Can Agronomic Phosphorus Recommendations for Potato be Environmentally Sustainable?

By Ester Zamuner, Jaume Lloveras, and Hernan Echeverría

A better understanding of the relationship between the agronomic and environmental optimum for soil test P can guide potato growers in Buenos Aires province towards improved P fertilizer management.

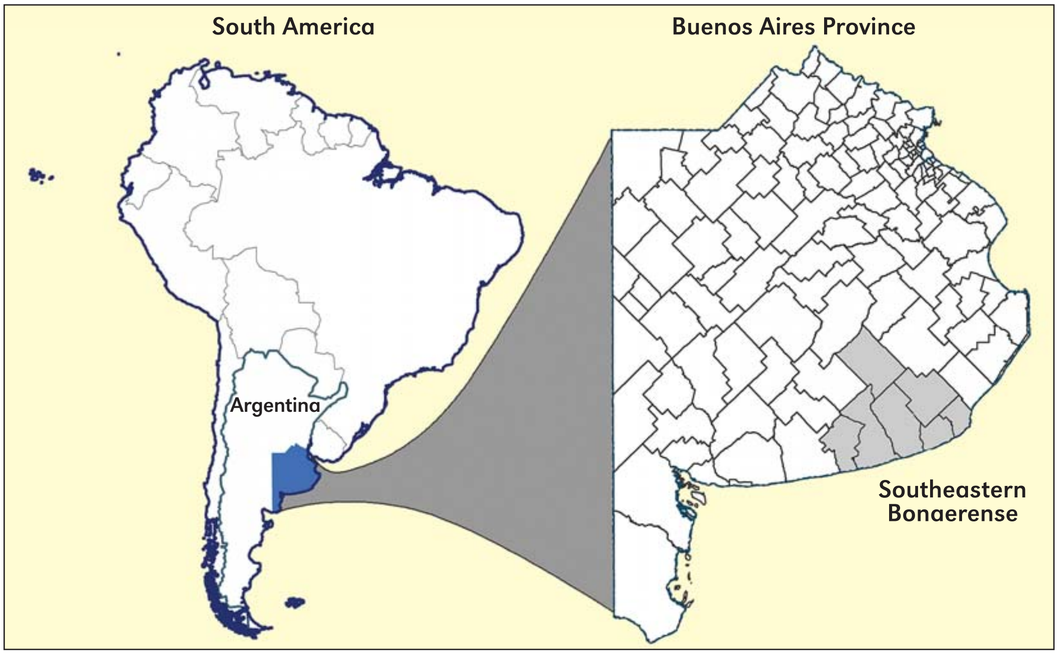


Figure 1. Shaded area shows the experimental area in the Southeastern Buenos Aires Province, Argentina.

The management of P is a critical component for potato production systems since the crop has a high P requirement but low P use efficiency, mostly because of its low root density (Fixen and Bruulsema, 2014; Rosen et al., 2014). In the southeastern Pampas region of Argentina (**Figure 1**) soils are commonly found to have low extractable P concentrations (less than 10 mg/kg) as determined by the Bray and Kurtz 1 (Bray-1 P) method. But in this region, potato crops typically respond to P fertilization even in soils with P availability that is considered high for other crops.

