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Phosphorus use efficiency, tuber yield and quality of potato processing varieties grown under different P levels in the Argentinian Pampas

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Summary

To assess the effect of different P rates on Phosphorous Use Efficiency (PUE), tuber yield, quality, and economic return, a field trial under central pivot irrigation, with cultivars Daisy and Innovator, was carried in the southeast region (Balcarce, 37º 45' SL; 58º 18' WL, 130 masl) in a typical Argiudoll soil. In Daisy, increasing P rates increased dry matter accumulation in haulms and tubers, mainly in the period up to 90 days after planting (DAP). The higher P rates increased P level both in haulm and tubers up to 90 DAP, but decrease PUE at the higher P rate. In Innovator the response to P rates was much higher and this variety resulted more efficient in P use than Daisy. In Innovator, increasing P rates lead to a higher tuber yield and a higher net economic return. In these two varieties, a different fertilization approach must be followed to improve P use efficiency and crop return. Lower levels of P can be used in Daisy which will not impact on final tuber yield, while in Innovator higher levels of P are required to achieve higher yields and increase crop net return.

Additional Keywords: Potato, Tuber Yield, Phosphorus Use Efficiency, Economic Return.

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Eficiencia en el uso de fósforo, rendimiento de tubérculos y calidad de variedades de papa cultivadas bajo diferentes niveles de P en la Pampa Argentina

Resumen

Para evaluar el efecto de diferentes dosis de P sobre la eficiencia en el uso del fósforo (EUF), el rendimiento del tubérculo, la calidad y el retorno económico, se realizó un ensayo de campo bajo riego, con los cultivares Daisy e Innovator. El ensayo se realizó en Balcarce (37º 45' SL; 58º 18' WL, 130 m snm) en un suelo Argiudol típico. En Daisy, el aumento de la dosis de P incrementó la acumulación de materia seca, el nivel de P en el follaje y los tubérculos y el rendimiento hasta los 90 DAP. Por último, las dosis crecientes de P disminuyeron la EUF. Por su parte, en Innovator, el aumento en la dosis de P condujo a un incremento significativo en el crecimiento de la parte aérea y los tubérculos. Del mismo modo, se observó una mayor acumulación de P y mayor rendimiento en tubérculos. En Innovator la respuesta a las dosis de P fue mucho mayor y esta variedad resultó más eficiente en el uso de P que Daisy. Por último, en Innovator mientras las dosis de P aumentan, también el retorno económico neto presenta mayor valor. Bajo estas condiciones se debería seguir un enfoque de fertilización diferente para mejorar la EUF y el retorno del cultivo en estas dos variedades. En Daisy niveles menores de P que no impactaron en el rendimiento final del tubérculo, mientras que en Innovator se requieren niveles más altos de P para lograr mayores rendimientos y aumentar el retorno neto del cultivo.

Palabras claves adicionales: Papa, Rendimiento en Tubérculos, Eficiencia en el Uso del Fósforo, Retorno Económico.

Introduction

Potato *(Solanum tuberosum* L.) is the third staple food crop on a global basis, after rice and wheat (Torero, 2018). Moreover, in some regions and countries, potato utilization into processed products has also significantly increased during the last 20 years. For example, at present, in Argentina 25% of the total potato production is devoted to the processing industry, mainly for frozen French Fries (Napolitano, 2012). In the southeast region of the Argentinian Pampas (province of Buenos Aires), where the environment is very suitable for potato growing, more than 32,000 ha of the crop are grown annually, being this region the most important regarding potato production for processing crops (Argenpapa, 2018).

The French fry industry, particularly, requires specific high yielding varieties, with suitable tuber shape and length, relatively high levels of tuber dry matter concentration and low levels of reducing sugars, among other characteristics (Haverkort, 2018). To achieve high yield and quality, crop demands in term of resources are high, mainly regarding water and nutrients; the latter being one of the most limiting factors in the southeast region (Caldiz *et al*., 2018). However, if any of these resources are applied beyond the optimum levels, their effects could negatively impact on the system. For example, when high N rates are applied, nutrient losses and reduction in tuber dry matter concentration could occur (Giletto *et al*., 2011).

In the Argentinian Pampas, one of the reasons for over application of nutrients is the relatively low cost of the fertilizers, which represents less than 15% of the total production costs in processing crops (Argenpapa, 2021). Then, in some cases, fertilizers are applied without considering their real impact on yield and quality and

their major role in sustainability of the whole production system (Giletto *et al*., 2011; Caldiz *et al*., 2018). In parts of Europe and North America fertilizer strategies have increased the nutrient status of soil to levels that are excessive in terms of crop requirements and (potentially) pose a threat to surface – and ground water (Van Rotterdam-Los, 2010). In the region under study, the most suitable soils for potatoes, normally show low Phosphorus (P) availability (< 10 mg kg^{-1}, Sainz Rozas and Echeverría, 2008).

A study carried out by Rozas *et al*. (2012) also showed that soil P-Bray levels are lower or equal to 15 mg kg^{-1} in the Buenos Aires province, east of La Pampa, southeast of Córdoba and south of Santa Fe (approximately 15,227,000 ha), and therefore, P availability could limit crop production in this area. On the other hand, soils with available P concentrations higher than 15 mg kg^{-1} occupy 45% of the area (approximately 12,774,000 ha), and these soils are located mainly out of the pampas region. The decrease of available P concentration in the last 25 years was more important in the west and north than in the south of the Pampas region.

Within this framework, it is clear that a specific nutrient management would be beneficial for potatoes grown in the Argentinian Pampas. Otherwise, fertilization with P could not bring the desired effects on yield and quality, and could also negatively impact on the economic return and sustainability of the system (Caldiz *et al*., 2018). Therefore, a fertilization approach that could improve yield and tuber quality, while reducing possible environmental impacts due to nutrient losses from the soil system is required. Then, the aim of this work was to assess the effects of different P rates in tuber yield and quality and crop economic returns. To achieve these objectives a field trial was carried out with two of the most important varieties grown for the processing French fry industry in the Argentinian Pampas.

Materials and Methods

The field work was carried out during the agricultural season 2011-2012, at Balcarce (37º 45' SL; 58º 18' WL, 130 masl), Buenos Aires province, Argentina. Soil was a typical Argiudoll (Soil Survey Staff, 1992) without no limitations. Main soil characteristics are shown in **Table 1.**

Table 1. Main soil characteristics at the experimental site.

