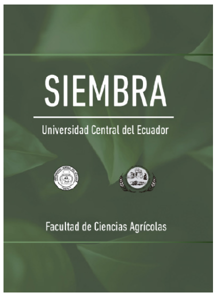
Nitrogen use efficiency in potato crop (Solanum tuberosum L.) in volcanic soils of Chimborazo, Ecuador



Eficiencia de uso del nitrógeno por el cultivo de papa (Solanum tuberosum L.) en suelos volcánicos de Chimborazo, Ecuador

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Abstract

Chimborazo province is one of Ecuador's main potato (*Solanum tuberosum* L.) production areas, where crop nutrition management is a key factor limiting yield. This study aimed to determine the Nitrogen Use Efficiency (UE_N) and the Nitrogen (N) rates needed to achieve yield goals for the Superchola and INIAP-Natividad potato varieties. Field experiments were conducted using a split-plot design with three replicates in two potato growing areas (Cortijo Bajo and Chañag) of Chimborazo province in Ecuador, from May to November 2016. The variables evaluated were total plant N recovery and total tuber yields, which were used to calculate Nitrogen Agronomic Efficiency (AE_N) and the N fertilizer rates needed to reach the yield goals for these potato varieties. Results indicated that the increase in potato yield consistently diminished as N fertilizer rates increased, with a clear quadratic function response for the two varieties. The AE_N for the Superchola variety ranged from 130 to 160 kg of tuber kg^{-1} of applied N, while the AE_N for the INIAP-Natividad variety ranged from 120 to 150 kg of tuber kg^{-1} of applied N. These values determined the N fertilizer rates required to achieve the yield goals in the following potato production cycle for the fertilizer recommendation domain: 120 kg^{-1} N ha^{-1} and 80 kg^{-1} N ha^{-1} for Superchola, and 80 and 110 kg^{-1} N ha^{-1} for INIAP-Natividad in Cortijo Bajo and Chañag, respectively. The study concluded that calculating the AE_N effectively adjusts N fertilization recommendations for potato crops under the soil and climatic conditions studied.

Keywords: fertilizer recommendation domain, increasing nitrogen rates, nitrogen agronomic efficiency, potatoes yield.

Resumen

La provincia de Chimborazo es una de las zonas de mayor producción de papa (*Solanum tuberosum* L.) en el Ecuador y el manejo de la nutrición del cultivo es uno de los limitantes para alcanzar altos rendimientos. El objetivo de la presente investigación fue determinar la eficiencia de uso del nitrógeno (EU_N) y las dosis de nitrógeno (N) necesarias para llegar a la meta de rendimiento de las variedades de papa Superchola e INIAP-Natividad. Los experimentos se implementaron bajo un Diseño de Parcela Dividida con tres repeticiones en dos localidades paperas (Cortijo Bajo y Chañag) de la provincia de Chimborazo-Ecuador, desde mayo a noviembre del año 2016. Las variables evaluadas fueron extracción de N y rendimiento total de tubérculos, con las cuales se calcularon la eficiencia agronómica de N (EA_N) y las dosis de fertilización nitrogenada necesarias para las dos variedades de papa evaluadas. Los resultados indicaron que el aumento en rendimiento del cultivo de papa fue consistentemente menor a medida que se incrementaron las dosis de N con una clara respuesta cuadrática para las dos variedades. La EA_N de la variedad Superchola varió entre 130 y 160, mientras que la EA_N de la variedad INIAP-Natividad entre 120 y 150 kg de papa kg^{-1} de N aplicado; estos valores de EA_N permitieron determinar la dosis de fertilización nitrogenada (120 kg^{-1} N ha^{-1} y 80 kg^{-1} N ha^{-1} para Superchola y 80 y 110 kg^{-1} N ha^{-1} para INIAP-Natividad en Cortijo Bajo y Chañag, respectivamente) que serán necesarias para lograr la meta de rendimiento en el siguiente ciclo de siembra de papa en el correspondiente dominio de recomendación de fertilización. Se concluye que el cálculo de la EA_N permite ajustar efectivamente las recomendaciones de fertilización nitrogenada para el cultivo de papa bajo las condiciones edafo-climáticas estudiadas.