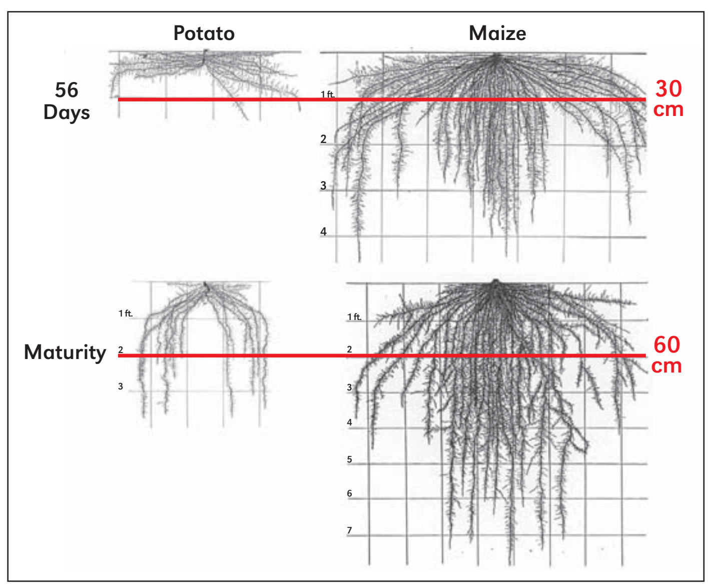
Since the cost of fertilization represents a low proportion of the final cost of production (approximately 8%) for this high value crop, producers often use larger amounts of P than necessary to reduce their risk of soil P insufficiency. If excessive P fertilizer is applied, the concentration of soil P can exceed the soil's retention capacity and the risk of P loss (via runoff or leaching) rises, especially during conditions of excess water. Excess P in streams, rivers, and lakes leads to eutrophication and can impact end-use quality and value (i.e., water supply, irrigation, recreation, etc.). The use of established thresholds for soil P availability can ensure high levels of crop productivity while minimizing environmental impact.

The definition of the agronomic critical P threshold is the soil P concentration beyond which no significant increase in yield will be expected with a further increase in fertilization.

Abbreviations and notes: N = nitrogen; P = phosphorus.

In this study, data from 13 P fertilization trials conducted between 2005 and 2014 were used to calculate this threshold for the potato-producing area of southeastern Buenos Aires province. This region has an average annual temperature of 13.8°C and average rainfall during the crop growing season of 670 mm. Most of the soils are non-calcareous, with no evident limitations for agricultural use. Some of the chemical properties of the experimental sites are listed in **Table 1**.

In each trial, soil samples (0 to 20 cm depth) were collected before planting. Extractable P was determined by the Bray and Kurtz 1 method. In each field experiment, potato, cv. Innovator, was planted between mid-October and mid-November. Four to six P fertilizers rates were evaluated at each field trial, using triple superphosphate (20% P) as the P source (**Table 1**). In order to maintain an appropriate N supply, urea (46% N) was added to each plot using 120 kg N/ha at planting and 100 kg N/ha at hilling. Irrigation was applied and disease and



Potato versus maize root development at 56 days after planting and at maturity (Weaver, 1926). Reprinted with permission from Fixen and Bruulsema. 2014, p.128. © Springer.

Table 1. Some soil characteristics (0 to 20-cm depth) and average tuber yields for the six P rates evaluated at the thirteen field trials conducted at southeastern Buenos Aires province (Argentina) conducted between 2005 and 2014.

Field trial	Bray-1 P mg/kg	pH	Organic matter %	Potato yield with P rates[1], kg/ha 0	25	50	100	150	200
				----------- t/ha					-----------
1	19	6.2	5.2	49.1 c	55.5 bc	62.8 ab	69.7 a	-	-
2	27	6.0	4.2	36.6 a	39.3 a	39.1 a	42.2 a	-	-
3	33	6.1	5.2	44.6 a	46.6 a	44.2 a	45.9 a	-	-
4	15	5.8	5.2	30.6 b	41.1 a	42.0 a	47.8 a	-	-
5	14	5.8	5.2	54.1 c	59.2 b	67.2 ab	75.3 a	-	-
6	22	6.1	5.4	37.1 b	39.9 b	43.9 a	45.9 a	-	-
7	9	6.2	5.4	44.7 b	64.4 a	65.7 a	73.5 a	-	-
8	29	5.9	5.8	66.3 a	-	-	65.1 a	-	75.6 a
9	11	6.6	3.8	49.4 c	53.6 bc	64.0 b	67.5 ab	-	75.5 a
10	45	5.9	6.1	58.5 a	65.3 a	66.1 a	70.5 a	-	-
11	20	5.9	6.5	63.7 b	64.5 ab	70.8 ab	77.2 a	81.2 a	75.5 a
12	19	6.0	5.0	43.5 c	50.4 bc	54.2 ab	57.2 ab	60.7 ab	65.1 a
13	19	6.0	5.6	46.9 c	51.5 bc	55.0 bc	57.9 ab	65.4 a	62.9 ab