Soil variable	Content
pH	6.1
Organic matter, in g g 100^{-1}	4.7
P (0 - 20 cm), in mg kg^{-1}	8.3
$N\text{-}NO_3$ (0 - 40 cm), in mg kg^{-1}	24.35
N mineralization potential[(a)], in kg ha^{-1}	152
Ca^{+2}, in cmol kg^{-1}	11.3
Mg^{+2}, in cmol kg^{-1}	2

(a) Calculated based on Echeverría and Bergonzi (1995).

Two separate trials were performed with the processing potato varieties Daisy and Innovator. Seed tubers (50 g per seed piece, at a rate of 5 seed pieces per lineal m^{-1}) were planted with a 4-row Grimme planter, on 24th October 2011 in a randomized block design with three replications of 4 rows x 10 m long, each. With the planter a base rate of 75 kg P ha^{-1} (P source was triple superphosphate –TSP-, always) were applied, except for the control treatment. In each trial, P was applied at 0, 75, 100, 125 and 150 kg ha^{-1}, for the control, T1, T2, T3, and T4 treatments, respectively. As soil initial P was 20 kg ha^{-1}, final P rates were 20, 95, 120, 145, and 170 kg P ha^{-1}, but for simplicity previous description will be used.

To compensate for Ca supplied by TSP, $NO_3(Ca)_2$ was applied to the control, T1, T2 and T3 treatments, as follows: 105; 52; 35, and 17,5 kg ha^{-1}, respectively. Finally, for all treatments, N sources were Urea and $NO_3(Ca)_2$ that were applied at 50 kg N ha^{-1} at planting, and 150 kg N ha^{-1} at 45 days after planting. Except for the initial P base rate, all other fertilizers were applied by hand and incorporated, either at planting or at hilling. Hilling was performed immediately after planting, while all soil tillage operations and weeds, pests and disease management were carried out as normally done for these varieties (Caldiz, 2004; Hernández and Caldiz, 2006). The crop was irrigated with a traditional sprinkler system and irrigation started when soil water dropped to 50-60% field capacity. In total 786 mm were applied (rainfall + irrigation) during crop cycle. The crop was harvested after natural death of the haulm, on 12th March 2012.

Crop growth and nutritional assessment

At 60, 90 and 120 days after planting, 5 complete plant samples were harvested from each replication and split into haulm and tubers. Haulm and tuber fresh tuber weight were recorded at each sampling date. Afterwards each sample (tuber + haulm) was dried at 60 ºC for 72 h or until constant weight to assess dry weight. A dry sub-sample from haulm and tubers was used to assess N concentration by the Kjeldahl method (Nelson and Sommers, 1973). Another dry sub-sample was use to assess total P after digestion in Nitric and Perchloric acids (Blanchard *et al.* 1965).

During crop growth, also petiole samples from the fourth leaf from the top were collected 5 times during early-December to late-February. A total of 30 petioles were sampled from each plot on each sampling date. Petioles were oven dry at 60°C and ground through a 1 mm screen with a Wiley mill. Tissue was ground and total P was determined using an inductively coupled plasma spectrometer (Munter *et al*. 1984). Phosphorus use efficiency (PUE) was assessed based on the formulae: PUE= (kg DM fertilized tubers – kg DM control tubers) / kg P applied.

Yield and quality assessment

At crop maturity, 2 lineal meters of the two central rows of each plot were harvested to assess tuber number, yield and quality. Fresh tuber weight of each sample was recorded, and the relative yield (RY) was calculated as the ratio between yield of each treatment and the highest average yield of the trial. Tuber dry matter concentration was derived from the specific gravity, which was calculated based on the weight in air – weight in water method from a tuber sample of 3.5

kg, from each plot. Tubers defects, such as greening, Common scab, insect damage, *Fusarium* spp. blackspot bruise, Brown center, other internal defects, malformations, rotten, mechanical damages (shatter bruise), hallow heart and external defects were assessed following the McCain Receiving Lab protocol. Values are expressed in percentage regarding the total sample weight of each plot.

Crop economic return

The economic net return was calculated based on the gross sale value of the crop minus the cost of the fertilizer applied, including the application cost, following the methodology proposed by Constantino (2005). The price for commercial tubers (> 50 mm in diameter) was the average for the season 2020-2021 (Argenpapa, 2021). N and P fertilizer price were calculated as the average fertilizer price for the period 2001–2021 (www.indexmundi.com) as follows: urea at 287 U$S t^{-1}; triple superphosphate at 361 U$S t^{-1} and calcium ammonium nitrate at 230 U$S t^{-1}. Results were analyzed with the Statistical Analysis Systems program (SAS Institute, 1988). Values were compared using the least significant difference test (LSD) at $p \leq 0.1$ when the ANOVA was significant.

Results and Discussion

Previous work has demonstrated that P is one of the most critical limiting factors in the road to improve tuber yield and quality in the Argentinian Pampas (Cabello et al., 2011). In the present work particular evidence about the role of P on crop growth, yield and tuber quality and use efficiency are shown.

Crop Growth

In Daisy, increasing P rates increased dry matter accumulation in haulms and tubers, mainly in the period up to 90 days after planting (DAP). At 120 DAP no differences were observed in haulm growth while differences in tuber growth were also not significant when compared to the control treatment **(Fig. 1a and Fig. 1b).**

In Innovator, increasing P rates lead to a significant increase in haulm and tuber growth. Early haulm growth was significantly improved early in the season (60 DAP) which has an impact on radiation interception, the main driver of dry matter accumulation (Haverkort, 2018; **Fig. 2a**). This was clearly reflected on tuber growth that was higher at higher P rates during mid and late growth (90 and 120 DAP, **Fig. 2b)**

P evolution during crop growth

P was followed at petiole level, as it is normally done to assess crop nutritional status (Collins et al., 2016) and also on dry basis in haulms and tubers. In both cultivars higher P rates increased P petiole content early in the season (43 and 69 DAP). Later on the season P petiole level did not differ in Daisy, but continue to show significant differences in Innovator **(Fig. 3a and 3b).** Results showed that P levels in Innovator were critical to maintain a higher P petiole level in the crop late in the season. The lower the P rate, the lower the P petiole content at the end of crop growth.

