Nutrient uptake of the criolla potato (*Solanum phureja* var. Galeras) for the determination of critical nutritional levels

Absorción de nutrientes en papa criolla (*Solanum phureja* var. Galeras) para determinar niveles críticos nutricionales

Jaime Torres B.[1] and Carlos A. Suarez M.[2]

ABSTRACT

Based on the nutrient uptake of the criolla potato (*Solanum phureja* var. Galeras), the critical nutritional levels were determined on a farm in the Carrizal district of the municipality of Granada (Cundinamarca). Five fertilizing treatments were used: 0 fertilization (control), commercial control (CC), proposed recommendation + 50% (PR + 50%), proposed recommendation (PR), proposed recommendation - 50% (PR – 50%); organized with a random complete block design with three repetitions and repeated measurements over time; in each one, the material and nutrient absorption were evaluated in four phonological stages; in which the harvest, yield and profitability were measured. It was observed that the dry material increased rapidly until 113 days after planting (dap) and was higher in treatments CC and PR + 50% with 8,818 and 7,743 kg ha^{-1}, respectively. The statistical analysis showed that the elements: N, P, K, Ca, Mg, S, Zn, Cu and B did not present significant differences over time after 77 dap in treatments CC and PR + 50%. There were no significant differences in yield for treatments CC and PR + 50% but there were significant differences between these treatments and the others. The economic analysis showed that treatment CC had the highest profitability, confirming this as the critical level for the Galeras variety in Granada (Cundinamarca).

Key words: fertilization, dry matter, crop growth stage, yield, root vegetables.

RESUMEN

Con base en la absorción de nutrientes en papa criolla (*Solanum phureja* var. Galeras), se determinaron los niveles críticos nutricionales para una finca localizada en la vereda Carrizal del municipio de Granada (Cundinamarca). Se emplearon cinco tratamientos fertilizantes [0 fertilización (control), control comercial (CC), recomendación propuesta + 50% (PR + 50%), recomendación propuesta (RP) y recomendación propuesta - 50% (PR – 50%)] dispuestos en un diseño de bloques completos al azar con tres replicaciones y medidas repetidas en el tiempo, en cada uno se evaluó materia seca y absorción de nutrientes en cuatro etapas fenológicas; en cosecha se midió rendimiento y rentabilidad. Se observó que la materia seca aumentó rápidamente hasta 113 días después de siembra (dds) y fue mayor en los tratamientos CC y PR + 50% con 8.818 y 7.743 kg ha^{-1}, respectivamente. El análisis estadístico mostró que los elementos N, P, K, Ca Mg, S, Zn, Cu y B no dieron diferencias significativas en el tiempo después de los 77 dds para los tratamientos CC y PR + 50%. No se encontraron diferencias significativas en rendimiento para los tratamientos CC y PR + 50%, pero sí de estos con los demás. El análisis económico mostró que la mayor rentabilidad la dio el tratamiento CC, constituyéndose los valores extraídos por la planta con este, como los niveles críticos para la variedad Galeras en Granada (Cundinamarca).

Palabras clave: fertilización, materia seca, etapas de crecimiento del cultivo, rendimiento, hortalizas de raíz.

Introduction

The principal producer of the criolla potato in the world is Colombia. In 2008, close to 8,300 ha year^{-1} were established, which represents approximately 6% of the cultivated area for potatoes in the country, with 90% of the production in the departments of Nariño, Cundinamarca, Boyaca and Antioquia. Colombia is the biggest consumer and exporter in the world with numbers close to 1,000 t year^{-1} (Fedepapa, 2009). Due to the high acceptance of the criolla potato with its nutritional quality and organoleptic characteristics, new crops that are being established are geared toward its commercialization, with a view towards increasing exports (Rodríguez *et al.,* 2009).

Scarce agronomic information for the criolla potato in all its developmental stages has meant that the employed management technologies are extrapolated for the potato each year, including fertilization, which is not applied in a suitable manner, shortening the production cycle of the phureja

Received for publication: 29 January, 2014. Accepted for publication: 19 March, 2014.

[1] Department of Agronomy, Faculty of Agricultural Sciences, Universidad Nacional de Colombia. Bogota (Colombia). jtorresb@unal.edu.co
[2] Agricultural Professional Assistant, Epsagro Asoprotecam. Puente Nacional (Colombia).

group, which allows for three harvests per year (Rodríguez *et al.*, 2009), different from the two harvests per year for the potato. This has resulted in the productive potential of this genetic resource not being expressed adequately and, therefore, inadequate profitability and competitive limitations due to an apparent excess of fertilization.

Fertilization represents close to 39% of the total costs of production (Porras, 2005), where the higher demand is for the fertilizer compounds nitrogen, phosphorus, potassium, and potassium, elements that cause production limitations due to their marked interaction, which has been proven in various studies on the papa de año (Andigena potato), according to Guerrero (1989).

The nutrient demands of the criolla potato have not been established; however, in preliminary studies that compared dose with production, it was observed that demands for P_2O_5 are between 40 and 100 kg ha^{-1}, but no yield response has been seen for values above 50 kg ha^{-1} of P_2O_5 (Rozo, 2006). In regards to nitrogen (N), the criolla potato responds favorably to doses between 50 and 100 kg ha^{-1} (Guerrero, 1989). For potassium (K), yields of 20 t of tubers can be achieved with an extraction of 154 kg ha^{-1} (Barrera and Tamayo 2000). According to Castro (2005), for the production of 30 t ha^{-1} of tubers, 60 kg ha^{-1} of Ca, 17 kg ha^{-1} of Mg and 15 kg ha^{-1} of S are required. For minor elements, only information for B has been reported, which, according to Baker and Pilbeam (2007) and Pérez *et al*. (2008), consists of an estimation of between 1 and 1.5 kg ha^{-1}. Critical nutritional levels are those that, according to Bertsch (1998), are the extraction value of a nutrient, under which and above which the expected response of plants to fertilization is not generated. Considering the above, the present study was developed, which was financed and technically supported by the PBA corporation, with the aim of establishing the nutrient uptake of the criolla potato (S*olanum phureja* var. Galeras) in order to determine the critical nutritional levels. This study was developed simultaneously with another on the Colombia variety carried out by Bautista *et al.* (2012) with the same goal.

Materials and methods

Location

This test was carried out on the Encenillos farm, Carrizal district, in the municipality of Granada, in the department of Cundinamarca, with geographical coordinates 4°32' N and 74°17' W, altitude of 2,650 m a.s.l., average temperature of 13°C, average annual precipitation of 698 mm and relative humidity 80%. The present study did during the months of October of 2010 to February of 2011.

The soils are Pachic Melanudands and possess slopes between 12 and 25%, characterized by large effective depths, good drainage, fine textures, high CICs, low saturations of bases and moderate fertility, with low contents of calcium, magnesium and potassium; phosphorus is high in the first horizon and low in the inferior horizons. The fertility of these soils is low (IGAC, 2000). The chemical analysis of the soil of this test is presented in Tab. 1.

Vegetative material

The present study used *Solanum phureja* var. Galeras criolla potatoes, developed by the Grupo de Investigación en Papa (Potato Research Group) of the Universidad Nacional de Colombia, using a clonal cross (*S. phureja* var. Colombia × *S. tuberosum* var. Parda pastusa), adapted to altitudes between 2,500 and 3,000 m a.s.l., with an average production potential of 30 t ha^{-1}, excellent culinary quality, predominance of thick potatoes, a vegetative period of 130 d, and moderate resistance to *Phytophthora infestans* (Rodríguez *et al.*, 2006).

