Methods

The experiment was conducted in an Andisol type soil in southern Chile (38°53’2,77’ S; 72°30’19,10” W). The soil corresponds to the Freire Series (medial, mesic Typic Placudands, Ciren 2002). The parent material is silt on gravel, with a sandy matrix of mixed composition. The topography is characterized by low and flat to slightly undulating soils, occupying fluvial or remnant terraces, with external and internal drainage and average annual rainfall ranging from 1,500 to 2,500 mm. The annual rainfall at the study site was 1,355 mm. The main chemical soil properties were 14 mg Olsen-P kg^{-1}, 61.2 mg N kg^{-1}, pH 6.0, 15.44% organic matter, and 10.23 $\mathrm{cmol_c}$ kg^{-1} of effective cation exchange capacity (CECe). The experimental treatments consisted of two types of inorganic P fertilizers and an organic enhancer. In the orthophosphate-based fertilizer (OF) treatment, a commercial product containing 24% available P, 0.1% chelated iron in ethylenediaminetetraacetic acid (EDTA) and 8.0% ammonia (Chemical Company, 2015) was used. Ammonium polyphosphate-based fertilizer (APF) is a commercial product containing 11.1% ammonia and 37% P (70/30 ratio polyphosphate/orthophosphate) (Simplot Company, 2014). The effects of the APF were evaluated by applying the product alone and in combination with an enhancer based on a liquid organic complex of fulvic acids (FF), which is found to be a commercial product based on alkyl-polyoxyethylene ether fulvic acid.

The experiment was established in a randomized complete block design with 11 treatments (ten fertilizer treatments and a control treatment) and four replications. Potato (*S. tuberosum*) cv. Patagonia-INIA was cultivated as experimental plant material during the 2016/17 cropping season. Tuber seeds were sown in November 2016 at a rate of 62,500 tubers ha^{-1}. Harvesting was performed in March 2017. Forty-four 20-m^2 plots, each consisting of four rows (3.32 m wide × 6.00 m long), were established. Seed tubers were planted with a spacing of 20 cm between plants and covered with a 5-cm soil layer. The different treatments used in the experiment are shown in Table 1. T0 was an absolute control (no fertilization), and T1 was fertilized with 143.5 units P_2O_5 ha^{-1} applied as triple superphosphate (46% P_2O_5). Treatments T2 to T10 received 175 units of P_2O_5 as triple superphosphate and 31.5 units of liquid P fertilizer as OF or APF, depending on the treatment. Triple superphosphate was applied along furrows at sowing, and liquid P fertilizers (60 L ha^{-1}) were sprayed on the soil at sowing by using a hand pump. The treatments that included FF (T3, T6 and T9) used an amount of 0.78 L ha^{1}. Liquid P fertilizers were applied at different phenological stages (Table 1): as preemergence (such as at sowing), as post-emergence (such as close to tuberization, at 20 days after sowing), and as pre + postemergence (50% and 50% at pre- and postemergence periods, respectively) treatments; all experimental plots received fertilization consisting of potassium 292 kg K_2O ha^{-1} as potassium chloride and nitrogen (N) as urea (74 kg N ha^{-1}). However, as liquid P fertilizers contained N, this amount was considered from T2 to T10, in which 65 kg N ha^{-1} of urea was applied, and 9 kg N ha^{-1} was considered as contributed by the liquid fertilizer.

Twenty days after postemergence application (80 days after sowing), three plants per replicate were harvested. Biomass was washed, while dry mass was measured after drying to constant mass at 60 °C for 2 to 3 days, and total leaf P content was determined by the colorimetric method of Sadzawka R. et al. (2007). Once the crop reached physiological maturity, the two central rows of each plot were harvested manually. The number of stems was determined, and the tubers were washed, air-dried, and weighed. Subsequently, tuber size was determined, and tubers were classified by diameter into commercial (28–45 mm) and noncommercial potatoes (<28 and >45 mm). Analysis of variance (ANOVA) was performed after the data were tested for normality and homogeneity of variance (Shapiro–Wilk and Levene's tests). Differences among the treatments were determined, and means were separated using Fisher's least square differences ([LSD]; $p \leq 0.05$; Di Rienzo et al., 2014).

Results and Discussion

Plant performance varied depending on the type of applied fertilization. However, no significant differences were observed in the amount of foliar P between the treatments, except for T2, since APF application at preemergence resulted in the greatest amount of foliar P, with a value of 20.12

Table 1. Foliar phosphorus (P) and stem number in potato plants under different P fertilization treatments.