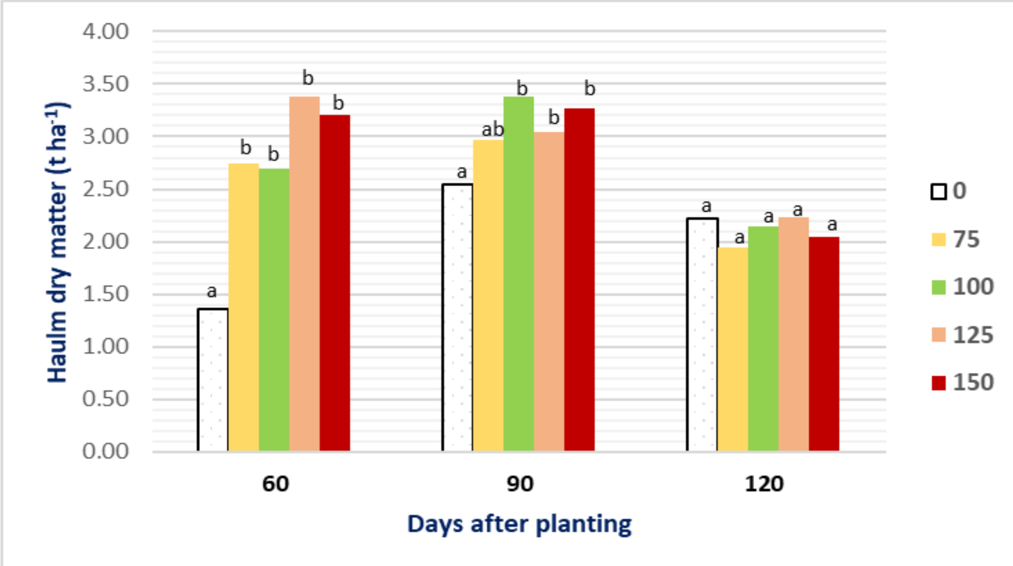

Figure 1a. Effect of P rates (0; 75; 100; 125 and 150 kg P ha^{-1}) on haulm dry matter accumulation in **cv. Daisy** at 60, 90 and 120 days after planting (DAP). Equal letters indicate non-significant differences (α=0.1), LSD Test. References: 60 dap CV (%) 18.37, P value 0.0041; 90 dap CV (%) 10.55 P value 0.0701; 120 dap CV (%) 22.57, P value 0.9344

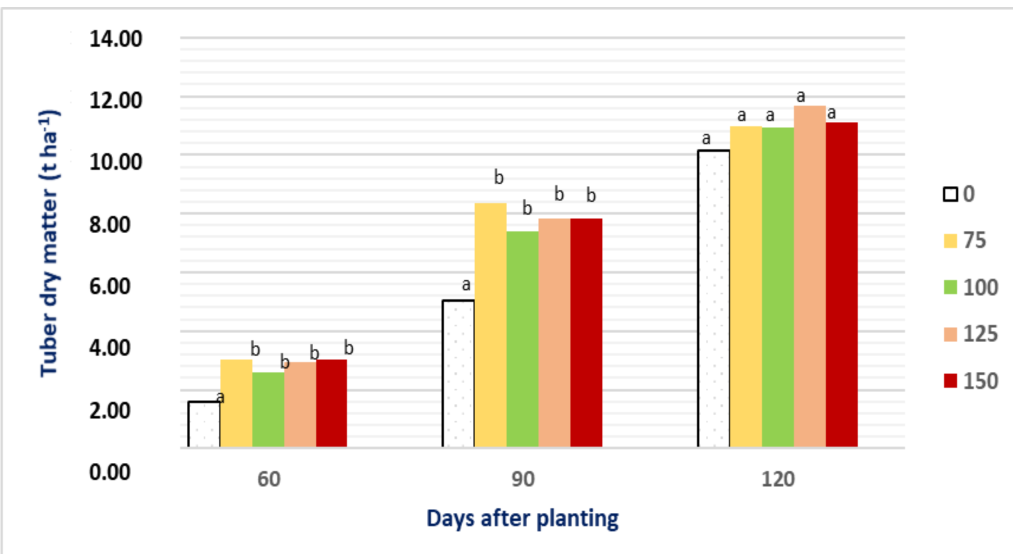

Figure 1b. Effect of P rates (0; 75; 100; 125 and 150 kg P ha^{-1}) on tuber dry matter accumulation in **cv. Daisy** at 60, 90 and 120 days after planting (DAP). Equal letters indicate non-significant differences (α=0.1). LSD Test. References: 60 dap CV (%) 18.44 P value 0.0187; 90 dap CV (%) 10.86 P value 0.0033; 120 dap CV (%) 12.50 P value 0.7424

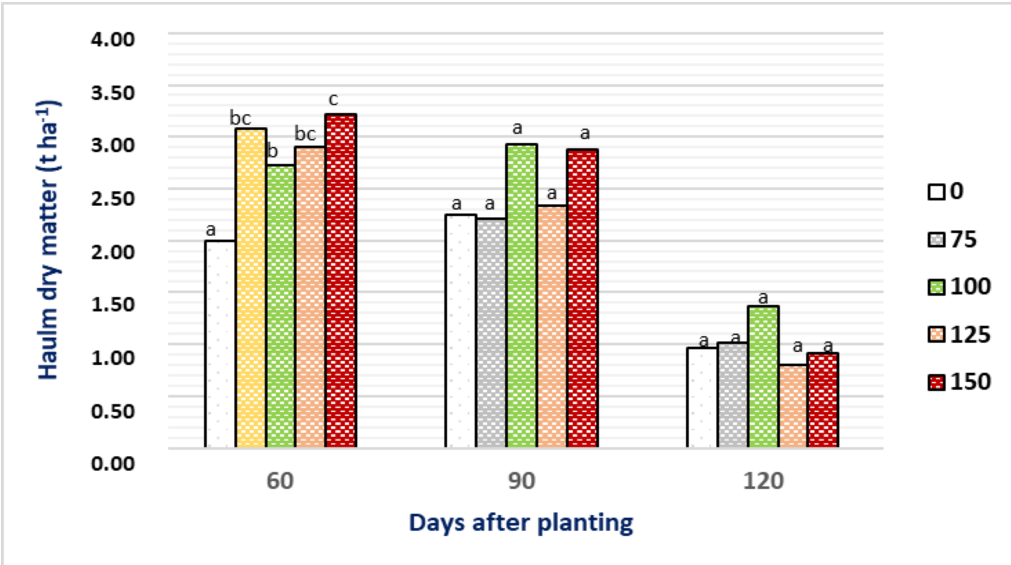

Figure 2a. Effect of P rates (0; 75; 100; 125 and 150 kg P ha^{-1}) on haulm dry matter accumulation in **cv. Innovator** at 60, 90 and 120 days after planting (DAP Equal letter indicate non-significant differences (α=0.1), LSD Test. References: 60 dap CV (%) 9.07 P value 0.0013; 90 dap CV (%) 22.67 P value 0.3891; 120 dap CV (%) 29.06 P value 0.2586