Palabras clave: recomendación de fertilización por dominio, dosis crecientes de N, eficiencia agronómica de nitrógeno, rendimiento de papa.

1. Introduction

Potato (*S. tuberosum*) has an average consumption of 26 kg $person^{-1}$ $year^{-1}$, and it is one of the most important crops in Ecuador (Ministerio de Agricultura y Ganadería [MAG], 2019). In 2018, the sown potato surface was 22,107 ha with a total production of 517,655 t. The province of Carchi concentrates the majority of the potato production in Ecuador with 38 % of the total national, followed by Chimborazo with 16.6% and Tungurahua with 10.3 % (Instituto Nacional de Estadística y Censos [INEC], 2019). In the same year, the highest average yield was obtained in Carchi, which surpassed the national media (23.4 t ha^{-1}) with 32.0 t ha^{-1}; while Cotopaxi was the province with the lowest yield with 11.2 t ha^{-1} (MAG, 2019).

The high yields of the potato crop are closely related to a precise and adequate fertilization based on macro and micronutrients (Yara, 2021) due to the high demand of agricultural fertilizers by hectare, making fertilization a key factor to increase the yield and obtain quality tubers (Nick & Borém, 2017). This demand is given by the root system of the crop, which is relatively shallow and with reduced development in relation to its yield (Muleta & Aga, 2019).

Research about nutrition and fertilization of the potato crop in the soils of the central-north highlands of Ecuador showed that N is the most limiting nutrient for the production (Arroyo Terán, 2015). Nitrogen plays a fundamental role in the growth and development of the plants, and it constitutes around 1 to 4 % of the dry matter of the plant. The plants absorb N in the form of nitrate (NO_3^-) or ammonium (NH_4^+). In the interior, they get combined with compounds produced by the metabolism of carbohydrates for the formation of basic organic molecules such as amino acids and proteins (Bell, 2016). Being nitrogen the main component of proteins, it is part of the majority of main processes for the development of the plants and it influences positively in the yield of tubers. Additionally, an ideal quantity of N in the potato plant helps in the absorption of other nutrients and maximizes the production and productivity of the crop (Kahsay, 2019). On the other hand, the inadequate use of nitrogenated sources can cause important loses of this nutrient from the soil by nitrification processes, leaching and volatilization. In addition, the excess of N that is not absorbed by the crop could lead to contamination of water by leaching of nitrates (NO_3^-) and could contribute to global warming due to the emission of N oxides (Fagodiya et al., 2020).

The efficiency on the use of nitrogen [EU_N] depends, in a great deal, on the properties of the soil, which if adequately understood and managed could avoid the loss of this nutrient, promote the accumulation of biomass and keep biodiversity in the soil. The EU_N can be studied through the evaluation of adequate sources, doses, periods and forms of application of N (Instituto Internacional de Nutrición de Plantas [IPNI], 2012). To generate a recommendation on N fertilization for a specific site or for a recommended domain (areas with similar conditions on soil and climate), it should be considered the crop yield target (the highest yield obtainable in the site with the lowest N quantity) as well because the recommended N dose is associated to the genetic potential of the variety, adaptation to the soil characteristics and agronomic management (Camacho Gallardo, 2018).

The chemical analysis of N in the soil is not necessarily a good support tool to develop a recommendation of fertilization based on the bioavailable quantity of N in the soil for the crop because the content of the different chemical forms of N is influenced by soil and climate conditions of the site of recommendation. This is why alternative methods for the evaluation of nutritional state have been developed for the crop to make adjustments targeted to reach the desired yield (García & Espinosa, 2008). Among these methods is the visual detection of deficiency symptoms in the plants (Havlin et al., 2014) and non-invasive tools such as chlorophyll measurement to estimulate the concentration of N in the leaves (Cassman et al., 2002). However, an effective alternative to find the required nutritional dose to reach the targeted yield is the methodology based on the plant behaviour in a specific site, and it seeks to fill the gap between the nutrient quantity needed by the crop to accumulate the targeted yield and the nutrient input present in the soil (Alvarado Ochoa et al., 2011; Witt et al., 2006).