Treatment	Application	Type of fertilizer	Foliar P (kg ha^{-1})[a]	Number of stems per meter[a]
T0	Absolute control	Without fertilizers	6.89 ± 0.52c	7.65 ± 0.50c
T1	Pre	TSF	13.47 ± 1.05b	8.56 ± 1.32bc
T2	Pre	APF	20.12 ± 2.31a	8.33 ± 3.59bc
T3	Pre	APF+FF	9.23 ± 0.80bc	8.92 ± 0.81ab
T4	Pre	OF	14.15 ± 0.19ab	8.27 ± 0.25bc
T5	Pre+Post	APF	11.64 ± 0.81bc	9.06 ± 0.92ab
T6	Pre+Post	APF+FF	12.47 ± 1.09bc	9.92 ± 1.23a
T7	Pre+Post	OF	10.42 ± 1.23bc	8.98 ± 1.32ab
T8	Post	APF	11.89 ± 0.67bc	8.35 ± 0.80bc
T9	Post	APF+FF	11.31 ± 0.79bc	9.13 ± 0.88ab
T10	Post	OF	10.87 ± 1.23bc	8.77 ± 1.37b

[a] Data are means ± SEs; Pre, preemergence; Post, postemergence; TSF, triple superphosphate fertilization; APF, ammonium polyphosphate-based fertilizer; OF, orthophosphate-based fertilizer; FF, organic complex based on fulvic acids. Means followed by different lowercase letters within columns are significantly different (Fisher's least squares difference [LSD] test; $p \leq 0.05$).

kg P ha^{-1} (Table 1). With respect to the number of stems, T6 (APF + FF) reached an average value of 9.92 stems m^{-1} at both phenological stages (pre- and postemergence) (Table 1).

P is an essential plant nutrient whose deficiency affects diverse functions, such as metabolic pathways of carbohydrates, lipids, and organic acids, along with chlorophyll and carotenoid biosynthesis (Navarro & Navarro, 2013). Accordingly, crop productivity increased with liquid P fertilization (T2–T10; Figure 1). Thus, higher potato yields were obtained with the application of APF+FF at both phenological stages (41.7 Mg ha^{-1}; T6). However, no significant differences were found between T6 and the other liquid P fertilizer treatments, with an average yield of 37.7 ± 2.6 t ha^{-1}. Meanwhile, significantly lower yields (27.2 ± 0.48 t ha^{-1}) were obtained in T0 and T1, which showed 38% lower productivity than the treatments with the application of liquid P fertilizers. It is important to note that plants in T0 showed a similar response in terms of yield compared to the treatments under traditional fertilization (T1), probably due to the characteristic high rate of P fixation in Andisols. This high capacity for P fixation is caused by different conditions, such as pH-dependent reactions, clay type and content as well as iron, aluminum, and organic matter content, among others (Shoji et al., 1993).

Therefore, it is important to determine an adequate strategy to increase soil P availability to improve yield. In our study, plants subjected to the combined pre- and postapplication of APF + FF (T6) showed an adequate yield performance, which was also related to an increase in the number of stems (Table 1). The increase in yield with the application of APF + FF might be related to the effects of fulvic acids (contained in FF) due the formation of stable organo-mineral compounds, which allow P to remain as exchangeable P for plant uptake. Increased plant growth and yield derived from humic acids has been previously

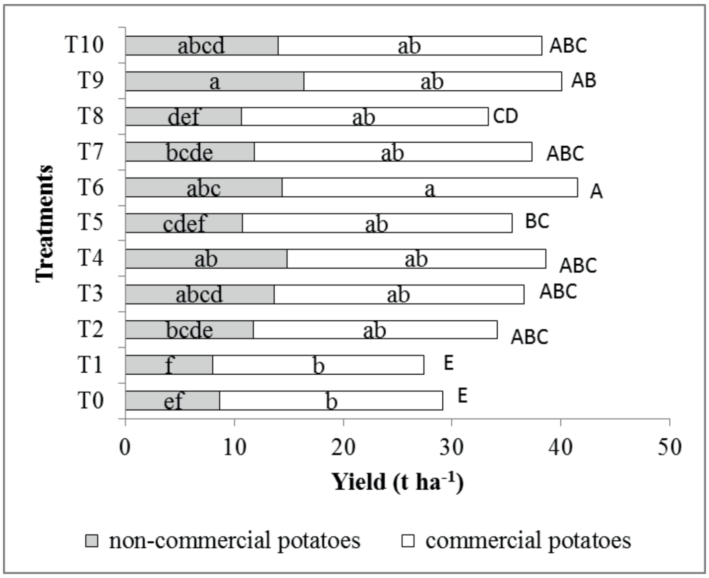

Figure 1. Potato yield (t ha^{-1}) and contribution of tuber size to total yield (t ha^{-1}).