Experimental design

A random complete block design was used (DBCA), with three repetitions and repeated measurements over time, with each of the five fertilizer treatments describe in Tab. 2; the blocks were organized on a sloped basis. The size of the experimental unit was 30 m^2 for a total of 450 m^2 and a cultivation density of 33,000 plants/ha. Four samplings were conducted in the cultivation cycle, which corresponded to the phonological stages: vegetative growth (45 days

TABLE 1. Chemical analysis of soil in Granada (Colombia).

pH	CO	N	Ca	K	Mg	Na	Al	ECEC	CEC	
	(%)	(%)	(cmol kg^{-1})							
5.4	11.8	1.02	6.15	0.43	1.05	0.09	1.08	7.73	51.9	
P	S	Cu	Fe	Mn	Zn	B	Ar	L	A	Texture
(mg kg^{-1})							(%)			
6.91	10.1	0.98	41.1	0.82	1.74	0.5	6	25	68	FA

pH, soil:water ratio (1:1); OC, organic carbon (Walkley-Black method); N, estimated from the CO (employed factor: 0.0862); exchangeable Ca, Mg, Na, K: extraction with ammonia acetate 1N pH 7; Al and H change: extraction with KCl 1M; CEC cation exchange capacity: displacement of NH_4 through an exchange with NaCl 1M; usable P: Bray II method; Mn, Zn, Fe, Cu: extraction with DTPA; B: extraction with monobasic phosphate (Azometine-H).

after planting, dap); flowering (77 dap); fruiting (100 dap) and maturity and senescence (113 dap). The fertilization was carried out on the planting day in a band incorporated in the sol. The sources of the fertilizers (13-26-6, potassium sulfate, magnesium oxide and Agrimins® which contains total N of 8%, P_2O_5 5%, CaO 18%, MgO 6%, S total 1.6%, B 1%, Cu 0.75%, Mo 0.005% and Zn 2.5%) were applied separately in order to create an adequate control of the fertilizer proportion for each experimental unit; for logistical reasons, it was not possible to vary the dose of Ca, Mg or the minor elements in treatments PR and PR - 50%. The employed agronomic management was traditional for the zone, without which sanitation problems would have been seen in the development cycle.

Analysis of variance and multivariate analysis were used to process the data with Tukey mean comparison tests at 95% confidence. The statistic software SAS v9.3 was used.

Evaluated variables

Dry matter. Destructive sampling was carried out, taking three plants per experimental unit, which were weighed both for their aerial part (AP) and for their tubers and roots (TR), with subsequent drying in an oven at 70°C until constant moisture.

Nutrient uptake. Ten grams samples of dry matter were taken both from the AP and the TR, which were utilized for the chemical analysis according to the methodology employed by the water and Soil Laboratory of the Faculty of Agricultural Sciences of the Universidad Nacional de Colombia, Bogota.

Yield. During the harvest, the tubers was classified according to the following categories: first (PT1, ø 4 – 6 cm), second (PT2, ø 2 – 4 cm), third (PT3, ø < 2 cm) and total (PTT), and conversions were carried out to tons per hectare assuming a population of 33,000 plants/ha.

TABLE 2. Treatments of nutrient in criolla potato var. Galeras.

Treatments	N	P_2O_5	K_2O	CaO	MgO	S	Fe	Mn	Cu	Zn	B
	(kg ha^{-1})										
Zero fertilization (Control)	0	0	0	0	0	0	0	0	0	0	0
Control commercial (CC)*	190	263	75	0	0	0	0	0	0	0	0
Proposed recommendation + 50% (PR + 50%)	150	75	150	30	24	30.0	0	0	0.35	2.85	1.6
Proposed recommendation**	100	50	100	30	24	20.0	0	0	0.30	2.00	1.2
Proposed recommendation - 50% (PR – 50%)	50	25	50	30	24	10.0	0	0	0.25	1.15	0.6

* Agricultural fertilization of the zone (100 kg ha^{-1} of fertilizer 13-26-6); ** Fertilization based on the analysis of the soil and dose per element consulted in the bibliography.

TABLE 3. Accumulation means of dry matter over time in criolla potato var. Galeras.

Dry matter (kg ha^{-1})	Treatment	Days after planting			
		45	77	98	113
Aerial part weight	Control	121 b	532 c	435 c	761 b
	CC	324 a	2164 a	1967 a	1,674 a
	PR + 50%	213 b	2240 a	1234 b	1,475 ab
	PR	173 b	959 b	880 bc	1,116 ab
	PR - 50%	196 b	825 bc	717 bc	1,343 ab
Tubers and roots weight	Control	48 c	393 d	1,800 c	2,732 c
	CC	142 a	2748 a	5,473 a	7,144 a
	PR + 50%	79 b	1957 b	3,709 b	6,268 ab
	PR	69 b	873 c	3,450 b	4,942 bc
	PR - 50%	75 b	691 cd	2,273 c	4,556 bc
Total dry weight	Control	169 d	925 d	2,235 c	3,493 c
	CC	466 a	4,912 a	7,440 a	8,818 a
	PR + 50%	292 b	4,196 b	4,943 b	7,743 ab
	PR	242 cd	1,832 c	4,330 b	6,059 bc
	PR - 50%	271 bc	1,516 cd	2,989 c	5,899 bc

Means with different letters in the same column indicate significant differences according to Tukey test ($P \leq 0.05$). Abbreviations see Tab. 2.

Economic analysis. with the costs, the obtained production and net revenue, the profitability for each of the treatments was calculated to determine the critical level.

Results and discussion

Dry matter

The dry matter in the AP (Tab. 3) in treatments CC, PR + 50%, and PR + 50% displayed high increases from 45 dap until 77 dap (Tab. 3), after which there was a decreasing tendency until 113 dap, while the TR accumulated dry material from 45 dap until 113 dap in treatments CC and PR + 50% (Tab. 3), presenting significant differences between treatments over time. Santos (2010) found that the 'Galeras' attains maximum accumulation in the stem and leaves at 77 dap; afterwards, the maximum accumulation of dry material in the tubers is seen at 90 dap. Bautista *et al.* (2012), in the 'criolla Colombia' in a simultaneous study and in the same location, found a response for the accumulation and distribution of dry material similar to the results of the present study.

Nitrogen

Figure 1A and 1B show that the AP and TR increased nitrogen uptake starting at 45 dap, with maximum accumulation for the AP at 77 dap, notably so in treatments PR + 50% and PR with 95.1 and 84.3 kg ha^{-1}, respectively, which presented significant differences from the other treatments; and for the TR, the highest absorption was seen at 113 dap in CC and PR + 50%, which presented significant differences from the other treatments. This agrees with Cabalceta *et al.* (2005), who found higher nitrogen uptake in the AP at 60 dap, with subsequent decline over time, and, in the TR, the accumulation progressed from 33 dap until 135 dap with a maximum of 110 kg ha^{-1}, which agrees with Santos and Segura (2005), who confirmed that the highest absorption in the AP correlated with the highest biomass production in the vegetative stage and afterwards in the reproductive stage where the AP converts into tuber filler with this element.