2. Materials and Methods

The research was conducted in the localities of Cortijo Bajo and Chañag, located in the parish Quimiag in the Chimborazo province, Ecuador, between the months of May and November 2016. The sites are located at 3,149 and 3,273 m a.s.l., respectively. They have an annual precipitation of 618.1 mm and an average annual temperature of 11.2 °C according to the data reported by the closest meteorological station (Instituto Nacional de Meteorología e Hidrología [INAMHI], 2015).

The location is 1º 42' 18.631" S latitude and 78º 34' 20.495" W longitude for Cortijo Bajo, and 1º 37' 17.953" S latitude and 78º 31' 38.28" W longitude for Chañag. The soil of the two sites is classified as Hapludand, whose physical and chemical characteristics are presented in Table 1.

Table 1. Physical and chemical characteristics of the soils in Cortijo Bajo and Chañag, Chimborazo.

Soil properties	Localities	
	Cortijo Bajo	**Chañag**
Slope	20 %	25 %
Texture	Sandy silt clayey sand	Sandy silt clayey sand
pH	6.4 LA	6.7 M
MO (%)	8.4 A	7.5 A
P ($mg\ kg^{-1}$)	19.5 A	9.8 M
K ($cmol_{+}kg^{-1}$) Ca	0.5 A	0.3 M
($cmol_{+}kg^{-1}$) Mg	20.1 A	22.6 A
($cmol_{+}kg^{-1}$) S	4.7 A	1.7 M
($mg\ kg^{-1}$)	10.2 M	9.3 B
Zn ($mg\ kg^{-1}$)	2.6 M	1.7 B
Cu ($mg\ kg^{-1}$)	12.9 A	8.4 A
Fe ($mg\ kg^{-1}$)	353.5 A	228 A
Mn ($mg\ kg^{-1}$)	6.7 M	4.6 M
B ($mg\ kg^{-1}$)	0.3 B	0.5 B

A= High, M= Medium, B= Low, LA= Slightly acid

Source: Instituto Nacional de Investigaciones Agropecuarias [INIAP] (2016)

The effect of increasing doses of N was evaluated (0, 60, 120, 180 and 240 kg of N ha^{-1}) in the total absorption of N, tuber yield and Nitrogen Agronomic Efficiency [AE_N] in two varieties of potato, Superchola and INIAP-Natividad. The nitrogenated fertilizer used was urea (46 % N). All the treatments received a homogeneous application of 300 kg P_2O_5 ha^{-1} (triple super phosphate), 100 kg K_2O ha^{-1} (monopotassium phosphate) and 30 kg S ha^{-1} (sulpomag) with bases on the soil analysis. Each experimental unit had a surface of 35.7 m^2 (5.95 m x 6 m) with 5 grooves separated by 1.20 m and with a surface of 0.35 m between plants. A Divided Plot Design was used, being the variety the big plot and the doses of N the subplots. Each treatment was replicated three times. To evaluate the total extraction of N, three plants were taken randomly from the three central grooves in each plot net at physiological maturity. The plants were divided into foliage, root and tubers, they were weighted in fresh and then dried at 65 °C until the weight was constant. The dry matter of each organ was grounded and sifted with a net No. 40, which was then analysed for total N through the method semi micro-Kjeldahl (Bremner, 1996).

With the results of the total N concentration and of the dry matter of each organ, the total extraction of N per plant (kg ha^{-1}) was calculated. To determine the total yield of tubers, the tubers from the three central grooves of each experimental unit were harvested, weighted, and reported in t ha^{-1}. The results were statistically analysed with the statistical program Infostat professional version (Di Rienzo et al., 2018). The EA_N was calculated through the equation [1].

$$AE_N = \frac{Y_{+N} - Y_{-N}}{Doses\ N} \quad [1]$$

where:

- AE_N = kg tuber per each kg of N used.
- Y_{+N} = Yield with the application of each N dose.
- T_{-N} = Yield without N application (control).

Additionally, the graphic method to estimate the AE was used, where the yield curve is contracted against the agronomic efficiency values with the evaluated doses. Thus, the AE_N to be used is located in the point that this starts to decrease. At this point the interception of the AE curve and the yield curve is located.