[1]For each field trial, values followed by the same letter are not significantly different ($p < 0.05$).

pest controls followed recommended local practices. Crops were harvested between mid-February and mid-March and the fresh yield was determined. Potato yields obtained from the field experiments were then used to estimate yield responses to P fertilization and expressed as relative yield (RY). The RY was calculated for each trial by dividing the mean yield of the unfertilized treatment by the mean yield of the fertilized treatment with the highest yield, and then multiplying the result by 100.

Potato yields ranged from 31 to 81 t/ha across the different trials and P rates (**Table 1**). Phosphorus fertilization produced significant yield increases in 9 of the 13 experiments. On average, the unfertilized plots yielded 22 t/ha less than those fertilized with the highest P rate.

Average RY for each trial were plotted against initial soil Bray-1 P (**Figure 2**). The P threshold required to identify soils with positive responses to P fertilization was 32 mg/kg. No significant yield increase was observed above this threshold (Zamuner et al., 2016).

Agronomic versus Environmental Thresholds

Soil tests that assess the potential impact of soil P on the amount of P delivered to water bodies are commonly referred to as "environmental" methods. One of these methods is based on the extraction of P using calcium chloride (P-$CaCl_2$). Pöthing et al. (2010) concluded that if the value of P-$CaCl_2$ is greater than 5 mg/kg—known as the environmental critical P level—there is a risk of P loss from the soil. Use of such an environmental threshold is not common in Argentina and its on-farm implementation would still require the need to conduct two separate soil tests: one to establish the need for fertilization (Bray-1 P), and another to assess the environmental risk (P-$CaCl_2$).

In order to establish a relationship between Bray-1 P and P-$CaCl_2$, 137 soil samples obtained from the 13 field trials were analyzed (**Table 1**). Using the regression equations, a critical environmental threshold range of 37 to 39 mg/kg Bray-1 P was correlated to 5 mg P/kg P-$CaCl_2$ (Zamuner et al., 2015; **Figure 3**). This critical range should be considered a preliminary result since there is a large scatter in the Bray-1 P data around the value of 5 mg P/kg P-$CaCl_2$. However, since this preliminary range of critical environmental P values is greater than the range of critical agronomic P values (**Figure 4**), it can be concluded that a conflict between the productivity and environmental sustainability goals is unlikely for this potato production system.

Bray-1 P values for surface soil samples taken from this region of the Pampas rarely exceed the environmental threshold of 37 to 39 mg/kg Bray-1 P, so it is quite safe to assume that there would be no general risk of P loss. However, we can use field trials 7, 8, and 12 to illustrate how Bray-1 P measurements can change during the potato-growing season in response to P fertilization, and raise concern depending on the site.

Generally, Bray-1 P values increase in immediate response to the application of P fertilizer, but then decrease due to the effect of soil chemical reactions and crop uptake (**Figure 5**). Soil in trial 7 had low initial Bray-1 P (9 mg/kg; **Table 1**) and application of the recommended rate of 100 kg P/ha did not raise Bray-1 P above the environmental limit at any point in the growth cycle. At trial 8, pre-plant Bray-1 P was relatively high at 29 mg/kg, but still lower than the agronomic critical P threshold. The recommended rate of 25 kg P/ha did not elevate Bray-1 P beyond the environmental critical P threshold during the growing season; however, application rates of 50 and 100