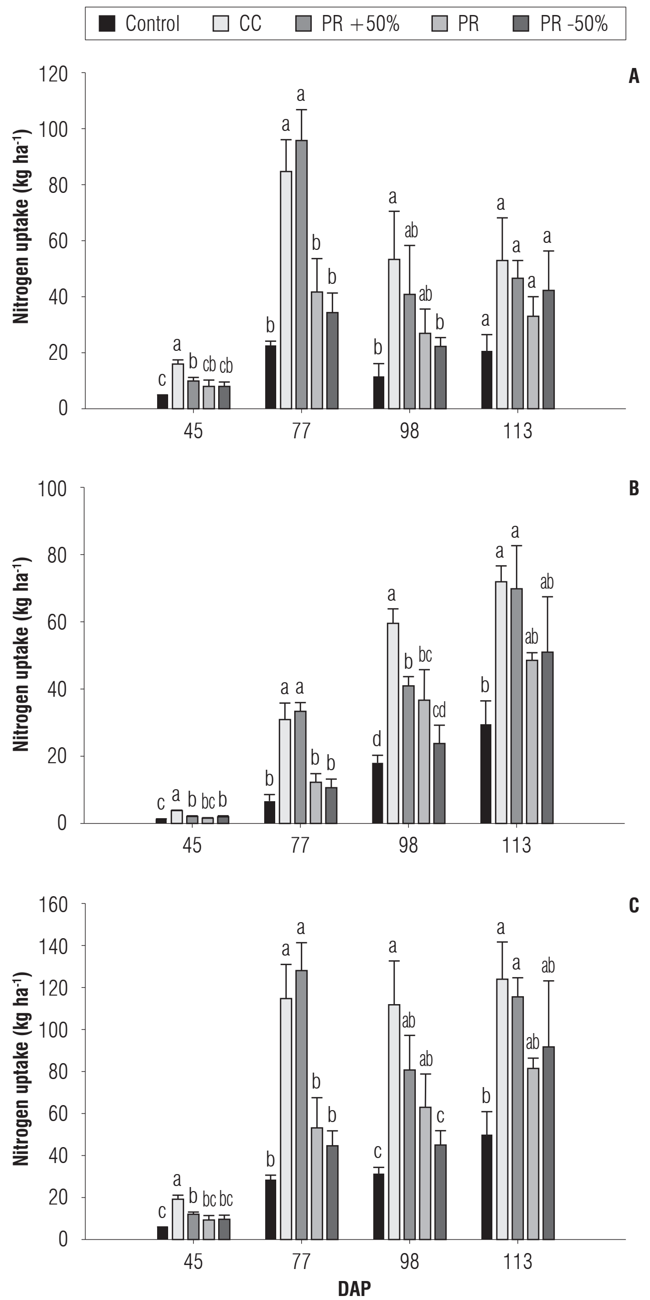

FIGURE 1. Nitrogen uptake; A, aerial part; B, tuber and root part; C, total. Error bars indicate standart deviation. Means with different letters in the same day after planting indicate significant differences according to Tukey test ($P \leq 0.05$).

Phosphorus

There were significant differences for phosphorus in the AP (Fig. 2A) at 77 dap, with treatments PR + 50% and CC with 6.9 and 6.6 kg ha^{-1}, respectively, which presented the higher uptakes. In the case of the TR (Fig. 2B), significant differences were seen in the first three samples, with CC and PR + 50% presenting the higher means over time with 5.2 and 3.6 kg ha^{-1}, respectively at 98 dap. The total uptake (Fig. 2C) presented significant differences in all the samples, with 77 dap and treatments CC and PR + 50% having the higher accumulations, coinciding with the stage of highest vegetative growth, root expansion and tuberization initiation (Villamil, 2005). In the yield, a similar behavior was seen, the highest uptake value was seen in CC with 25.4 kg ha^{-1} of P_2O_5 close to the value seen by Bautista *et al.* (2012) in the 'criolla Colombia', 20 kg ha^{-1}of P_2O_5, considered low values in contrast to the high applied doses in soils with andic properties, which, in the present study, would explain part of the response. Another characteristic that complements this behavior was

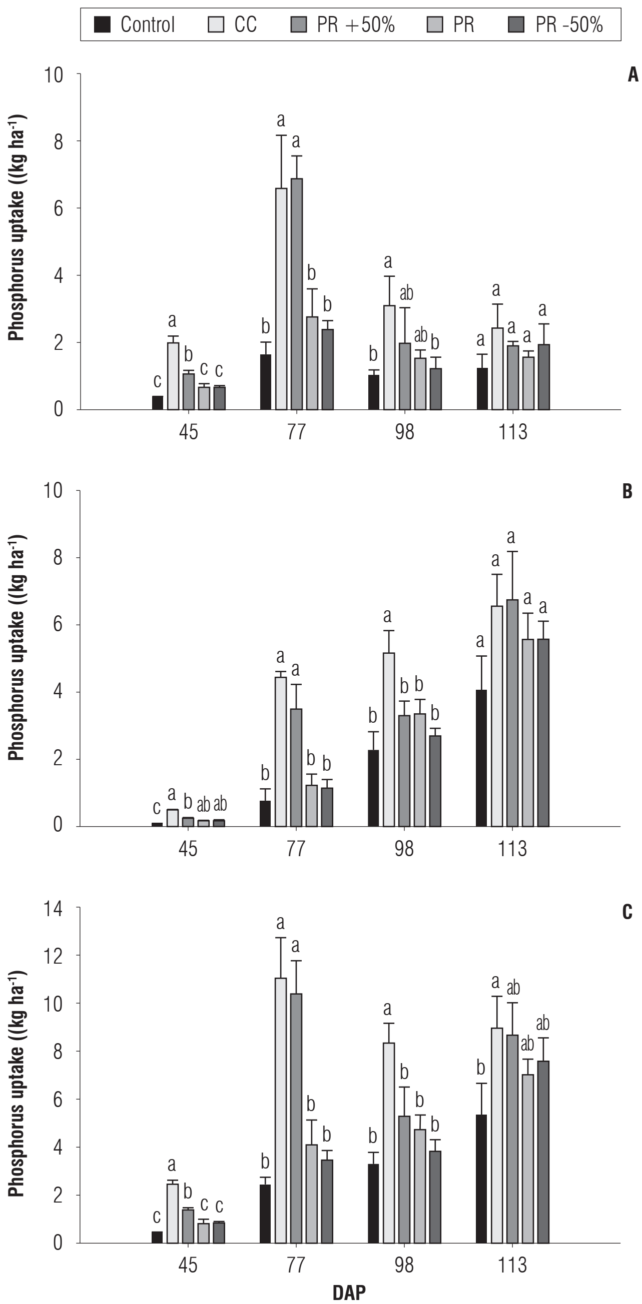

FIGURE 2. Absorption of phosphorus; A, aerial part; B, tuber and root part; C, total. Error bars indicate standart deviation. Means with different letters in the same day after planting indicate significant differences according to Tukey test (*P*≤0.05).