T0, absolute control (no fertilization); T1, triple superphosphate fertilization applied at preemergence. Treatments applied at preemergence, T2, APF; T3, APF + FF; T4, OF. Treatments applied 50% preemergence and 50% postemergence: T5, APF; T6, APF + FF; T7, OF. Treatments applied postemergence: T8, APF; T9, APF + FF; T10, OF. Different uppercase letters indicate significant differences between total yields (LSD Fisher, $p \leq 0.05$). Different lowercase letters indicate significant differences between treatments in noncommercial and commercial potatoes (Fisher's LSD test; $p \leq 0.05$).

attributed to direct and indirect effects that induce an increase in the absorptive surface area of the roots by stimulating plant hormone production, which induces the proliferation of roots, or by interacting with microorganisms that contribute to P uptake (Jindo et al., 2020). This is likely to increase potato tuber yield and quality (Mosa, 2012). However, a study conducted by Suh et al. (2014) reported that potato tuber yield was not influenced by fulvic or humic acid treatments.

The distribution of commercial and noncommercial potatoes is shown in Figure 1. The largest commercial calibers were obtained in the pre + post APF + FF treatment (T6). The control treatment (T0) and T1 did not differ in tuber size and showed a lower production of commercial potatoes (26%) compared with T6. Our results showed that T6 produced the largest proportion of tubers of a higher quality (e.g., of a larger size), which are in high demand and are better priced on the market. In this sense, Noaema and Sawicka (2019) reported that various foliar fertilizers resulted in a higher contribution of large tubers (51–60 mm and > 60 mm in diameter) to the total tuber yield in a sandy loam. Conversely, Jasim et al. (2020) found no effects of different P doses on tuber size or potato yield in fine-lime soils with medium and high P levels, indicating that different fertilization strategies may be used for this cropping system.

Conclusions

Potato plants responded to orthophosphate and polyphosphate liquid fertilizers, and the effects of ammonium polyphosphate-based fertilizer were enhanced by the addition of fulvic acid. The foliar P content was similar among the different liquid P fertilizers under study. The highest number of stems was observed with the application of ammonium polyphosphate combined with fulvic acids. Higher proportions of commercial tubers were obtained by the application of liquid P fertilizers using ammonium polyphosphate-based fertilizer combined with fulvic acids pre- and postemergence. Further research is required for the economic analysis of this fertilization.

Compliance with Ethical Standards

Conflict of Interest: The authors declare that they have no conflicts of interest.

Resumen

I. Bustos, M. Schoebitz, E. Zagal, y C. Muñoz. Evaluación de fertilizantes líquidos fosforados y ácidos fúlvicos en un cultivo de papa en un suelo tipo Andisol. 2022. Int. J. Agric. Nat. Resour. 123-129. Los Andisoles son suelos derivados de cenizas volcánicas, caracterizados por altas concentraciones de fósforo (P). Sin embargo, gran parte del fósforo no está disponible para las plantas debido a las propiedades físico-químicas de estos suelos. El objetivo de este estudio de campo fue evaluar los efectos de fertilizantes líquidos de fósforo en el desarrollo y rendimiento de un cultivo de papa en un Andisol en el sur de Chile. Se aplicaron diez tratamientos antes y / o después de emergencia, incluyendo fertilizantes a base de ortofosfato o polifosfato de amonio, aplicados solos o en combinación con sustancias fúlvicas y fertilizantes granulares; además, se incluyó un control no fertilizado (T0). Se encontraron diferencias significativas entre los tratamientos de fertilizantes en cuanto a rendimiento, número total de tallos y tamaño de los tubérculos. El contenido de P foliar fue similar entre los fertilizantes líquidos probados, pero el número de tallos fue mayor en el tratamiento de combinación de polifosfato de amonio / ácido fúlvico. Además, se obtuvo una mayor producción de papas (38%) y proporción de tubérculos grandes (17%) mediante la aplicación de fertilizantes líquidos de fósforo. Los efectos de los fertilizantes líquidos de ortofosfato y polifosfato en la papa se vieron reforzados por la adición de ácido fúlvico al suelo.

Palabras clave: Etapas fenológicas, fertilizantes, ortofosfato, polifosfato, suelo volcánico, sustancias húmicas.

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