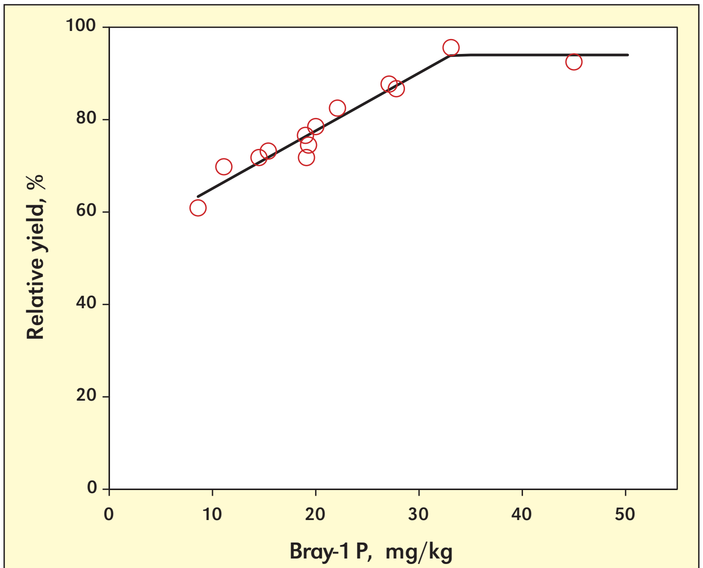


Figure 2. Relationship between extractable soil Bray-1 P and potato relative yield. RY = 1.25 (± 0.13)* P-Bray 1 + 52.6 (± 2.5) when RY < 92%, R^2 = 0.96 (Zamuner et al., 2016).

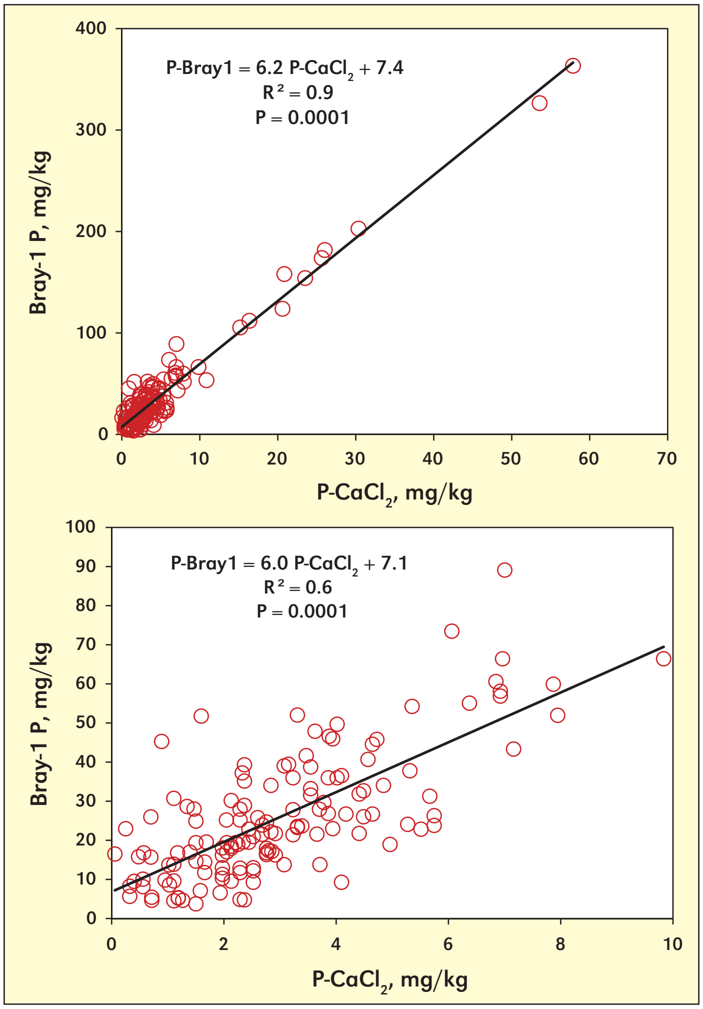


Figure 3. Relationship between soil P concentrations extracted with calcium chloride (P-$CaCl_2$) and Bray-1 P. The top figure shows the relationship for the whole range of soil P concentrations explored, and the bottom figure shows the relationship for the range of soil P concentrations around the environmental critical of 5 mg/kg of P-$CaCl_2$ suggested by Pöthig et al. (2010).

kg P/ha did raise Bray-1 P above the environmental threshold during the first 60 days after planting. Lastly, trial 12 had an initial Bray-1 P concentration of 19 mg/kg and recommended P rates in excess of 50 kg P/ha generated Bray-1-P values over the environmental threshold during the first two months after planting.