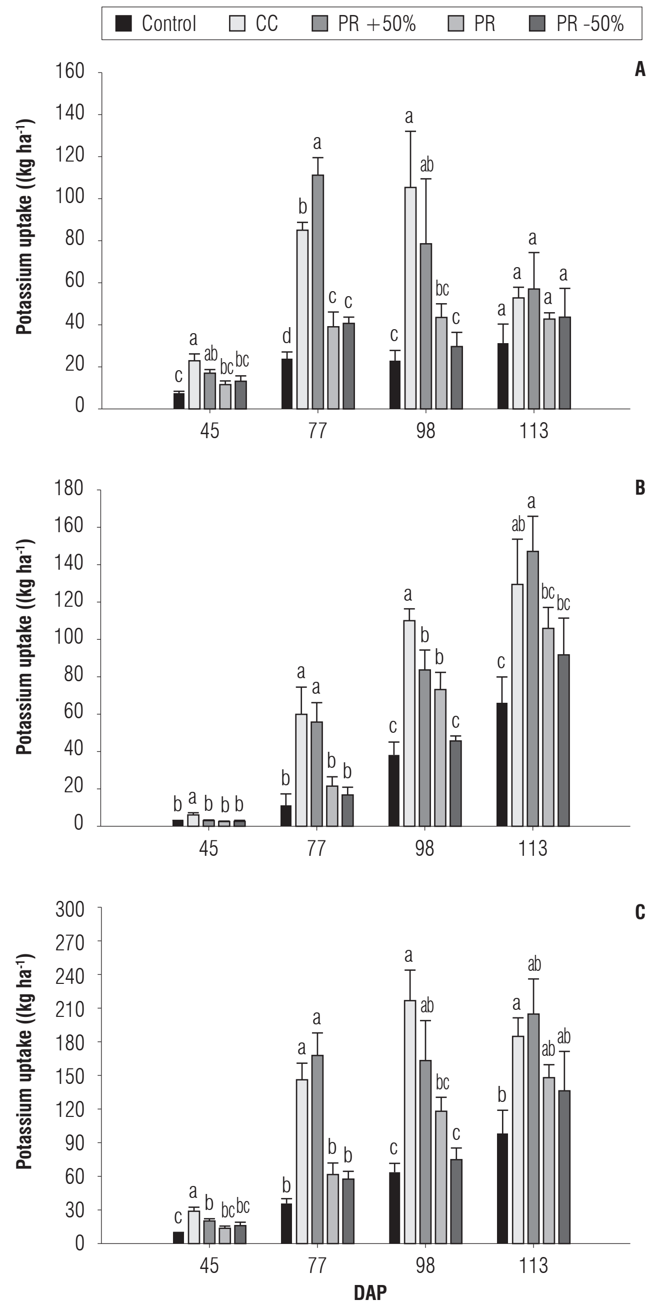

FIGURE 3. Potassium uptake; A, aerial part; B, tuber and root part; C, total. Error bars indicate standart deviation. Means with different letters in the same day after planting indicate significant differences according to Tukey test (*P*≤0.05).

reported by Ñústez *et al.* (2006), who indicated that diploid materials ('Galeras') present a low requirement for phosphorus with respect to tetraploid crops.

Potassium

Potassium is the nutrient with the highest concentration in the plants, presenting significant differences between the treatments at 113 dap in the TR. Fig. 3A shows that PR + 50% presented maximum accumulation at 98 dap, coinciding with maximum foliar development; Fig. 3B shows a progressive increase for K in the different sampling periods and in all the treatments, with CC and PR + 50% displaying the higher accumulations in each period, especially PR + 50% at 113 dap. Fig. 3C also presents a progressive increase for the sampling periods and the treatments but at a lower level in CC and PR + 50% at 113 dap due to the lower accumulation value for the AP, as a result of a high translocation towards the TR, as evidenced by Fig. 3B and coinciding with reports from Cabalceta *et al.* (2005), who confirmed that K is absorbed at higher quantities than N and that their uptake mechanisms and translocation are similar, increasing the production and mobilization of sugars and starches from the aerial part towards the tubers. This concept is collaborated by the report of Villamil (2005), who confirmed that the potato can assimilate 9% of K to dry material when the plant initiates flowering or when the maximum foliar area index has been reached, later decreasing the foliage concentration.

Calcium

Figure 4 shows that most of the calcium was accumulated in the AP. Accumulation of this element was seen in the AP (Fig. 4A) until 77 dap. The treatments that presented the higher accumulations over time were CC and PR + 50%, presenting significant differences between each other only at 77 dap. In the TR (Fig. 4B), the absorbed quantities increased from 77 dap until 113 dap, with PR + 50% and PR having the higher accumulations during this period with 6.1 and 4.5 kg ha^{-1}, respectively, but without significant differences. The highest calcium uptake was accompanied by a low mobility in the transport and distribution of calcium in the plant because Ca follows the transpirative flow of water, which is higher in the leaf veins, and so its translocation to the organs is slower, thereby maintaining a low transpirative ratio for the fruits, young leaves and tubers. This ratio can reach a level that is 10 times higher in mature leaves than in other organs (Alarcón, 2005).

Magnesium

Treatments PR + 50% and CC presented the higher uptakes for magnesium at 77 dap in the PA (14.2 and 13.0 kg ha^{-1}, respectively, Fig. 5A) and for total (17.9 and 17.5 kg ha^{-1}, respectively, Fig. 5C), without significant differences between them but with significant differences with the other treatments. For the TR (Fig. 5B), the uptake increased until 113 dap, where PR + 50% and CC had the higher values but with means lower than those of the AP and of the total. No significant differences were seen between them at the end of the cycle. Similar data was reported by Bautista *et al.* (2012), who found that the commercial and the overdosage treatments had the higher uptakes at 114 dap for the TR, while, for the AP, these values were obtained at 77 dap, this result is explained by the fact that these treatments had higher supplies of nitrogen and its synergy with magnesium favored its adequate utilization by the plants for the production of organic compounds (Cieslik and Sikora, 1998). Magnesium, being part of the chlorophyll molecule, is utilized by the plants at appreciable quantities in the AP

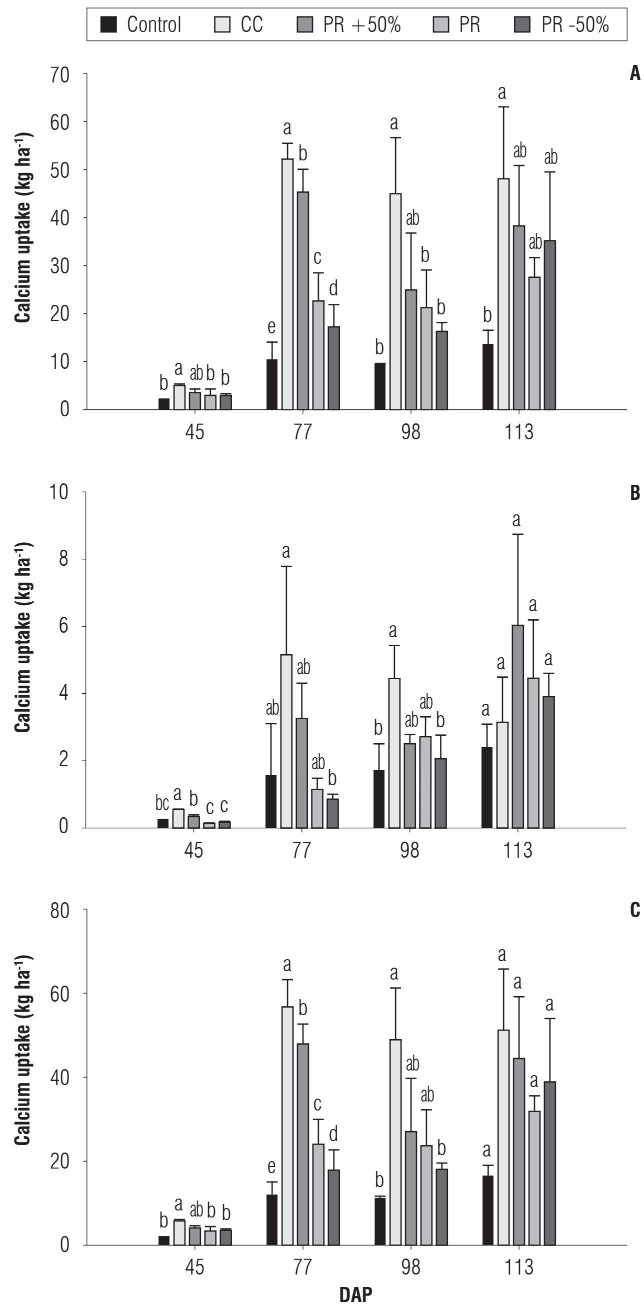

FIGURE 4. Calcium uptake; A, aerial part; B, tuber and root part; C, total. Error bars indicate standart deviation. Means with different letters in the same day after planting indicate significant differences according to Tukey test ($P \leq 0.05$).

for later translocation in a partial form towards the tubers (Cabalceta *et al.*, 2005).

