Nutrient uptake of the diploid potato (*Solanum phureja*) variety Criolla Colombia, as a reference point to determine critical nutritional levels

Absorción de nutrientes de la papa diploide (*Solanum phureja*) variedad Criolla Colombia, como punto de partida para determinar niveles críticos nutricionales

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ABSTRACT

In the production costs of in the diploid potato var. Criolla Colombia, fertilizer represents 17% of the total costs, and it's inappropriate and sometimes excessive use translates into expensive investments with technical inefficiency. This is mainly due to a lack of nutrient absorption levels of the selected variety. The research was conducted in Granada (Colombia) with five fertilization treatments (absolute control, commercial control, technical recommendation + 50%, technical recommendation and technical recommendation - 50%) arranged in a randomized complete block design with three replications. We evaluated dry matter, nutrient uptake, yield and specific gravity. The analysis showed that the most important elements were N, P, K, Ca, Mg, Zn, B and S, with higher absorption in the 113 days after planting (dap) with the commercial control, technical recommendation + 50% and technical recommendation, from highest to lowest. There were no statistically significant differences in yield for commercial control, technical recommendation + 50% and technical recommendation, but the economic analysis showed that the critical level of fertilization was found in commercial control.

Key words: tubers, fertilization, yield, dry matter.

RESUMEN

Un rubro representativo de los costos de producción en la papa diploide var. Criolla Colombia, son los fertilizantes, cuya participación corresponde al 17% de los costos totales. El uso inapropiado y en ocasiones excesivo de estos insumos se constituyen en inversiones onerosas, que conllevan ineficiencia técnica. Lo anterior es consecuencia del desconocimiento de los niveles de absorción de nutrientes de la variedad seleccionada. El ensayo se realizó en la vereda El Carrizal, Granada (Colombia), se utilizaron cinco tratamientos de fertilización (testigo absoluto, testigo comercial, recomendación técnica + 50%, recomendación técnica y recomendación técnica - 50%) dispuestos en un diseño de bloques completos al azar, con tres replicaciones. Se evaluó materia seca, absorción de nutrientes, rendimiento y gravedad especifica. El análisis mostró que los elementos de mayor relevancia fueron N, P, K, Ca Mg, Zn, B y S, encontrando la mayor absorción hacia los 113 días después de siembra (dds) con la recomendación comercial, recomendación técnica + 50% y recomendación técnica, ordenados de mayor a menor. No se encontraron diferencias estadísticas significativas en rendimiento para la recomendación comercial, recomendación técnica + 50% y recomendación técnica, pero el análisis económico mostró que el nivel crítico de fertilización se encuentra con la recomendación comercial.

Palabras clave: tubérculos, fertilización, rendimiento, materia seca.

Introduction

Criolla potato cultivation poses major challenges for Colombia, its current production and consumption are steadily increasing, becoming a key product for food security and an important source of income for farmers (Bonilla *et al.*, 2009). In recent years, production increased from 64.600 to 80.600 t, creating 974 new jobs (Bonilla *et al.*, 2009). For 2008, of the total planted area of potatoes in Colombia (close to 138,315 ha), approximately 6% was for the criolla potato with exports close to 1,000 t year^{-1} (Fedepapa, 2010). Of the total production costs of this crop, fertilizers account for 17% (SIPSA, 2010), meaning a significant investment. Improper and sometimes excessive use generates costly investments with technical inefficiency, making it necessary to produce research that uncovers efficient management of fertilization in this variety considering nutrient absorption levels with cost reduction and production optimization.

Bertsch (2003), states that the extraction of nutrients depends on internal (such as genetic potential of the plant and age) and external factors (related to the cultivation environment, such as temperature, humidity, soil, etc.). It follows that although generic curves can be generated for extraction of nutrients for each species, it is important to

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understand that there may be differences in varieties for accumulation time of the phenological stage due to climatic and soil conditions.

Nitrogen is the nutrient that most affects the yield and tuber quality, high doses delay the onset of tuberization and promote foliage growth, reduce yields, affect quality and decrease the percentage of dry matter in tubers. The criolla potato responds well to nitrogen doses between 50 and 100 kg ha^{-1}, the most used sources are urea (46% N), ammonium sulfate (21% N), ammonium nitrate (34% N) or calcium nitrate (16% N) (Guerrero, 1998).

Phosphorus is considered an important element given the functions performed in the plant (Becerra, 2008), is critical for root and meristematic tissues development, and accumulates in parts of the plant with continuous growth and in seeds (Bernal and Espinosa, 2003). Requirements range between 40 and 100 kg ha^{-1} P_2O_5, but high use application rates are (200-300 kg ha^{-1} P_2O_5) due to sequestration in soil (Castro, 2005); a yield response above 50 kg ha^{-1} for P_2O_5 has not been found in criolla (Rozo, 2006), and its deficiency affects growth and development of the plant, resulting in small, stiff plants, and also reduces the formation of starch in the tubers (Pumisacho and Sherwood, 2002).

Potassium is important for increasing the osmotic potential of the cells, increasing turgor pressure. Its high mobility in the plant favors its distribution in new and old tissue as well as storage organs (Marschner, 1995); the transport of sugars from leaves to the tubers is another important function of K in the potato plant. In the criolla potato, Rozo (2006), found no differences in soil application of potassium in doses higher than 50 kg ha^{-1} of K_2O in soils with high potassium content, except in category 3 yield with a lower dose of 150 kg ha^{-1}.

Micronutrients in the criolla potato have not been studied deeply, so there are no defined nutritional requirements. Pérez *et al.* (2008) conducted an experiment with B at a dose of 1.5 kg ha^{-1}, Mn 3 kg ha^{-1} and Zn 3 kg ha^{-1}, finding that the early stage supply of B can promote absorption of phosphorus and potassium and thus good crop growth. The present study sought to evaluate the nutrient uptake of the criolla potato (*S. phureja*) as a reference point to determine critical nutritional levels, with the financial and technical support of the PBA Corporation.

Materials and methods

Location

The research took place at the Finca los Encenillos, Carrizal village in the municipality of Granada (Colombia), during the months of October 2010 to February 2011. The village of El Carrizal is located at 4°32' N and 74°17' W at an altitude of 2,650 m a.s.l.