Once the calculation of the AE_N was defined, with these results the doses of N to be applied was calculated changing algebraically the terms of the original formula. The formula for the calculation of the doses of N is described in equation [2].

$$Doses\ of\ N = \frac{Y_{+N} - Y_{-N}}{AE_N} \quad [2]$$

where:

- Y_{+N} = Yield with the application of each N dose.
- Y_{-N} = Yield without the application of N (control).
- AE_N = kg tuber per each kg of N used.

On the other hand, the optimal physiological dose [OPD] was linked to the level of nutrients necessary for the plant to reach a point in which a specific element does not become a limiting factor for its growth and development. To reach or to keep this level does not guarantee the obtention of maximum yields, but it is guaranteed by the rest of intervener factors in the system at optimal levels. The mentioned nutritional factor will not be an obstacle to reach the targeted yield (Thompson y Troeh, 1982). To determine the OPD and the optimal economic dose [OED], a model of multiple regression of second order was applied with a quadratic adjustment (Y= β0- β1X + β2X2) with the methodology described by Rebolledo (1999). In the following paragraph, the formulas for the calculation of OPD (equation [3]) and OED (equation [4]) are described.

$$OPD = \frac{-\beta 1}{-2\beta 2} \quad [3]$$

$$OED = \frac{-\beta 1 - RCN}{-2\beta 2} \quad [4]$$

where:

- *β1* y *β2* = regression parameters of the quadratic function.
- *RCN* = Cost relationship of the nutrient per kg.

While the graphic method was done through the contrast of yield in kg ha^{-1}, the AE_N and the dose of N, where the curve cut the height of a superior yield to the expected media, with an intermediate dose of fertilization.

Finally, the economic analysis was done with the partial budget analysis and the marginal rate of return of the treatments, which was proposed by the International Maize and Wheat Improvement Center (Perrin et al., 1983).

3. Results and Discussion

3.1. Extraction of Nitrogen by the crop

The results of the N extraction by the potato crop to the growing doses of N applied into the soil in Cortijo Bajo and Chañag were presented in the Figures 1 and 2, respectively. It was observed that the extraction of N increases linearly with the increment of N doses in the two varieties. This means that the plant absorbed in direct proportion to the N quantities supplied until the highest dose (240 kg N ha^{-1}). The plants cannot absorb nutrients indefinitely and the lineal answer in N extraction until the dose of 240 kg N ha^{-1} suggested that the potato in this soil could keep absorbing N to higher doses until its maximum absorbing capacity and show a quadratic response. Most of the absorbed N by the plant at high doses of application of this nutrient in the soil is a luxury and does not support higher yield (White, 2012).