Sulfur

Treatments PR + 50% and CC, with 11.2 and 9.9 kg ha^{-1}, respectively, demonstrated the higher absorptions in the AP at 77 dap (Fig. 6A), presenting significant differences from the other treatments. In the case of the TR and total (Fig. 6B and 6C), a gain was observed starting at 45 dap until

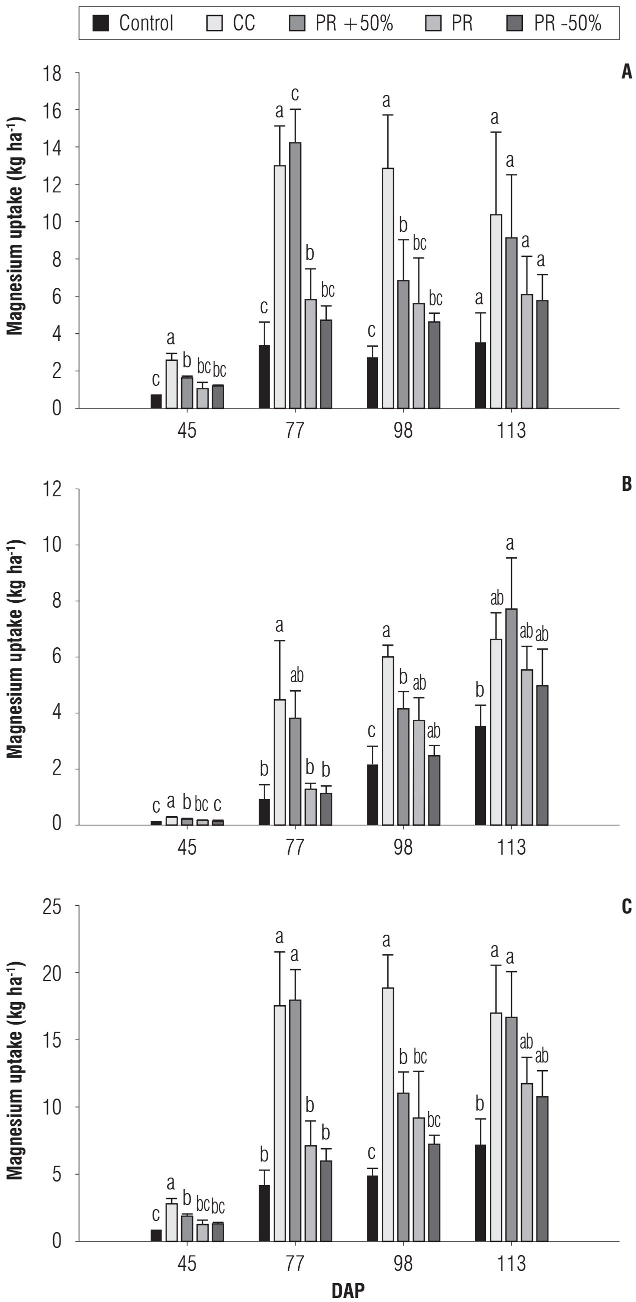

FIGURE 5. Magnesium uptake; A, aerial part; B, tuber and root part; C, total. Error bars indicate standart deviation. Means with different letters in the same day after planting indicate significant differences according to Tukey test ($P\leq0.05$).

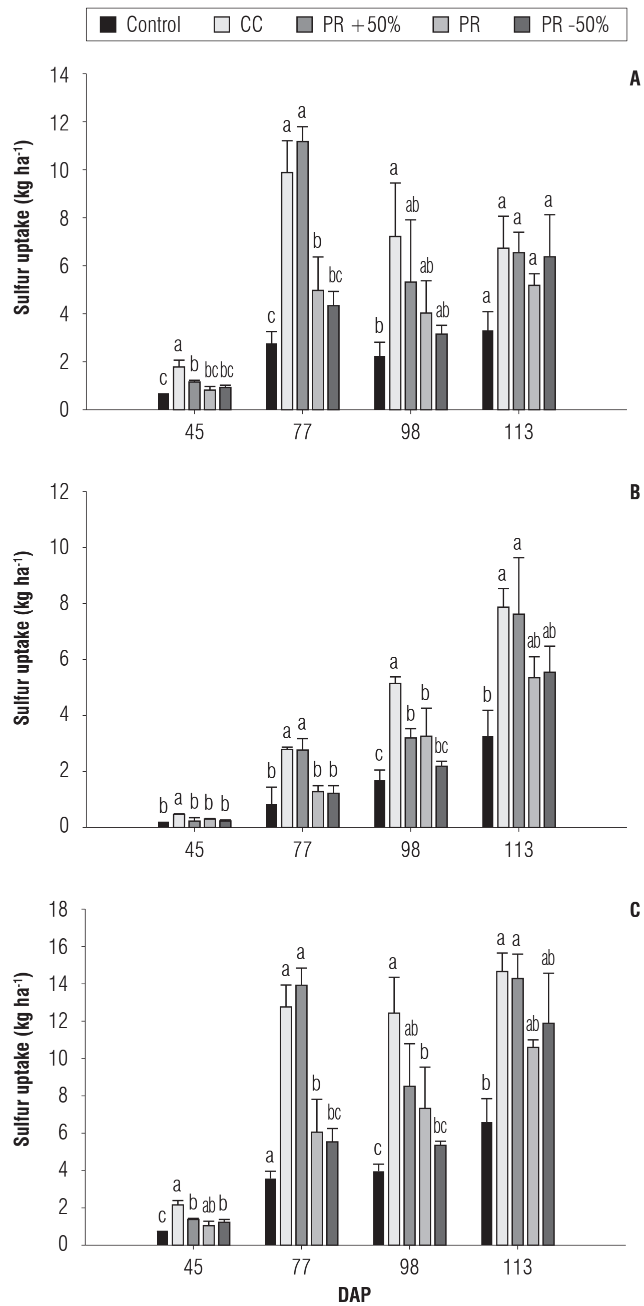

FIGURE 6. Sulfur uptake; A, aerial part; B, tuber and root part; C, total. Error bars indicate standart deviation. Means with different letters in the same day after planting indicate significant differences according to Tukey test ($P\leq0.05$).

113 dap; the best means, like in the AP, were in CC and PR + 50% which presented significant differences in the majority of the samples with the remaining treatments. The dynamic of S uptake was similar to that of N due to fact that it forms part of the structure of the majority of amino acids and participates along with N in vegetative growth and the subsequent engorgement of the tubers (Monge, 1981).