Test description

Land preparation was done traditionally; planting was carried out using row widths of 1.0 m and 0.3 m between

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

pH	CE	CO	N	Ca	K	Mg	Na	Al	CICE	CIC
		%		cmol kg^{-1}						
5.3	Ns	10.2	0.88	3.12	0.9	0.56	0.08	1.08	5.74	52.5
P	**S**	**Cu**	**Fe**	**Mn**	**Zn**	**B**	**Ar**	**L**	**A**	**Texture**
			mg kg^{-1}					%		
4.19	6.03	0.16	23.6	0.22	0.62	0.14	6	27	66	FA
Nutrient content in kg ha^{-1}										
N	**P_2O_5**	**K_2O**	**CaO**	**MgO**	**S**	**Fe**	**Mn**	**Cu**	**Zn**	**B**
44.8	1.92	31.1	149.7	52.42	1.21	2.36	0.02	0.03	0.12	0.03

TABLE 2. Treatments and doses per applied element in kg ha^{-1}.

Treatments	N	P_2O_5	K_2O	CaO	MgO	S	Fe	Mn	Cu	Zn	B
Absolute control*	0	0	0	0	0	0	0	0	0	0	0
Commercial control	175	261.9	91.1	149.7	52.42	0	0	0	0	0	0
Technical recommendation + 50%	150	75	150	30	24	20	3.2	0.98	0.1	0.3	1.2
Technical recommendation	100	50	100	30	24	20	3.2	0.98	0.1	0.3	1.2
Technical recommendation – 50%	50	25	50	30	24	20	3.2	0.98	0.1	0.3	1.2

* Quantity of element contained in the soil.

plants, placing 1 seed per site for a density of 33,300 plants/ha. The 100% fertilization was applied at planting, within a 7.5 cm band located on the sowing row. Other agronomic management tasks were performed in a timely and technical manner.

Seeds of the variety Criolla Colombia (*S. phureja*) were used, characterized by having smooth foliage, upright growth, dark purple flower color, round tubers, semi-deep eyes, predominantly deep yellow skin and flesh, early maturation (120 d), specific gravity of 1.088, lack of rest period and an average yield of 13 to 15 t ha^{-1} (Ñústez *et al.*, 2005).

The experimental area was 450 m^2, consisting of 15 plots of 30 m^2 with 100 plants each. Based on soil analysis (Tab. 1A), the nutritional content of the elements was determined in kg ha^{-1} (Tab. 1B), with which the treatments were defined (Tab. 2). The statistical design used was a randomized complete block with three replications and repeated measurements over time, the latter corresponding to the phenological stages: 1) vegetative growth (45 days after planting, dap); 2) bloom (75 dap); 3) fruiting (100 dap); and 4) maturity and senescence (113 dap). The number of repetitions was adjusted to the availability of budget and space.

The sources used for fertilization were: 13-26-6, urea, potassium sulfate, Agrimins® and magnesium oxide.

Analysis of variance and multivariate test were carried out for the obtained results with Tukey mean comparison with 95% reliability. Data were processed with SAS® software version 9.3.

Variables evaluated

Dry matter: the unified dry weights of stems and leaves (DWSL), of tubers and roots (DWR) and total weight (TDW) were determined.

Chemical analysis of plant material: a comprehensive analysis on samples taken from DWSL and DWR.

Yield: the tubers were classified according to various categories in the market: first (4 to 6 cm diameter), second (2 to 4 cm diameter), third (diameter <2 cm).

Economic analysis: the benefit-cost ratio was calculated for each treatment using production costs, yields and net income.

Results and discussion

Dry matter

In Tab. 3, we see that (DWSL) and (DWR) dry matter increased from 75 dap until maximum accumulation at 113 dap commercial control, technical recommendation + 50% and technical recommendation accumulated more dry matter in PSA and PSR (Fig. 1B, C and D), with statistically significant differences between them at 45, 75, 98 and 113 dap.

According to the results, PSR accumulated more dry matter than PSA, in agreement with Santos (2010) who found that the variety Criolla Colombia showed a dry matter gain in the aerial part for 77 dap, maximum

TABLE 3. Dry matter of potato variety Criolla Colombia

		Average values days after planting			
	Treatment	**45**	**75**	**98**	**113**
Dry weights of stems and leaves (kg)	Absolute control	75.3 c	340.9 b	338.4 b	549.8 c
	Commercial control	224.5 a	1574.3 a	1631. 3 a	1644.7 a
	Technical recommendation + 50%	123.7 bc	609.2 b	1645.2 a	1727.4 b
	Technical recommendation	128.7 b	665.6 b	256.1 b	1556.5 b
	Technical recommendation – 50%	111.8 bc	473. 8 d	332.7 b	570.7 c
Dry weights of tubers and roots (kg)	Absolute control	28.7 c	167.5 d	896.0 d	2120.1 c
	Commercial control	53.3 a	843.1 a	4613.4 a	4763.0 a
	Technical recommendation + 50%	38.4 bc	639.8 ab	3833.7 b	4896.9 a
	Technical recommendation	42.9 ab	507.4 bc	1800.3 c	3487.2 b
	Technical recommendation – 50%	47.4 ab	370.8 cd	1029.8 d	2713.5 c
Total dry weight (kg)	Absolute control	104.0 c	508.3 d	1234.4 d	2669.9 c
	Commercial control	277.8 a	2417.5 a	5944.7 a	6407.7 a
	Technical recommendation + 50%	162.0 b	1248.9 b	5178.9 b	6024.3 a
	Technical recommendation	171.7 b	1173.0 b	2056.3 d	4543.6 b
	Technical recommendation – 50%	159.2 a	844.6 c	1362.5 d	3284.1 c

Means in the same column followed by the same letters are not significantly differences according to Tukey's test ($P \leq 0.05$).

reported period, but contrary to Ñústez *et al.* (2009), who, in assessing dry matter in four potato varieties in Zipaquirá (Cundinamarca), found that 'Pastusa Suprema' accumulated more dry matter in the tuber than in the aerial part (11,158 and 8,545 kg ha^{-1} respectively) at 112 d after emergence.