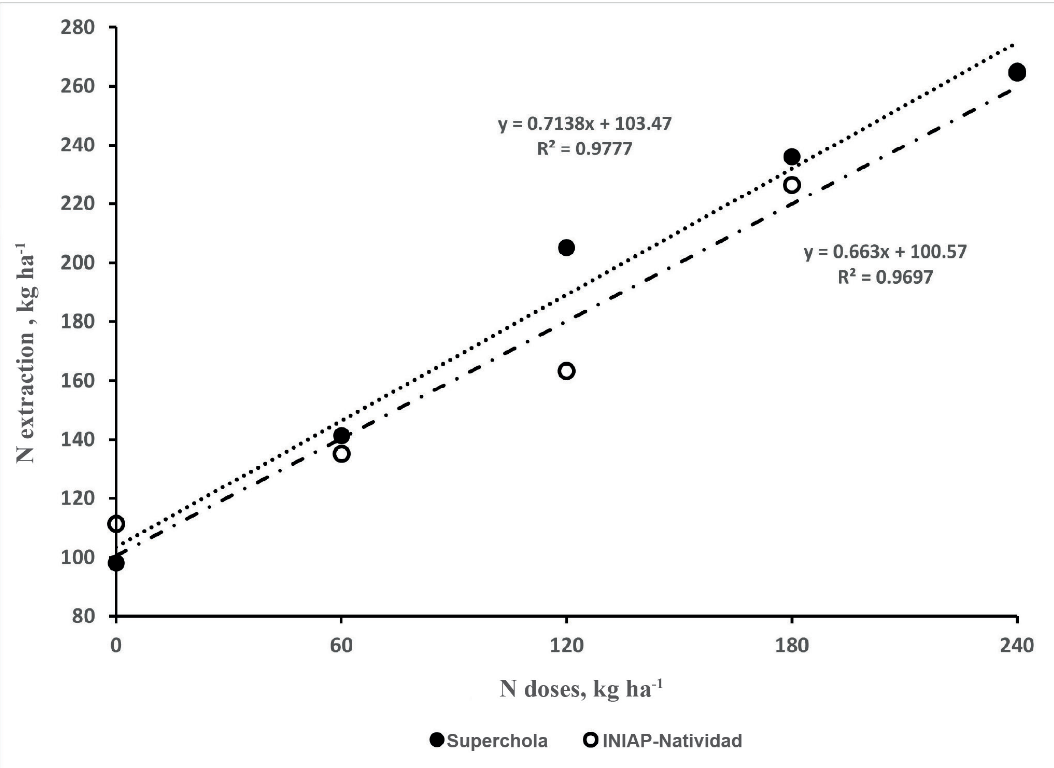

Figure 1. Total nitrogen extraction of the Superchola and INIAP-Natividad varieties in Cortijo Bajo, Quimiag, Chimborazo.

The extraction of nutrients by potato crop depends on the variety, soil fertility, environmental conditions, yield and crop management. Nutrient absorption by the potato crop studies in volcanic soils from Costa Rica reported by Bertsch (2009), showed that this crop absorbs 230 kg N ha^{-1} for a yield of 69 t ha^{-1}, and the maximum absorption occurred at 87 days after sowing. On the other hand, Oyarzún et al. (2002) mentioned that the potato crop in the highlands of Ecuador can extract 70 kg N ha^{-1} when the yield is 17 t ha^{-1} and 220 kg N ha^{-1} for a yield of 50 t ha^{-1}. Additionally, the potato plant absorbs most of the N before the maximum growing period and development of the tuber, which suggests that the plant assimilates more than 50 % of the total N absorbed before the tuber filling with a daily demand that varies between 6 and 7 ha^{-1} day^{-1} (Horneck & Rosen, 2008).

Finding a recommended quantity of N to be applied into the soil to reach the targeted yield in a specific site or in a recommended domain is a challenging task because of the dynamics of this nutrient in the soil. It could be thought that the total absorption of N at the physiological maturity could be a parameter that could help finding an appropriate dose of N to reach the yield targeted searching for replenish the nutrients that the crop has extracted from the soil and that have not been recycled (Gómez Sánchez, 2014).

The results from the present study showed that it existed a high extraction of N in the control treatment (no N application), suggesting an existence of an important input of native N from the soil in the sites that, according to the corresponding analysis, have a high organic matter content (Table 1). The high level of organic matter reported in the analysis and the answer to the nitrogenated fertilization could be explained by the quality of the stable organic matter that characterize the soils developed over volcanic ashes of the Northern highlands of Ecuador at elevations higher than 3,200 m.a.s.l., whose clay fraction is dominated by humus-aluminum complexes (Zehetner et al., 2003). Therefore, the trapped organic compounds in these complexes are inactive, ceasing to be part of the active organic fraction of the soil that is mineralized and is capable of releasing N to the soil (Benavides & Gonzales, 1998; Inoue & Higashi, 1988; Takahashi & Dahlgren, 2016).