Copper, zinc and boron

In the present study, the edaphic offering of these nutrients supplied the requirements for growth and development, especially with the uptake levels in treatment CC.

The copper uptake (Fig. 7) was considered low, not surpassing 60 g ha^{-1} for the plant total. The highest accumulation in the AP was only seen 77 dap in CC and PR + 50% (22.1

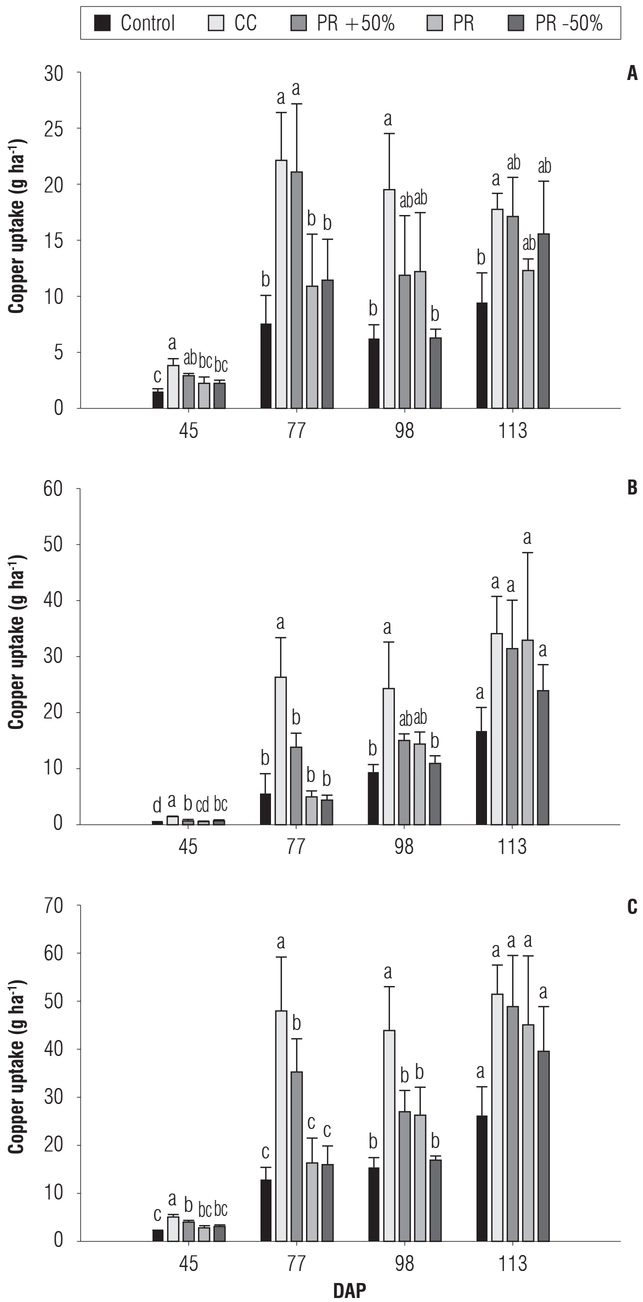

FIGURE 7. Copper uptake. A, aerial part; B, tuber and root part; C, total. Error bars indicate standart deviation. Means with different letters in the same day after planting indicate significant differences according to Tukey test ($P \leq 0.05$).

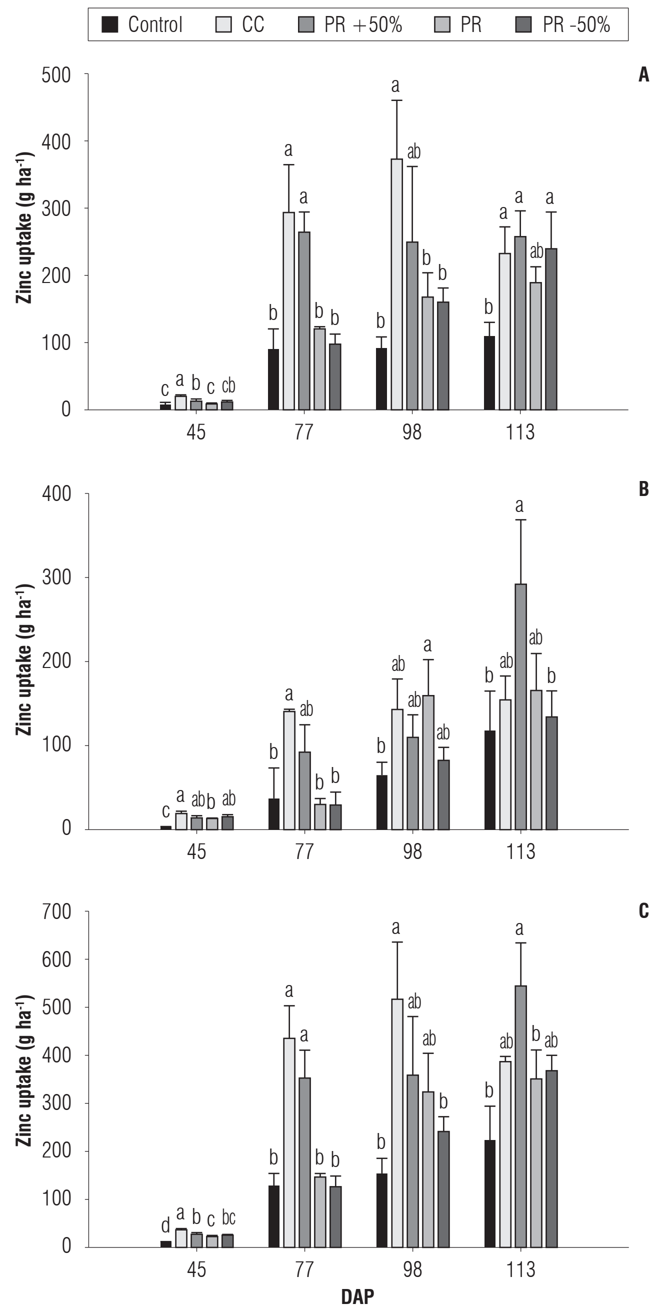

FIGURE 8. Zinc uptake. A, aerial part; B, tuber and root part; C, total. Error bars indicate standart deviation. Means with different letters in the same day after planting indicate significant differences according to Tukey test ($P \leq 0.05$).

and 21.1 g ha^{-1}, respectively), which presented significant differences with the other treatments; while, for the TR, the highest uptake was seen at 133 dap but without significant differences between the treatments. According to Guerrero (1998), copper participates in photosynthesis and the production of tanines, has low mobility in the plants and is translocated from the leaf veins to other organs, in the cultivation of the potato, it is absorbed at a higher proportion in the early developmental stages.

In the AP, zinc (Fig. 8) presented higher uptakes in treatments PR + 50% and CC, as well in the TR for PR + 50%, but the means of this treatment and of the others were below the means seen in the AP; in regards to the total, CC, with 545.5 g ha^{-1}, had the highest accumulation, presenting significant differences with just control. Pérez *et al.* (2008) and Marschner (1995) indicated that Zn intervenes in the metabolism of auxins and its activity is principally seen in the meristematic zone of young tissue; furthermore, levels of 3 kg ha^{-1} stimulate the utilization of magnesium which actively participates in photosynthetic processes.