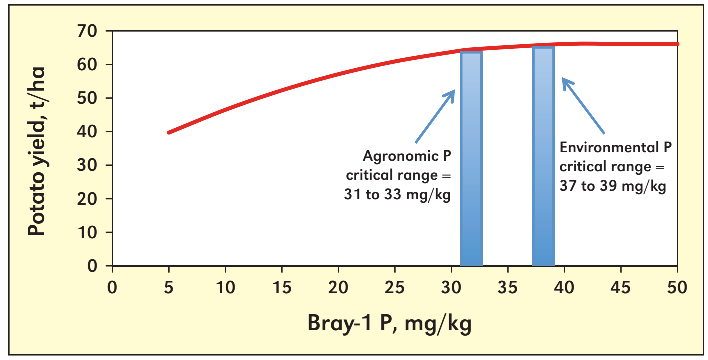


Figure 4. Relationship between extractable soil P as Bray-1 P and potato yield. Agronomic P critical range = P soil test range above which there is no significant crop response to P fertilization. Environmental P critical range = P soil test range below which there is no environmental P risk.

Summary

The results above highlight the importance of research that can accurately define critical soil test levels for cropping systems of concern. Irrigated potato production systems can be prone to conditions that increase the risk for environmental P loss; however, grower's can manage this risk by applying the concept of the critical P threshold. Fields with pre-plant Bray-1 P concentrations that are close to the critical environmental threshold should be managed in order to reduce the potential for leaching and runoff losses that can occur with excess irrigation water or rainfall, particularly on sloping surfaces and within the first 60 days after planting. BC

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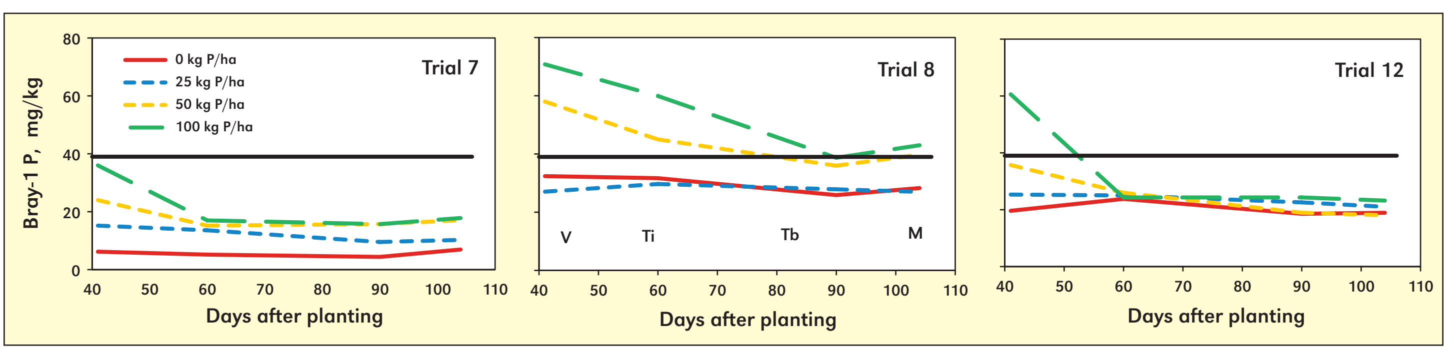

Figure 5. Extractable Bray-1 P in soil samples (0 to 20 cm) across two growing seasons for potato crops fertilized with 0, 25, 50, or 100 kg P/ha. Crop growth stages: V = vegetative growth; Ti = tuber initiation; Tb = tuber bulking; M = maturation. Horizontal black line corresponds to environmental P critical value.