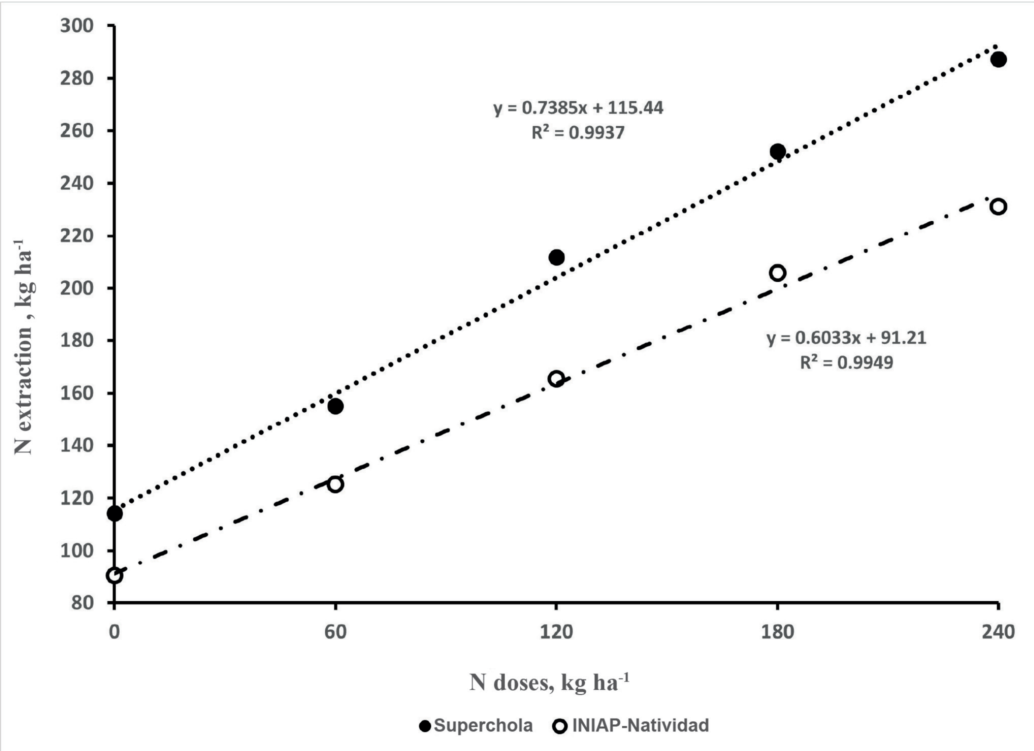

Figure 2. Total nitrogen extraction of the Superchola and INIAP-Natividad varieties in Chañag, Quimiag, Chimborazo.

3.2. Tuber Yield

The answer to the application of increasing doses of N in the tuber yield of potato had a different behaviour to the total N absorption in the two sites and in the two evaluated varieties because the increase in the yield was consistently lower as the doses of N were increasing in a clear quadratic response, which is known as decreasing yield to the application of N doses (Figures 3 and 4). This behavior has been reported in various locations of the world, showing different potential of yield depending on the evaluated varieties and fertility conditions of the soil (Banerjee et al., 2016).

With the values of the yield curves, the optimal physiological dose [OPD] (the highest point on the curve) can be calculated, which could show the necessary dose of N to reach that specific yield, N value that could be the recommended one for the site. However, these values are almost always very high because they do not consider the EU_N. In this study, the calculated values of OPD for the varieties Superchola and INIAP-Natividad in Cortijo Bajo were 227 y 538 kg de N ha^{-1}, respectively. The high and irregular numbers obtained in INIAP-Natividad can be explained because the calculation should find the highest theoretical point in the answer curve that continues growing after the last dose of N evaluated during the experiment (240 kg N ha^{-1}). The same proceeds to Chañag site (Figures 3 and 4). As observed, it is challenging to use the OPD as a recommended value of N fertilization in potato crop in the domain of recommendation of the studied sites. Oyarzún et al*.* (2002), consider that the value of OPD for the potato zones in the provinces of Pichincha, Cotopaxi, Carchi and Cañar are 160 kg of N ha^{-1}, which might be a more real value but that includes all the varieties and all the domains of recommendation of the zones of potato production in the North highlands of Ecuador.