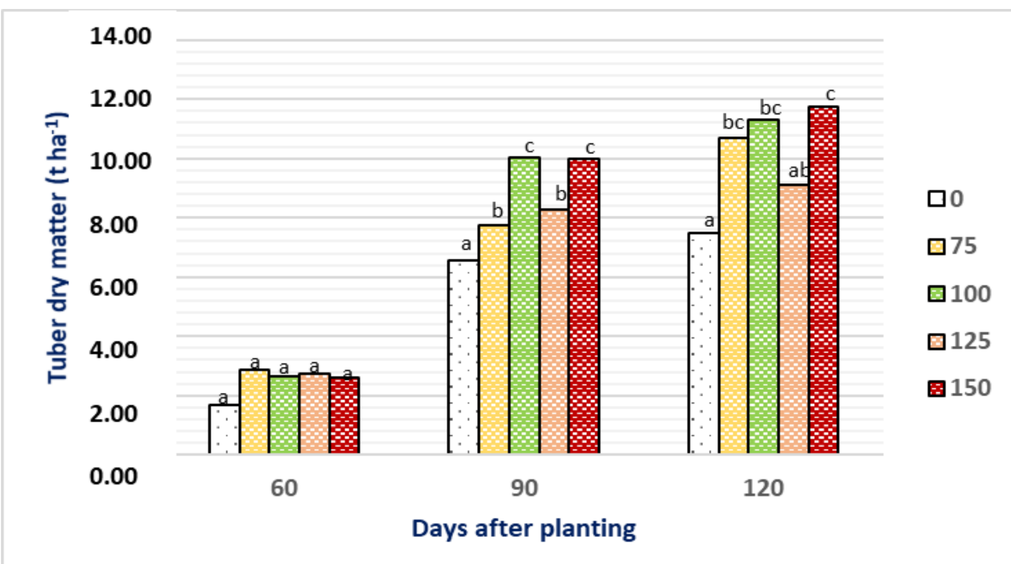

Figure 2b. Effect of P rates (0; 75; 100; 125 and 150 kg P ha^{-1}) on tuber dry matter accumulation in **cv. Innovator** at 60, 90 and 120 days after planting (Daisy response of dry matter accumulation in tubers at 60, 90 and 120 dap to different P rates (0; 75; 100; 125 and 150 kg P ha^{-1}). Equal letters indicate non-significant differences (α=0.1). LSD Test. References: 60 dap CV (%) 25.63 P value 0.2389; 90 dap CV (%) 8.11 P value 0.0004; 120 dap CV (%) 16.98 P value 0.0629

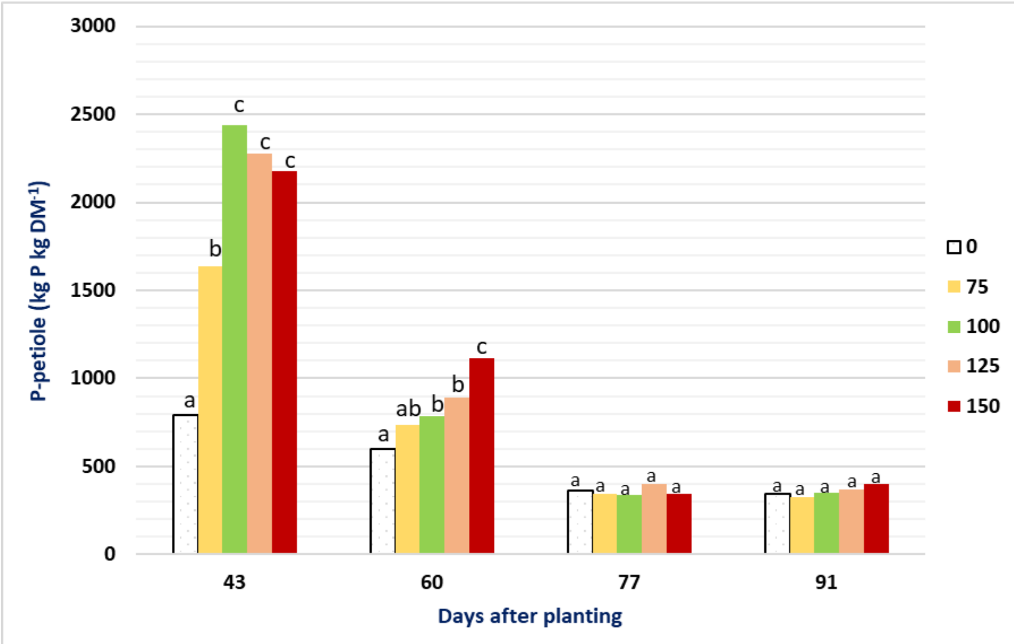

Figure 3a. P-petiole evolution in **Daisy** in response to different P rates (0; 75; 100; 125 and 150 kg P ha^{-1}). Equal letters indicate non-significant differences (α=0.1). LSD Test. References: 43 dap CV (%) 11.39 P value 0,0001; 60 dap CV (%) 15.39 P value 0.0057; 77 dap CV (%) 8.77 P value 0.1579; 91 dap CV (%) 8.98 P value 0.147