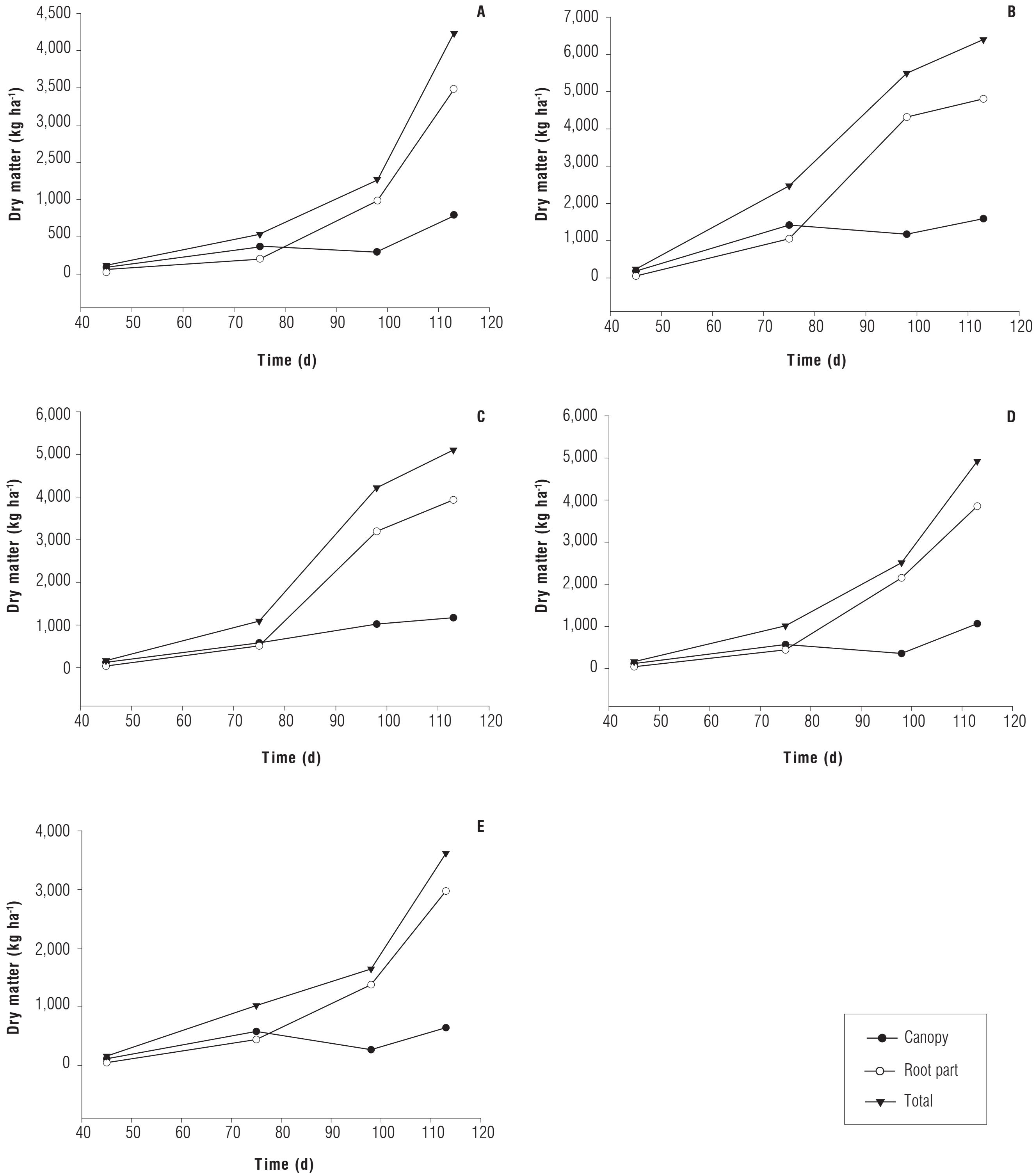

FIGURE 1. Dry matter in diploid potato variety Criolla Colombia with different doses of fertilizations. A, absolute control; B, commercial control; C, technical recommendation + 50%; D, technical recommendation; E, technical recommendation – 50%.

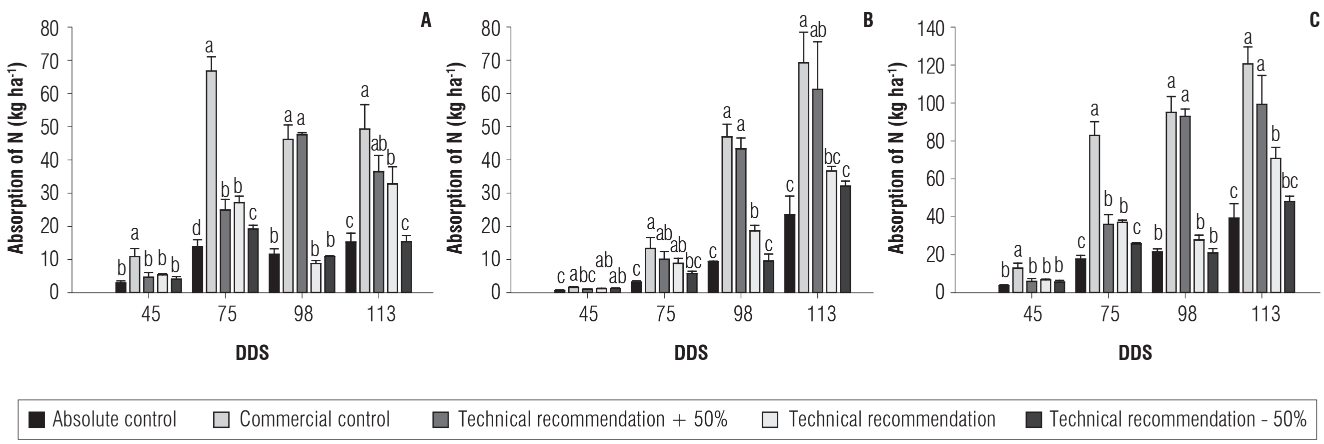

FIGURE 2. Absorption of N in diploid potato variety Criolla Colombia with different doses of fertilizations. A, aerial parts; B, root and tuber; C, total. T1, absolute control; T2, commercial control; T3, technical recommendation + 50%; T4, technical recommendation; T5, technical recommendation – 50%. Means with different letters indicate significant differences according to Tukey's test ($P \leq 0.05$).