In boron (Fig. 9A and 9B), the uptake increased in the AP and the TR, without which significant differences would be seen between treatments in the developmental period. In regards to total accumulation, higher values were obtained in treatments PR + 50%, PR - 50% and PR with 402.1, 281.5 and 269.5 g ha^{-1}, respectively, attributable to the supply of Agrimins®, in contrast with Control and CC, which did not receive it. Pérez *et al.* (2008) found increases for foliar tissue and tubers with the application of 1.5 kg ha^{-1} boron because this element precipitates a better absorption of N, Ca, and K and, together with these, participates in processes of growth, cellular division, metabolism, and protein and carbohydrate transpiration. Gómez (2005) confirmed that nitrogen increases in initial stages with the presence of boron and that potassium is related to boron in processes of carbohydrate and starch translocation, tuber components.

Total nutrient extraction

Table 4 shows that treatment CC had the highest nutrient extraction and the highest yield with 31.68 t ha^{-1}, followed by PR + 50% with 26.3 t ha^{-1}. In general, the sequence of accumulation of macronutrients, from highest to lowest, was K>N>Ca>P>Mg>S and for micronutrients it was Fe>Zn>B>Mn>Cu. An evident response in the present study that can be seen in Tab. 4 is that the higher the extraction of major elements, the higher the extraction of micronutrients, a response consistent with the views of Villamil (2005).

Yield

In Fig. 10, one can observe that the treatments with the higher yields were CC and PR + 50% with means of 31,680 and 26,307 kg ha^{-1}, respectively, without statistically significant differences between each other, but with statistically significant differences between CC and the other treatments. For the different tuber-size categories, it was seen that 2 and 3 did not present significant differences, while in 1, there were only significant differences between CC (16,077 kg ha^{-1})

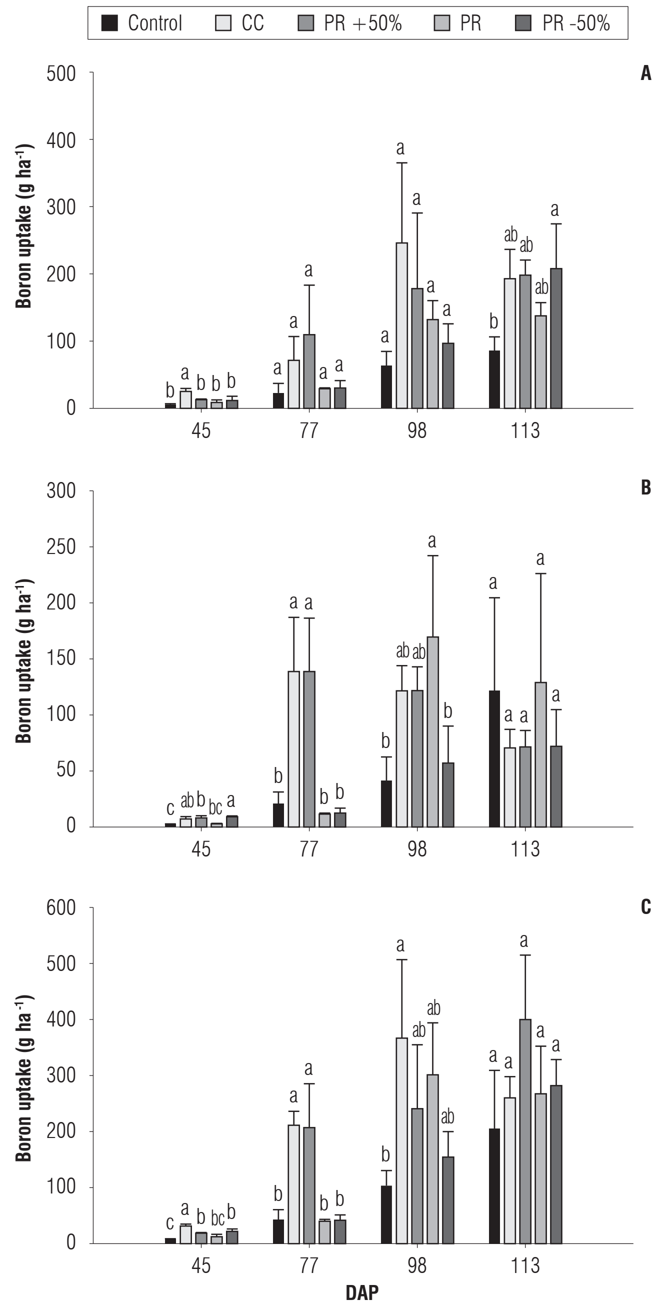

FIGURE 9. Boron uptake. A, aerial part; B, tuber and root part; C, total. Error bars indicate standart deviation. Means with different letters in the same day after planting indicate significant differences according to Tukey test ($P \leq 0.05$).

TABLE 4. Total nutrient extraction in the Galeras variety criolla potato at different fertilizer doses.

Treatments	N	P_2O_5	K_2O	CaO	MgO	S	Cu	Fe	Mn	Zn	B
	(kg ha^{-1})						(g ha^{-1})				
Control	49.8	12.2	115.7	16.1	7.1	6.6	26.5	584.3	109.0	224.0	206.5
CC	124.1	25.4	258.2	56.9	18.9	14.6	52.0	1192.6	376.8	514.6	268.9
PR + 50%	116.0	23.8	244.5	48.2	17.9	14.2	48.9	1018.0	285.9	545.5	402.1
PR	80.9	16.3	177.8	31.7	11.7	10.6	45.2	862.2	201.5	352.6	269.5
PR - 50%	92.4	17.4	161.9	38.9	10.8	11.9	39.8	1131.2	210.4	369.6	281.5

Abbreviations see Tab. 2.

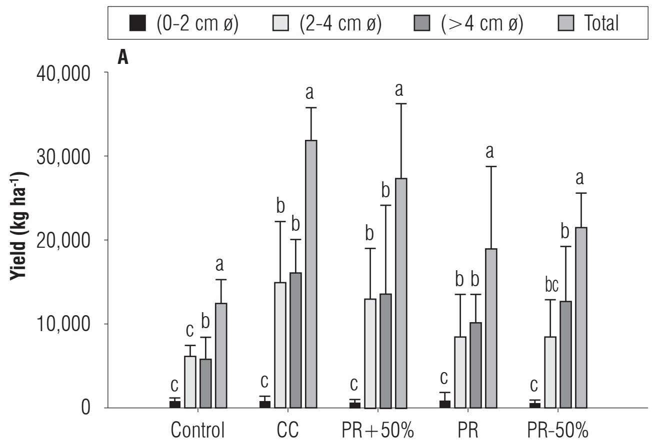

FIGURE 10. Production for treatments and category the variety Galeras criolla potato. Error bars indicate standart deviation. Means with different letters in the same tratamient indicate significant differences according to Tukey test ($P\leq0.05$). Abbreviations see Tab. 2.

and control (5,659 kg ha^{-1}). The obtained total tuber yields concur with the production mean of this cultivation, 30 t ha^{-1}(Rodríguez *et al.*, 2006).

The percentages per category (Tab. 5) show that the treatments with fertilizers obtained more than 49% for category 1 potatoes, in comparison with 46% in treatment control, which, although lower than the fertilized treatments, was close to sufficient, a response that one can attribute to the genetic characteristics of this variety, where the predominance of thick potatoes is normal (Rodríguez *et al.*, 2006); a result that contrasts with that found by Bautista *et al.* (2012), who worked with the Colombia variety, reporting mean values of 40% for category 1 potatoes for the fertilized treatments and 22% in the absolute control (without fertilization).