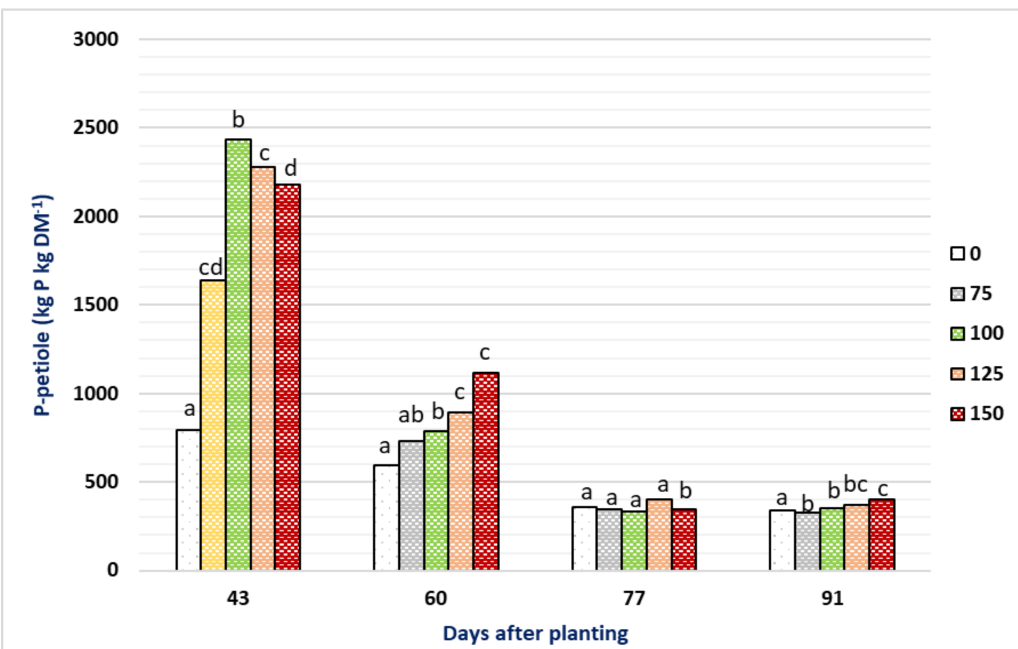

Figure 3b. P-petiole evolution in **Innovator** in response to different P rates (0; 75; 100; 125 and 150 kg P ha^{-1}). Equal letters indicate non-significant differences (α=0.1). LSD Test. References: 43 dap CV (%) 6.17 P value 0,0001; 60 dap CV (%) 12.27 P value 0.0012; 77 dap CV (%) 3.46 P value 0.0246; 91 dap CV (%) 14.07 P value 0.0017

P concentration in haulm and tubers

In Daisy the higher P rates increased P level both in haulm and tubers up to 90 DAP. At 120 DAP although differences were observed they were not significantly different. However, it is evident that the crop has the ability to extract and accumulate more P if it is available in the soil **(Fig 4a and 4b)**

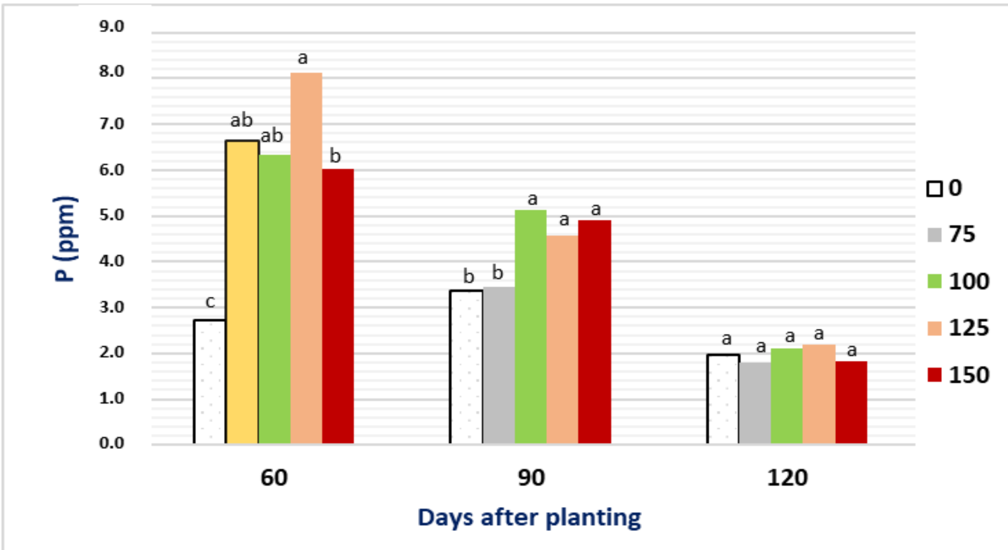

Figure 4a. Daisy P concentration (ppm) in haulm at 60, 90 and 120 dap to different P rates (0; 75; 100; 125 and 150 kg P ha^{-1}). Equal letters indicate non-significant differences (α=0.1). LSD Test. References: 60 dap CV (%) 23.56 P value 0.0102; 90 dap CV (%) 16.84 P value 0.0381; 120 dap CV (%) 30.9 P value 0.916

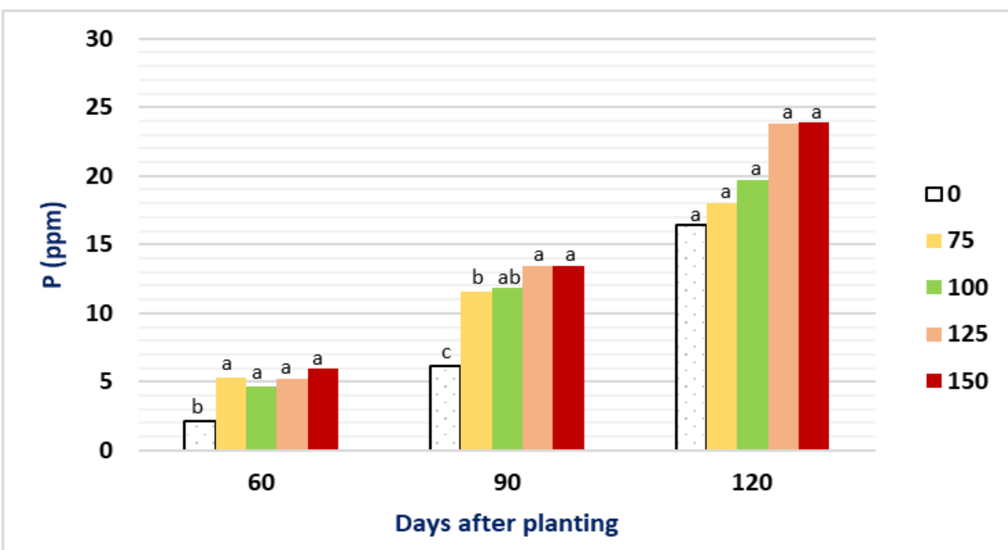

Figure 4b. Daisy P concentration (ppm) in tubers at 60, 90 and 120 dap to different P rates (0; 75; 100; 125 and 150 kg P ha^{-1}). Equal letters indicate non-significant differences (α=0.1). LSD Test. References: 60 dap CV (%) 24.94 P value 0.0187; 90 dap CV (%) 11.22 P value 0.0002; 120 dap CV (%) 22.98 P value 0.2575