Nitrogen

Figure 2A shows that the highest uptake of N in DWSL occurred in absolute control 75 dap (69.49 kg ha^{-1}), followed by technical recommendation + 50% and technical recommendation 113 dap (38.0 and 34.1 kg ha $^{-1}$, respectively). The absorption of nitrogen in DWSL and DWR (Fig. 2B) showed significant differences among the treatments for each of the sampling periods, with the highest absorption at 113 dap in commercial control (69.22 kg ha^{-1}). According to Hanway *et al.* (1963), the concentration of N in the plant increases with growth and yield by increasing the supply, however, the N in leaves is often not correlated with increased growth and yield. The increased uptake of N in DWR seen in the present study may be subject to the concept of Osaki *et al.* (1995), who noted that during the vegetative growth of potatoes grown in a nutrient solution containing NO_3^- or NH_4^+, N uptake in these two forms was similar in PSA, while in PSR, it was better with NO_3^-.

Phosphorus

Phosphorus uptake in DWSL presented significant differences (Fig. 3A), commercial control had the highest absorption followed by technical recommendation + 50% and technical recommendation. The time period when commercial control showed the most accumulation was 75 dap (5.49 kg ha^{-1}). The increased absorption of P in the DWR was observed in commercial control, technical recommendation + 50% and technical recommendation (5.87, 5.26 and 3.72 kg ha^{-1} respectively), without statistically significant differences (Fig. 3B). Furthermore, Becerra *et al.* (2007), affirmed that the Criolla potato is a diploid different from tetraploid cultivars by requiring less P. Rozo

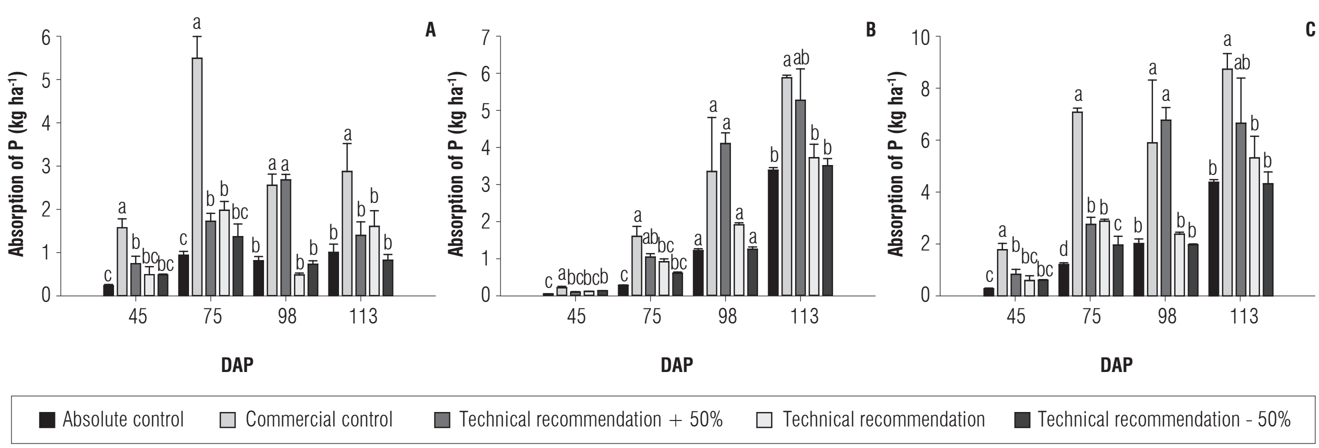

FIGURE 3. Absorption of P in diploid potato variety Criolla Colombia with different doses of fertilizations. A, aerial parts; B, root and tuber; C, total. T1, absolute control; T2, commercial control; T3, technical recommendation + 50%; T4, technical recommendation; T5, technical recommendation – 50%. Means with different letters indicate significant differences according to Tukey's test ($P \leq 0.05$).

(2006) found that doses up to 50 kg ha^{-1} of P_2O_5 can evoke a response from the Criolla Colombia cultivar.

Potassium

K showed increases over time in all treatments of DWSL, DWR and DWT, with commercial control and technical recommendation + 50% displaying a broad and sustained increase from 75 dap to the maximum at 113 dap (Fig. 4A, 4B and 4C), with a higher result in commercial control (75.12 and 104.73 kg ha^{-1} in PSA and PSR, respectively) and statistically significant differences between these two treatments for both DWSL and DWR. Corzo (2003) suggested that the K requirement of the plant is high, with an active participation in the formation of sugars and starches of the tubers. Rozo (2006), for cultivars of the Criolla Colombia potato, found no significant difference in yields with doses of 150 kg ha^{-1} K_2O, Durán and Peña (1997) found a response with the same dose in soil with low K.

Calcium

For Ca, increased absorption started at 75 dap in both DWSL and in DWR. The commercial control, technical recommendation + 50% t and technical recommendation had the highest values of absorption at 113 dap (40.36 25.0 and 24.23 kg ha^{-1} respectively), although there were no statistically significant differences between commercial control and technical recommendation + 50%, there were between commercial control and technical recommendation (Fig. 5A, 5B and 5C). Notably, DWSL showed the greatest accumulation of Ca over time. In the potato, Ca accumulates mainly in the leaves because of its immobility, so the tuber requires relatively high doses in the tuberization stage in order to absorb all that is needed; in the potato, Ca is mainly absorbed by the roots and moved to the leaves where it accumulates and is not retranslocated (Medina, 2008).