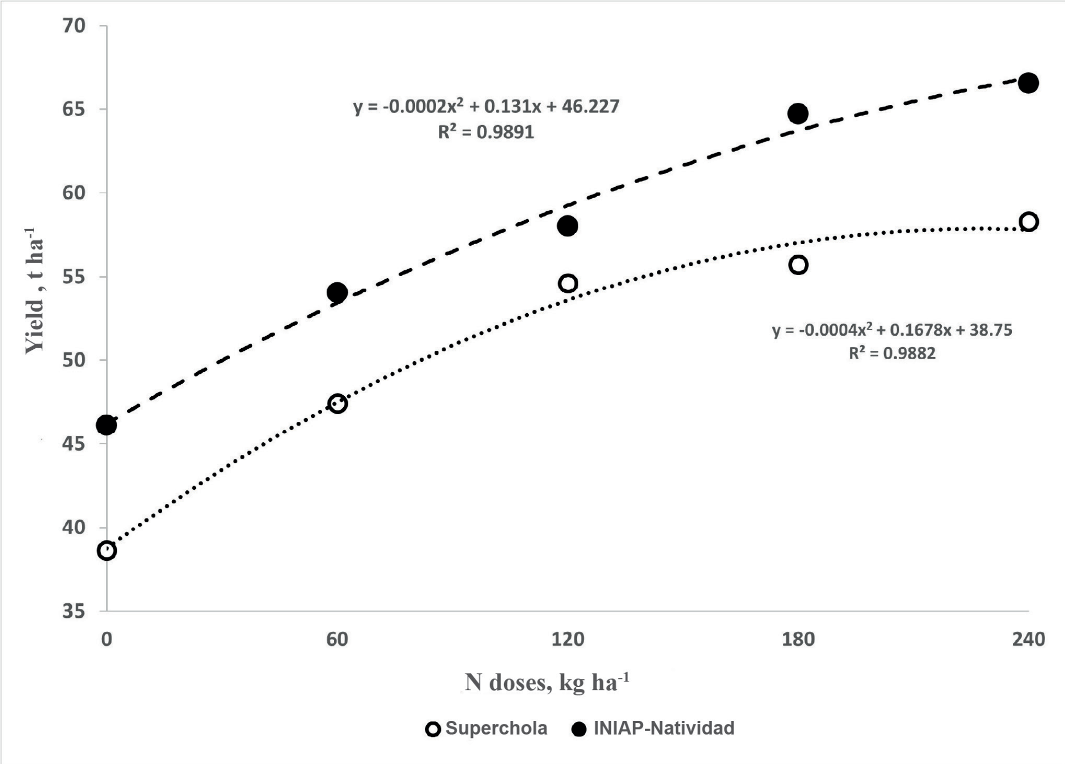

Figure 3. Effects of nitrogen doses on the total tuber yield of potatoes in Cortijo Bajo, Quimiag, Chimborazo.