A similar pattern was observed in Innovator, but in this variety, the higher the P rates the higher accumulated P, mainly in the tubers. Significant differences in P accumulation were observed between the control treatment and the increasing P rates **(Figure 5a and 5b)** P petiole evolution and P accumulation in haulm and tubers followed a similar pattern, being Innovator the variety showing a higher response to P rates.

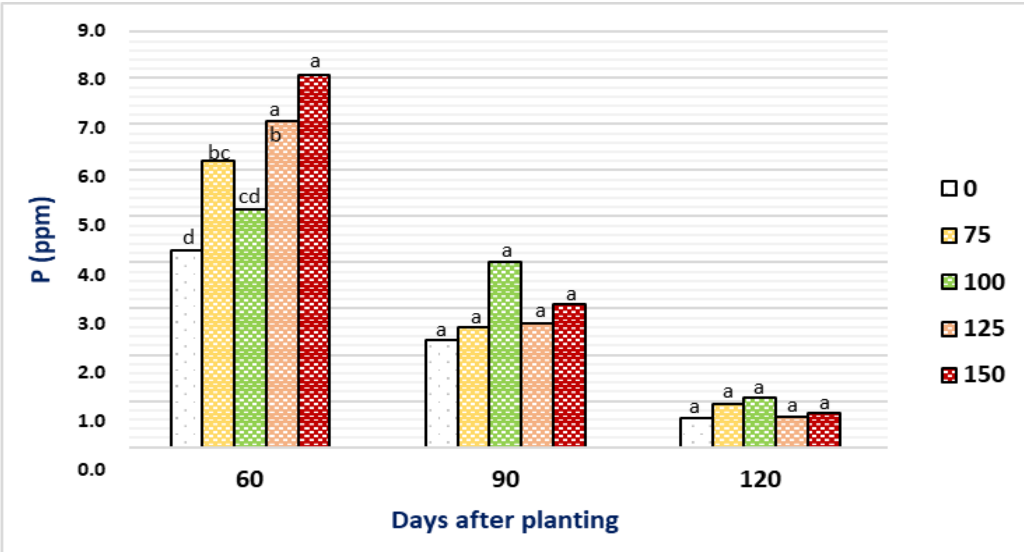

Figure 5a. Innovator P concentration (ppm) in haulm at 60, 90 and 120 dap to different P rates (0; 75; 100; 125 and 150 kg P ha^{-1}). Equal letters indicate non-significant differences (α=0.1). LSD Test. References: 60 dap CV (%) 13.81 P value 0.002; 90 dap CV (%) 26.98 P value 0.161; 120 dap CV (%) 30.55 P value 0.2063

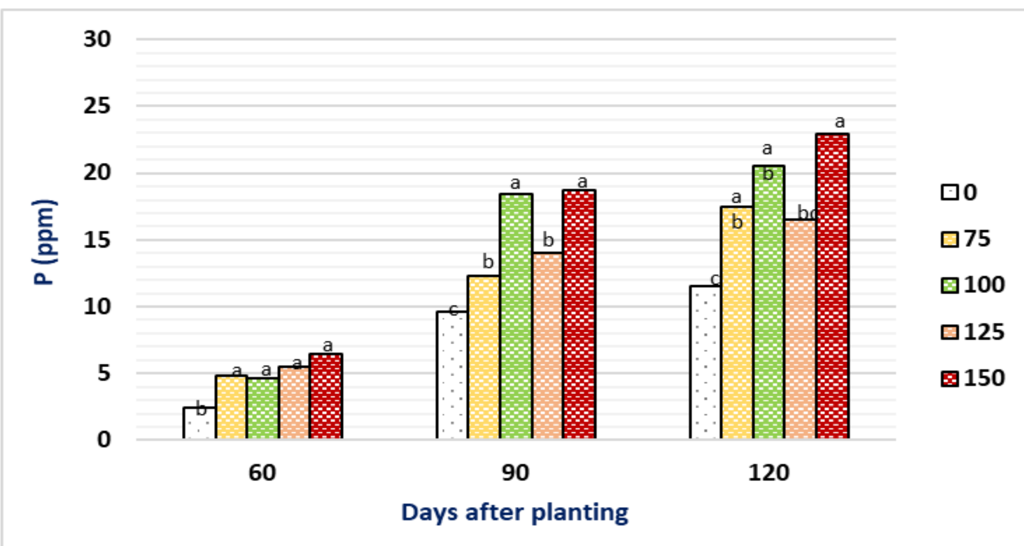

Figure 5b. Innovator P concentration (ppm) in tubers at 60, 90 and 120 dap to different P rates (0; 75; 100; 125 and 150 kg P ha^{-1}). Equal letters indicate non-significant differences (α=0.1). LSD Test. References: 60 dap CV (%) 29.54 P value 0.0557; 90 dap CV (%) 8.76 P value 0.0001; 120 dap CV (%) 20.97 P value 0.0343

Phosphorus use efficiency

Phosphorus use efficiency at harvest was assessed at tuber level. In Daisy the increasing P rates decrease PUE at the higher P rate. However, in T3 (125 kg P ha^{-1}) the PUE was higher both at plant and tuber level (Table 2).