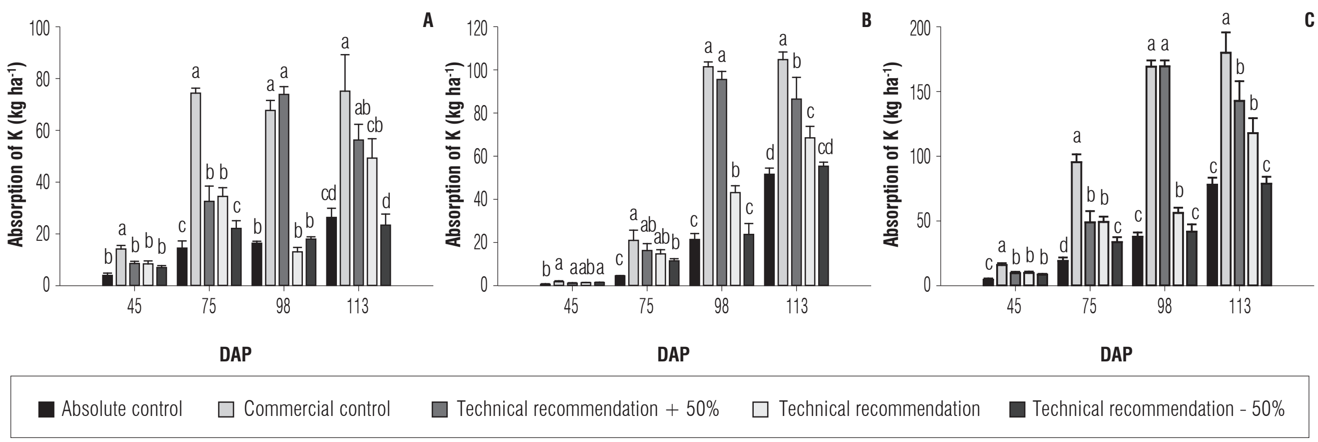

FIGURE 4. Absorption K in diploid potato variety Criolla Colombia with different doses of fertilizations. A, aerial parts; B, root and tuber; C, total. T1, absolute control; T2, commercial control; T3, technical recommendation + 50%; T4, technical recommendation; T5, technical recommendation – 50%. Means with different letters indicate significant differences according to Tukey's test ($P \leq 0.05$).

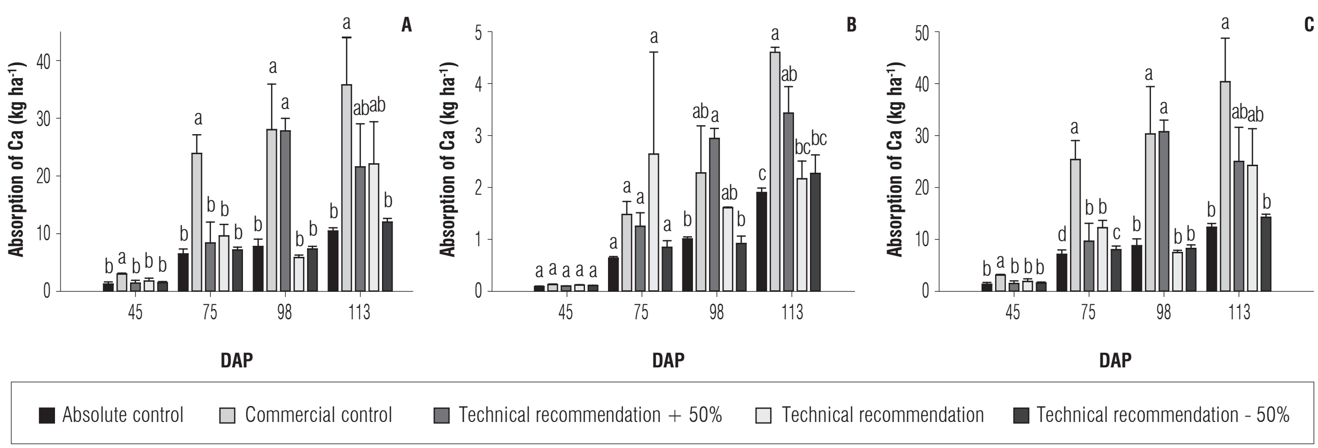

FIGURE 5. Absorption Ca in diploid potato variety Criolla Colombia with different doses of fertilizations. A, aerial parts; B, root and tuber; C, total. T1, absolute control; T2, commercial control; T3, technical recommendation + 50%; T4, technical recommendation; T5, technical recommendation – 50%. Means with different letters indicate significant differences according to Tukey's test ($P \leq 0.05$).

Magnesium

The period of greatest Mg absorption occurred at 113 dap for PSR and PST (Fig. 6B and 6C), while for PSA (Fig. 6A), it occurred at 75 dap. Interestingly, commercial control presented the highest values of absorption in the two fractions tested, higher in PSA (7.3 kg ha^{-1}); showing no significant differences with technical recommendation + 50% whose values (5.7 kg ha^{-1} in PSA for 75 dap) were those that came closest, but there were significant differences with all others. Cieslik and Sikora (1998), quoted by Ríos *et al.* (2010), argued that Mg allows the proper use of N, however excessive use of this leads to decreased absorption of Ca by plants. A likely cause for this increased accumulation of Mg in the shoot is that it forms part of the chlorophyll molecule (Mengel and Kirkby, 2001). Tabares *et al.* (2009) found no response to Mg in any of the categories of tubers in the variety Diacol Capiro with doses of 500 kg ha^{-1} of NPK with application of Mg.

Boron and zinc

The highest absorption of these elements was found in PSA and PSR (Fig. 7A, 7B, 7D, 7E) at 98 dap. Gregorio (2002), quoted by Brown *et al.* (2011) noted that the accumulation of Zn in plants is dictated by their genetic propensity to accumulate, nevertheless, it is clear that the trait depends on the genotype interactions with the environment with a wide range of expressions. Gómez (2005) stated that the availability of N increases with the presence of B because it stimulates root growth at early stages, furthermore the relationship with B and K for the sugar translocation process may influence the availability of K for the plant. Pérez *et al.* (2008) reported significant differences in levels of N, Ca and K, as an effect of applying B.

Because the dose used for trace elements was not changed technical recommendation + 50%, technical recommendation, or technical recommendation – 50%, the plant response to such was not adequate and antagonistic relationships might exist between major and trace elements, such as in the case of Zn and P where the relationship in absolute control for the test was 0.027 for the plant and 4.53 in the soil, where different and lower values had a negative effect on production and other evaluated variables. In light of the results, absolute control had the highest absorption of these elements, this indicates that the soil contributes most of the required trace elements; technical recommendation + 50% is close to two possibly because increasing doses of the majors could reduce the possible depressing effect of the trace elements in the antagonistic relations.