TABLE 5. Production percentage by category for the different treatments.

Treatment	First category > 4 cm Ø	Second category 2 - 4 cm Ø	Third category < 2 cm Ø
Control	46	49	6
CC	51	47	2
PR + 50%	49	49	2
PR	52	44	4
PR - 50%	58	39	3

Abbreviations see Tab. 2.

Economic analysis

Table 6 demonstrates treatment CC as the best alternative for the studied zone with a profitability of 156%, followed by treatments PR + 50% and PR - 50%, which presented 109 and 93% profitability, respectively.

Conclusions and recommendations

In the studied zone, the critical nutritional levels in the Galeras variety criolla potato were met by the commercial control, which obtained the highest production and profitability.

It is recommended that this test be repeated in the same location but with different sources of fertilizer in order to corroborate the critical level obtained in the present study. Furthermore, it is necessary to carry out the same test in other locations in order to establish the adjustment of the nutrient extraction of Galeras variety criolla potatoes.

Detailed studies on minor element requirements are suggested for the Galeras variety criolla potato along with their incidence on production and quality of tubers because, in the present study, there was no evidence of an effect from their application on the studied variables.

Literature cited

Alarcón, A.L. 2005. Diagnóstico agrícola. Escuela Técnica Superior de Ingeniería Agronómica. Cartagena, Spain.

Baker, V. and J. Pilbeam. 2007. Handbook of plant nutrition. Taylor and Francis Group. London.

Barrera, L. and A. Tamayo. 2000. Manejo integrado del cultivo de la papa. Corporación Colombiana de Investigación Agropecuaria (Corpoica), Mosquera, Colombia.

Bautista, H.F., W.L. Ramírez, and J. Torres. 2012. Nutrient uptake of the diploid potato (*Solanum phureja*) variety Criolla Colombia, as a reference point to determine critical nutritional level. Agron. Colomb. 30(3), 436-447.

TABLE 6. Profitability analysis for the fertilization treatments with a variety Galeras criolla potato crop in Granada in Colombian Pesos (COP).

Treatment	Yield (kg ha^{-1})	Gross revenue ($)	Total costs ($)*	Net revenue ($)**	Profitability (%)
Control	12,540	8,620,704	7,239,000	1,381,704	19
CC	31,680	22,034,321	8,599,000	13,435,321	156
PR + 50%	26,307	18,318,049	8,773,406	9,544,636	109
PR	19,102	13,218,224	8,263,317	4,954,907	60
PR - 50%	21,602	14,995,379	7,750,600	7,244,779	93

* Base price without fertilization or lime: $7,000,000. ** Prices from the supply center in Bogota 700 $ kg^{-1} for smooth, thick potatoes and 600 $ kg^{-1} for small potatoes. Abbreviations see Tab. 2.

Bertsch, F. 1998. La fertilidad de los suelos y su manejo. Centro de Investigaciones Agronómicas, Universidad de Costa Rica, San Jose.

Cabalceta, G., M. Saldias, and A. Alvarado. 2005. Absorción de nutrimentos en el cultivar de papa MNF-801. Agron. Costarr. 29(3), 107-123.

Castro, H. 2005. Balance y prospectiva de la investigación en la fertilización de papa en Colombia. pp. 31-43. In: Memorias I Taller Nacional sobre Suelos, Fisiología y Nutrición Vegetal en el Cultivo de la Papa. Centro Virtual de Investigación de la Cadena Agroalimentaria de la Papa (Cevipapa), Bogota.

Cieslik, E. and E. Sikora. 1998. Correlation between the levels of nitrates and nitrites and the contents of potassium, calcium and magnesium in potato tubers. Food Chem. 63(4), 525-528.

Fedepapa, Federación Colombiana de Productores de Papa. 2009. Estadísticas. In: http://www.fedepapa.org.co; consulted: February, 2014.

Gómez, S. 2005. Guía técnica para el manejo nutricional de los cultivos. Microfertisa, Bogota.

Guerrero, R. 1989. Fertilización del cultivo de la papa. pp. 8-67. In: Guerrero, R. (ed.). Fertilización en cultivos de clima frío. Monómeros Colombo Venezolanos, Bogota.

Guerrero, R. 1998. La fertilización con azufre para el cultivo de la papa en Colombia. pp. 69-83. In: Guerrero, R. (ed.). Fertilización en cultivos de clima frío. 2nd ed. Monómeros Colombo Venezolanos, Bogota.

IGAC, Instituto Geográfico Agustín Codazzi. 2000. Estudio general de suelos y zonificación de tierras del departamento de Cundinamarca. Bogota

Marschner, H. 1995. Mineral nutrition of higher plants. Academic Press, San Diego, CA.

Monge, L. 1981. Cultivo de la papa. Universidad Estatal a Distancia (EUNED), San Jose.

Ñústez, C.E., M. Santos, S.L. Navia, and J.M. Cotes. 2006. Evaluación de la fertilización fosfórica foliar y edáfica sobre el rendimiento de la variedad de papa "Diacol Capiro" (*Solanum tuberosum*L.). Agron. Colomb. 24(1), 111-121.

Pérez, L., L. Rodríguez, and M. Gómez. 2008. Efecto del fraccionamiento de la fertilización con N, P, K y Mg y la aplicación de los micronutrientes B, Mn y Zn en el rendimiento y calidad de papa criolla (*Solanum phureja*) variedad Criolla Colombia. Agron. Colomb. 26(3), 477-486.

Porras, P. 2005. Problemática general del sistema productivo de papa con énfasis en fisiología y manejo de suelos. pp. 1-4. In: Fisiología y nutrición vegetal en el cultivo de la papa. Cevipapa, Bogota.

Rodríguez, L.E., C.E. Ñústez, and S.L. Navia. 2006. Pruebas de evaluación agronómica para registro de nuevas variedades de papa criolla en la subregión Nudo de los Pastos, Nariño. Universidad Nacional de Colombia; Fedepapa; Asohofrucol, Bogota.

Rodríguez, L.E., C.E. Ñustez, and N. Estrada. 2009. Criolla Latina, Criolla Paisa y Criolla Colombia, nuevos cultivares de papa criolla para el departamento de Antioquia (Colombia). Agron. Colomb. 27(3), 289-303.

Rozo, Y. 2006. Evaluación del efecto de diferentes niveles de fósforo y potasio sobre el rendimiento de papa criolla (*Solanum phureja* Juz. et Buk) en dos localidades de Cundinamarca. Universidad Nacional de Colombia, Bogota.

Santos, M. and M. Segura. 2005. Evaluación de variables fisiológicas y componentes de rendimiento en cuatro variedades y dos clones avanzados de papa (*Solanum tuberosum* L.) en el municipio de Zipaquirá (Cundinamarca). Universidad Nacional de Colombia, Bogota.

Santos, M. 2010. Evaluación del crecimiento, desarrollo y componentes de rendimiento de cuatro cultivares de papa criolla en dos localidades del departamento de Cundinamarca. Universidad Nacional de Colombia, Bogota.

Villamil, H.J. 2005. Fisiología de la nutrición de papa. pp. 17-25. In: Memorias I Taller Nacional sobre Suelos, Fisiología y Nutrición Vegetal en el Cultivo de la Papa. Cevipapa, Bogota.