Table 2. Phosphorus use efficiency (PUE) at different P rates for Daisy and Innovator.
PUE= (kg DM fertilized tubers – kg DM control tubers) / kg P applied

P applied	------------- **Daisy** ------------		--------- **Innovator** ---------	
(Kg ha^{-1})	Tuber dry matter (t ha^{-1})	PUE	Tuber dry matter (t ha^{-1})	PUE
0	10.13		7.47	
75	10.98	11.34	10.7	43.1
100	10.95	8.19	11.3	38.28
125	11.68	12.4	9.12	13.22
150	11.12	6.58	11.75	28.53

In Innovator the response to P rates was much more higher and this variety resulted more efficient in P use than Daisy. More kilograms of dry matter were produced at tuber level when the P rates were higher. Innovator makes much more better use of P than Daisy. This must be considered in defining future fertilization strategies for these two varieties. From the present results is clear that P fertilization plays a key role in Innovator due to its positive impact on P petiole content, P absorption and P use efficiency.

Tuber yield and quality

Overall, in potatoes tuber yield and quality are the main drivers of sustainability and crop return.

Fertilizers are applied to obtain higher returns and in case of processing potatoes this is achieved through tuber yield and tuber quality. In Daisy higher P rates increased tuber yield early in the season and by 90 DAP yield in the higher P rates almost double that of the control. At 120 and 135 DAP although differences exist between the control and the higher P rates, these were not significant **(Fig. 6).** This could mean that at higher P rates, there was probably another nutrient limiting tuber yield (van Rotterdam-Los, 2010; Caldiz *et al*., 2018)

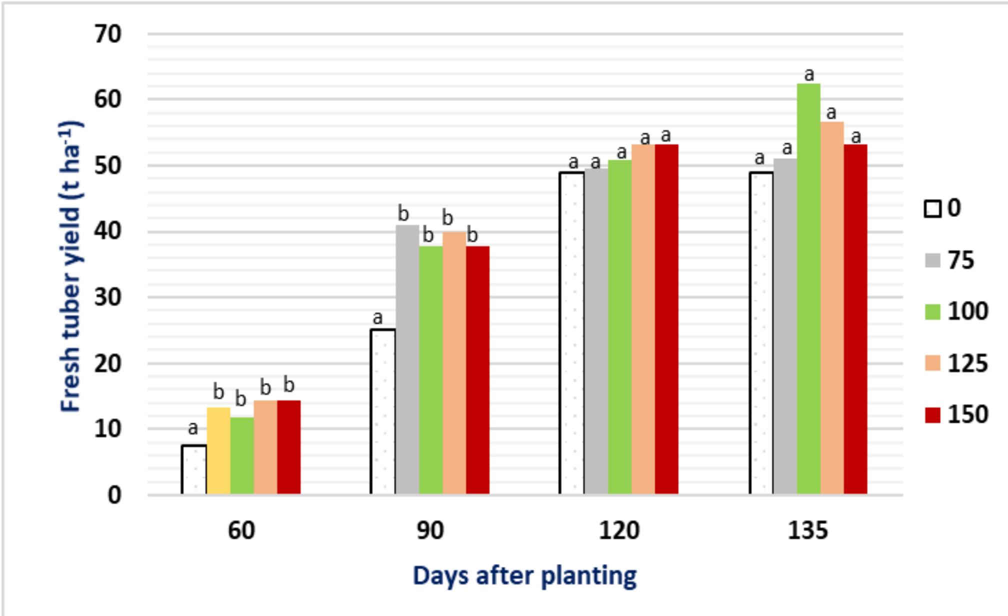

Figure 6. Daisy fresh tuber yield at 60, 90 and 120 dap to different P rates (0; 75; 100; 125 and 150 kg P ha^{-1}). Equal letters indicate non-significant differences (α=0.1). LSD Test. References: 60 dap CV (%) 17.26 P value 0,0132; 90 dap CV (%) 9.73 P value 0.0017; 120 dap CV (%) 10.67 P value 0.8099; 135 dap CV (%) 13.35 P value 0.2778.

In Innovator as already observed for other variables, increasing P rates lead to a higher response of the crop, in this case regarding tuber yield. Early in the season yield in the control treatment was 30.75 t ha^{-1} while in the higher P rate the yield was 48.09 t ha^{-1}, a very significant difference that showed the higher use of P by this cultivar. The same pattern was observed late in the season, where the yield was lower in the control treatment when compared with any of the P rates, specially at the final harvest **(135 DAP, Fig. 7).** Probably to achieve even higher yield the rate of other nutrients should be also increased (Caldiz et al., 2016).

In conclusion, Daisy and Innovator has a totally different behavior regarding P use. Daisy has a low P use efficiency than Innovator and in this variety high P rates are critical to achieve high yields. Moreover, in both varieties the increasing P rates did not impact negatively on the dry matter percentage of the tubers; moreover, in Innovator a slight tendency to show higher dry matter levels at higher P rates was observed **(Fig. 8).**

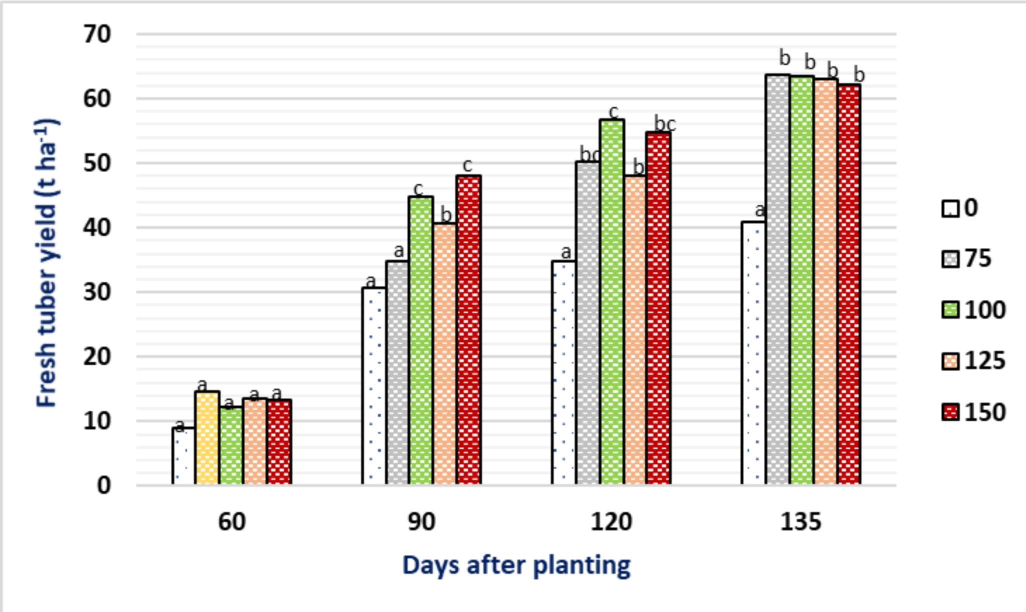

Figure 7. Innovator fresh tuber yield at 60, 90 and 120 dap to different P rates (0; 75; 100; 125 and 150 kg P ha^{-1}). Equal letters indicate non-significant differences (α=0.1). LSD Test. References: 60 dap CV (%) 21.05 P value 0.1655; 90 dap CV (%) 7.19 P value 0.0001; 120 dap CV (%) 10.98 P value 0.0041; 135 dap CV (%) 9.31 P value 0.0017.