Sulfur

The highest absorption of S was seen in commercial control at 75 dap for PSA and 113 in PSR (7.2213 and 6,837 g ha^{-1} respectively, Fig. 9A and 9B), with statistically significant differences between this and all other treatments for these two periods, with a tendency to diminish over time in PSA and increase in PSR. In a similar study by Coraspe *et al.*,2009 on the potato (*Solanum tuberosum* L.) in production of tuber-seed, the largest accumulation of S in both the aerial part and the root and tuber occurred at 70 dap, with 11,400 and 253 g ha^{-1} respectively.

In the analysis of the considered elements it was found that absolute control had the highest absorption for almost all the nutrients in the plant, followed by technical recommendation + 50%.

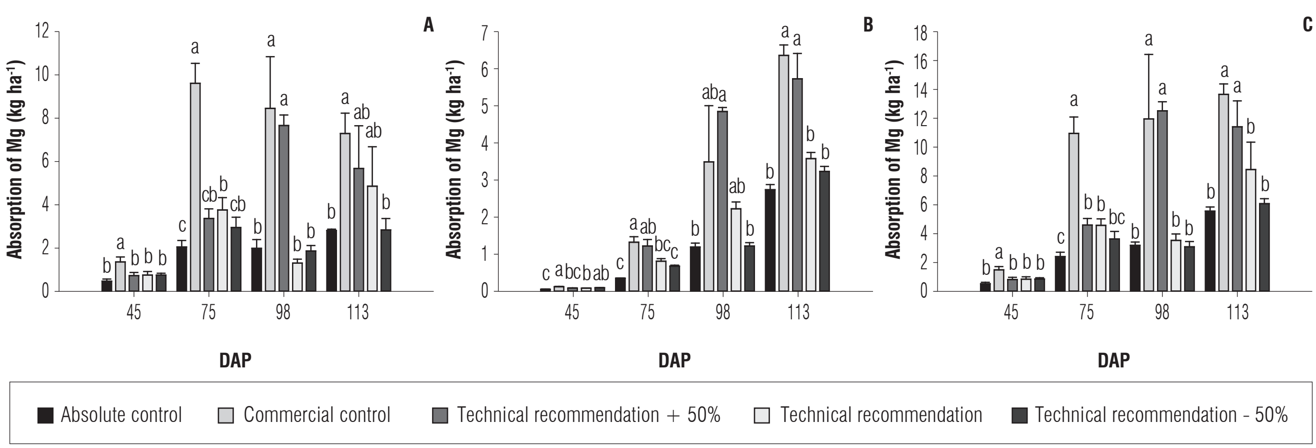

FIGURE 6. Absorption Mg in diploid potato variety Criolla Colombia with different doses of fertilizations. A, aerial parts; B, root and tuber; C, total. T1, absolute control; T2, commercial control; T3, technical recommendation + 50%; T4, technical recommendation; T5, technical recommendation – 50%. Means with different letters indicate significant differences according to Tukey's test ($P \leq 0.05$).

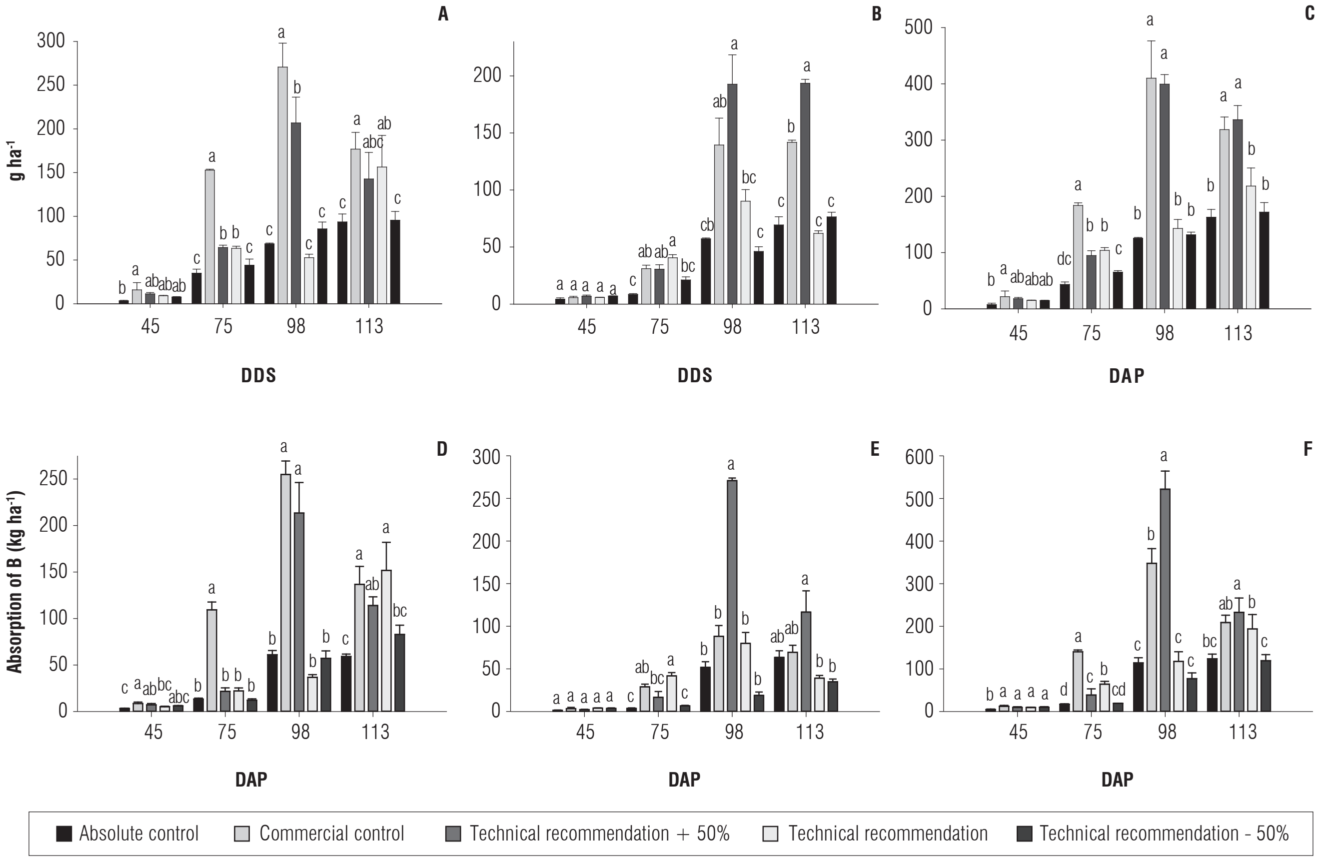

FIGURE 7. Absorption Zn and B in diploid potato variety Criolla Colombia with different doses of fertilizations. A, shoot Zn; B, root and tuber Zn; C, total Zn; D, aerial part B; E, root and tuber B; F, total B. T1, absolute control; T2, commercial control; T3, technical recommendation + 50%; T4, technical recommendation; T5, technical recommendation – 50%. Means with differentletters indicate significant differences according to Tukey's test ($P \leq 0.05$).