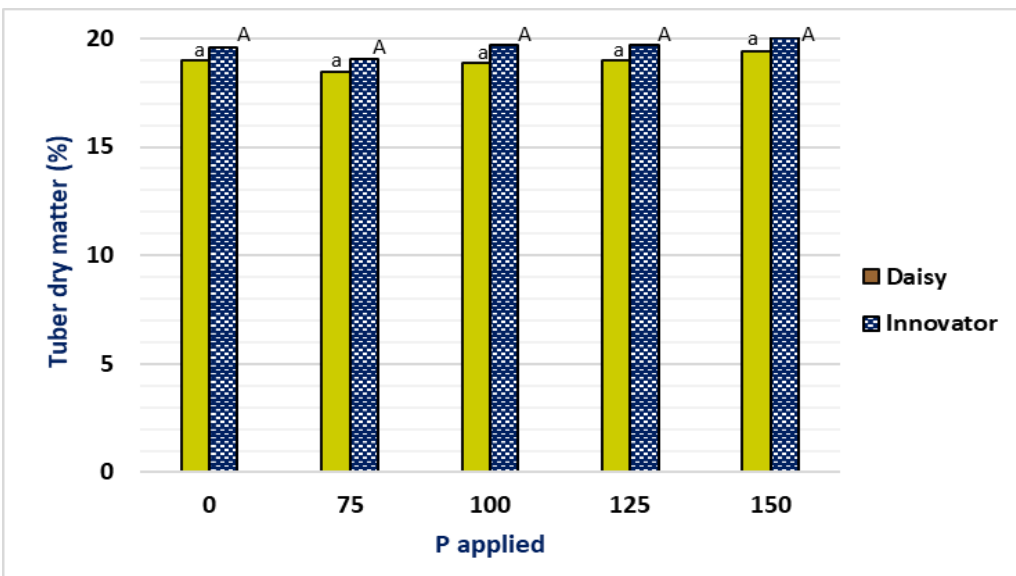

Figure 8. Tuber dry matter concentration at harvest, with different P rates (0; 75; 100; 125 and 150 kg P ha^{-1}). For each variety equal letters indicate non-significant differences (α=0.1). LSD Test.

Economic return

Results of the present study showed that applying P had a positive impact on net return at both varieties. However, they showed a different pattern. In Daisy, higher net return was estimated at 75 kg P ha^{-1}. Higher P rates reduce net economic return. On the other hand, in Innovator while P rates increase, also net economic return present higher value **(Fig. 9).**

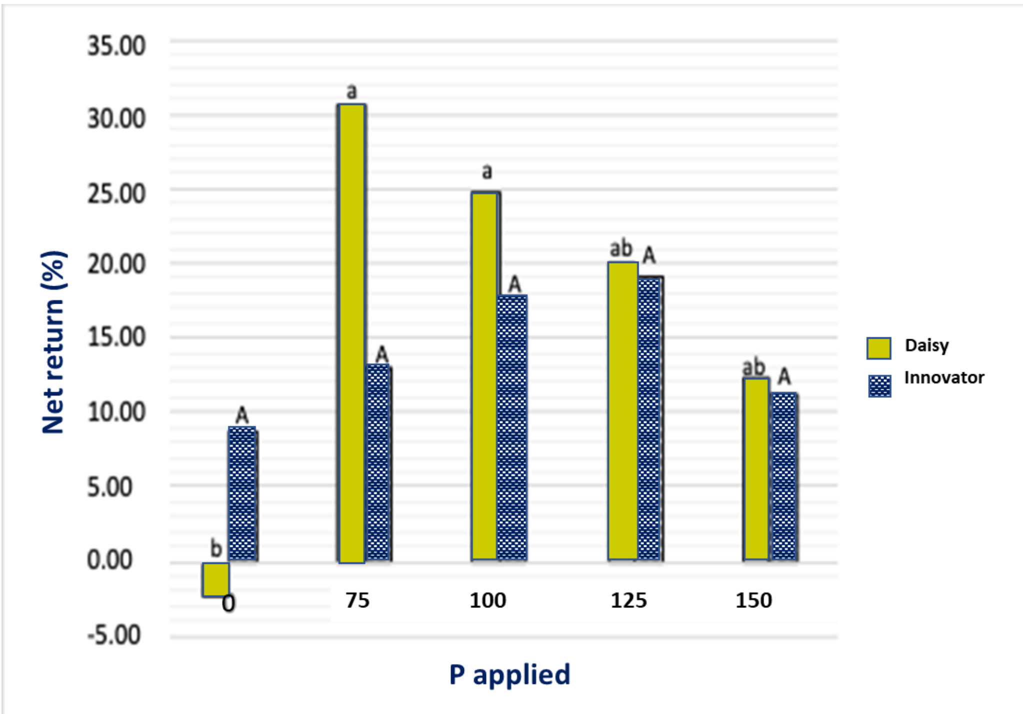

Figure 9. Effect of P rate on the economic net return for Daisy and Innovator. For each variety equal letters indicate non-significant differences (α=0,05). LSD Test. Net return was assessed based on the formulae: Net return (%) = (gross sale U$S ha^{-1} – total cost U$S ha^{-1}) / gross sale U$S ha^{-1} *100.

Then, for the Argentinian Pampas a different fertilization approached must be followed to improve P use efficiency and crop return in these two varieties. Lower levels of P can be used in Daisy which will not impact on final tuber yield, while in Innovator higher levels of P are required to achieve higher yields and increase crop net return.

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