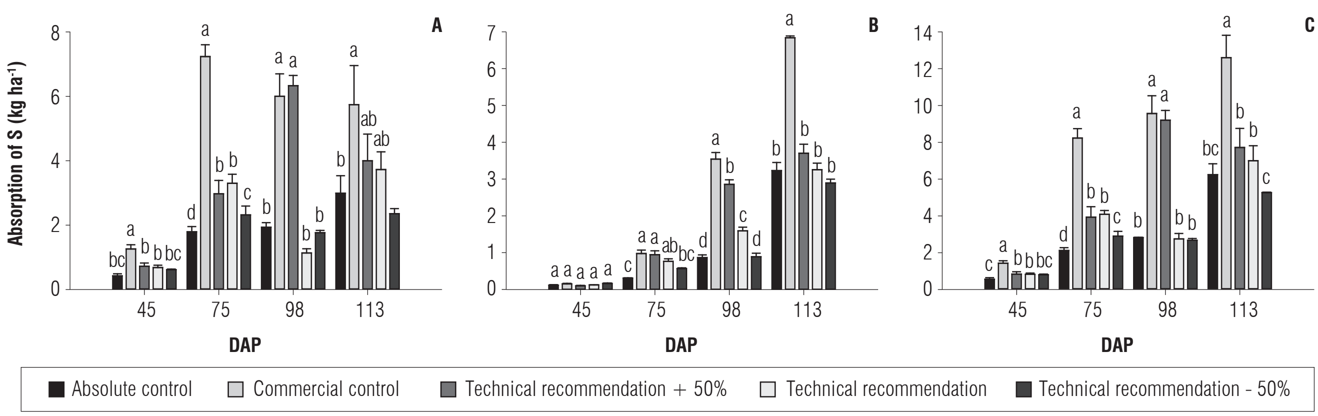

FIGURE 8. Absorption S in diploid potato variety Criolla Colombia with different doses of fertilizations. A, aerial parts; B, root and tuber; C, total. T1, absolute control; T2, commercial control; T3, technical recommendation + 50%; T4, technical recommendation; T5, technical recommendation – 50%. Means with different letters indicate significant differences according to Tukey's test ($P \leq 0.05$).

Yield

Yield category one

In the yield variable for category 1 (Fig. 9A), values between 2661 and 7981 kg ha^{-1} were obtained; commercial control, technical recommendation and technical recommendation + 50% achieved the highest average yield without significant differences (7,981; 7,748 and 7,551 kg ha^{-1} respectively), but with significant differences with technical recommendation – 50% and Absolute Control one (3,296 and 2,661

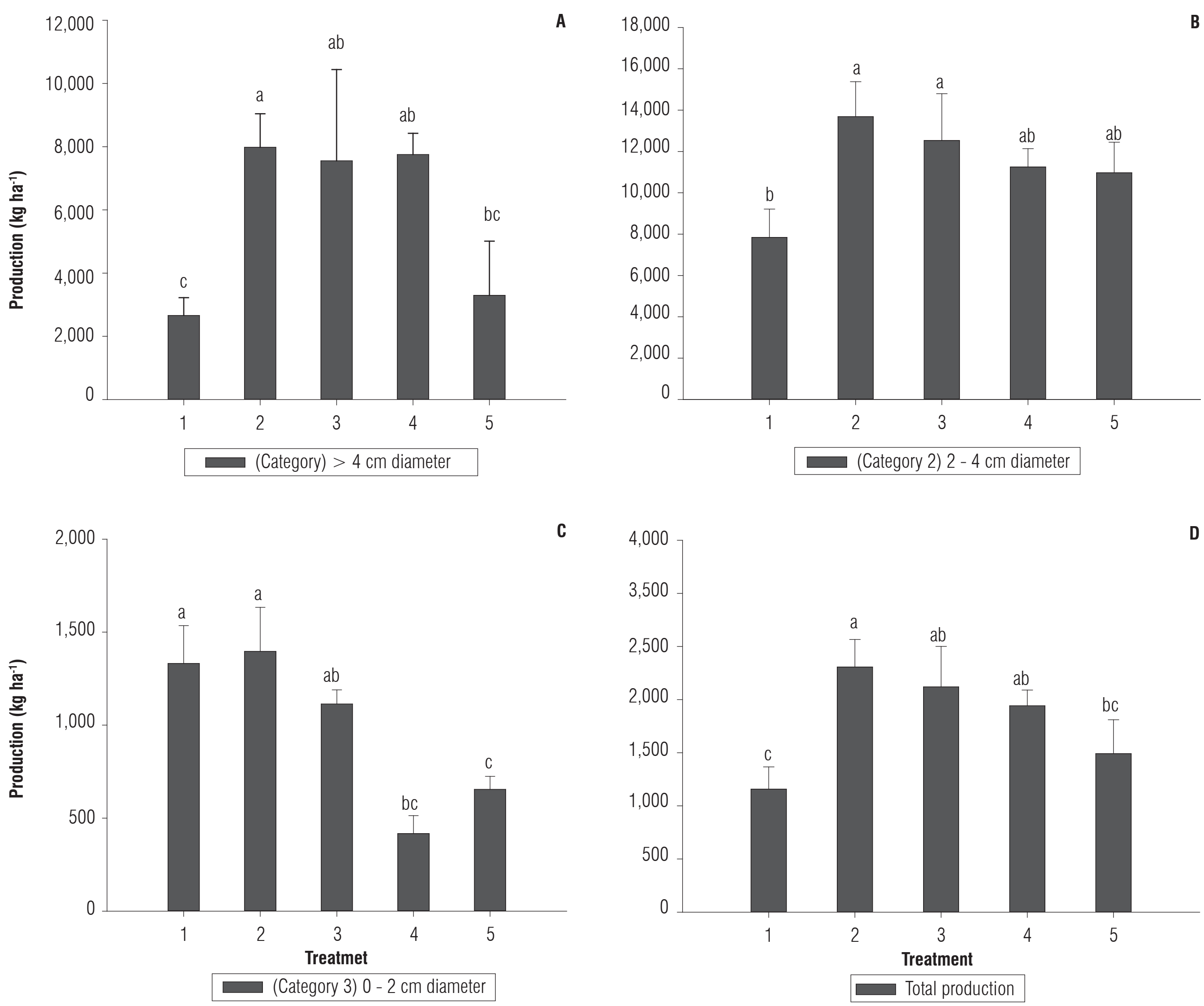

FIGURE 9. Yield of the potato variety Criolla Colombia with different fertilization treatments. A, category 1; B, category 2; C, category 3; D, total production. T1, absolute control; T2, commercial control; T3, technical recommendation + 50%; T4, technical recommendation; T5, technical recommendation – 50%. Means with different letters indicate indicate significant differences according to Tukey's test ($P \leq 0.05$).

kg ha^{-1}, respectively). These results exceed those reported by Rodríguez and Rodríguez (2005) and Navas *et al.* (2010) who found a yield of 5,500 and 7,430 kg ha^{-1} respectively, for this category and variety.

Yield category two

In this variable (Fig. 9B), the obtained values were between 7,839 and 13,691 kg ha^{-1}, with commercial control and technical recommendation + 50% showing the highest average yield (13,691 and 12,530 kg ha^{-1} respectively), without statistical differences with each other but with absolute control , technical recommendation and technical recommendation – 50% (7,839, 11,251 and 10,974 kg ha^{-1}, respectively). The yield values for the potato in the second category for commercial control, technical recommendation + 50%, technical recommendation and technical recommendation – 50% are within the range established for this category and variety (8,000 to 15,000 kg ha^{-1}) according to Pérez *et al.* (2008).

Yield category three

In this category (Fig. 9C), values were obtained between 417 and 1,396 kg ha^{-1}; commercial control, absolute control and technical recommendation + 50% had the highest average yield (1,396, 1,331 and 1,113 kg ha^{-1}, respectively), without statistical differences with each other but with technical recommendation – 50% and technical recommendation (654 and 417 kg ha^{-1}, respectively).

TABLE 4. Total nutrient absorption for commercial control and technical recommendation + 50% (kg ha^{-1}).

Treatment	N	P_2O_5	K_2O	Ca	Mg	S	Fe	Mn	Cu	Zn	B
Commercial control	120.5	20.0	217.6	40.4	13.6	12.6	0.28	0.61	0.03	0.41	0.35
Technical recommendation + 50%	99.16	15.5	204.9	30.7	12.5	9.2	0.89	0.29	0.03	0.40	0.52

Total yield

Values were obtained between 11,831 and 23,069 kg ha^{-1} (Fig. 9D); the commercial control, technical recommendation + 50% and technical recommendation were the most productive (23,068; 21,195 and 19,417 kg ha^{-1}, respectively), which did not have statistically significant differences with each other but did with technical recommendation – 50% and technical recommendation (14,924 and 11,831 kg ha^{-1}, respectively).

The yield was high for all treatments which had a fertilization application (commercial control to technical recommendation – 50%) and were in the range of potential production of this variety (15 to 25 t ha^{-1}) (Ñustez *et al.*, 2005), with absolute control having the highest value (23 068 kg ha^{-1}), equivalent to 92% of the production potential.

Tab. 5 highlights the fact that all treatments achieved over 55% of production in category two, this is important because it is the category that is most commercially handled and controls the market, noting that category one receives the same price.

Economic analysis

The cost-benefit analysis (BCR) (Tab. 6) shows the best ratio is for absolute control (1.8), which constitutes the best alternative in the present study, followed by technical recommendation + 50% and technical recommendation with slightly lower ratios (1.71 and 1.65) but are nonetheless viable options for the producer, who can choose one of these taking into account the cost of the sources of the utilized fertilizer.

TABLE 5. Production rate by category in diploid potato variety Criolla Colombia with different doses of fertilizations.

Treatment	First category	% of category second	Third category
Absolute control	22.5	66.3	11.3
Commercial control	34.6	59.4	6.1
Technical recommendation + 50%	35.6	59.1	5.3
Technical recommendation	39.9	57.9	2.1
Technical recommendation – 50%	22.1	73.5	4.4

Based on the above analysis and conclusion of the present study, fertilization treatment two determines the critical levels of absorption of nutrients for the study area as it meets the criteria proposed by Bertsch (1998), who defined critical level as that concentration of nutrients extracted from soil, above which the chances of finding responses to fertilization are very low, and below which yields will most likely be poor, and Alvarez and Carrillo (2009) defined it as the availability of nutrients necessary to obtain a yield equal to or greater than average for yields in the area, resulting in an economic gain for the farmer.

Conclusion and recommendation

In the present study, the commercial fertilization constituted the critical level, due to the increased nutrient absorption, increased production and improved cost-benefit ratio.

Further studies on the effect of trace elements on the production variables and quality of the tuber are recommended, since in the present study the application of these elements did not give significant responses in the evaluated variables.

Literature cited

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TABLE 6. Cost benefit analysis for potato variety Criolla Colombia with different doses of fertilizations.

Treatment	Yield (Kg ha^{-1})	Gross revenue ($COP)	Total cost ($COP)	Net revenue ($COP)	BCR
Absolute control	11,831.7	7,749,647.4	7,000,000	749,647.4	1.107
Commercial control	23,068.8	15,589,558.1	8,599,000	6,990,558.1	1.813
Technical recommendation + 50%	21,195.4	14,391,335.6	8,674,589	5,716,746.8	1.659
Technical recommendation	19,416.8	13,424,882.1	8,194,300	5,230,582.1	1.638
Technical recommendation – 50%	14,924.1	10,185,116.6	7,719,289	2,465,827.7	1.319

Price per kg for potato, 1st and 2nd category ($ 700 COP).

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