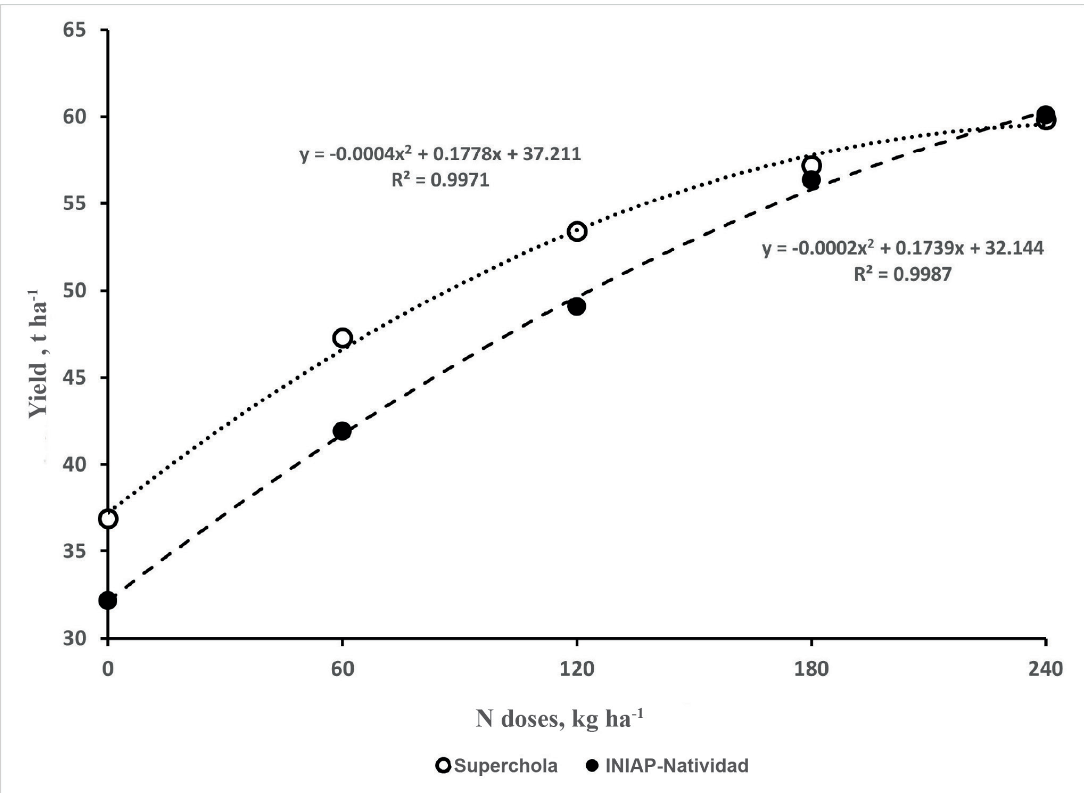

Figure 4. Effects of nitrogen doses on the total tuber yield of potatoes in Chañag, Quimiag, Chimborazo.

3.3. Efficiency of the use of nitrogen as a base for recommendation

An adequate supplement of N is required to obtain high and profitable yields of potato (Abdallah et al., 2016). However, it is important to highlight that the excessive use of N in the agricultural production systems contributes to environmental pollution, even more in eroded soils, where the efficiency of the N use from fertilizers is low because the third part of the applied fertilizer is lost to the atmosphere or it gets filtrated into underground water in the form of ammonia, nitrous oxide and nitrates (Vera Arteaga et al., 2019). On the other hand, the deficiency of N in the tuber stage significantly affects the yield of the crop (Marouani & Harbeoui, 2016).

The relationship between the yield of a crop and N supply is adjusted to a function of decreasing yields that makes challenging to reach higher yields without the increasing of environmental and health problems caused by the inefficient use of N. Nitrogen absorption and crop yield measured with field experiments increase with N dose until they gradually reach their maximum, which is determined by the performance potential of the evaluation site. The yield response to the low doses of N is big because N is the main limiting factor for growth and the final yield of the crop. As the doses of N increase, the yield response gets lower and, in occasions, negative in a typical quadratic response (Banerjee et al., 2016).

The EU_N is an index that incorporates the contribution of the native N from the soil (crop yield without N application into the soil), the efficiency of absorption and the efficiency of incorporation of N to the performance (potential performance). Dobermann (2007) and Snyder (2009) described the useful forms to define the EU_N presented in Table 2.

Table 2. Definitions of nitrogen use efficiency.

EU_N Term	**Formula***
Partial Factor of productivity [**PFP_N**]	Y/D
Agronomic Efficiency of applied N [**AE_N**]	$(Y-Y_0)$ /D
Physiological Efficiency of applied N [**PE_N**]	Uc/D
Apparent efficiency of N recovery [**ER_N**]	$(U-U_0)$ /D

* D = Amount of N applied (as fertilizer, organic residues and others); Y = Yield of the harvested portion of the crop with N application; Y_0 = Yield of the control treatment without N application; U_C = N content of the harvested portion of the crop; U_0 = Total N accumulation in the aboveground biomass of the crop without N application.
Adapted from: Dobermann (2007) and Snyder (2009)

The Partial Factor of Productivity of N [PFP_N], the wider form to measure the EU_N is the relationship between yield and applied N quantity. This factor does not consider the native N of the soil and gives high values of efficiency that are not realistic, most of the times it is used to develop estimation statistics for nutrient use.

The AE_N is the most practical form to calculate the EU_N and it can be easily implemented in the field. This index relates the difference between the yield with N application and the yield without N application with the doses of applied N. In this matter, the native N of the soil is considered in the calculation for the yield.

The Physiological Efficiency of N [PE_N] and the Apparent Efficiency of Recovery of N [ER_N] follow the same calculation scheme of the two previous efficiencies, but they are calculated with the total N absorption of the crop. They are less practical because they require the use of a laboratory.

As mentioned, the information of the yield curves as a response to the application of growing doses of N are not sufficient to define the N dose necessary to obtain the target yield in a particular site or in a domain of recommendation in a potato production area. In the majority of the cases the dynamics of N prevents the analysis of N in the soil from being a tool to help the determination of the required N quantity to obtain the target yield (Cassman et al., 2002). This situation made the development of diagnostic methods based on the plant necessary before than methods based on the soil (Witt et al., 2006). The yield curves in response to the N application can be used to calculate the EA_N (potato tuber quantity that can be obtained with each kg of N applied) according to the following relation: $AE_N = (Y_{+N} - Y_{-N})$ /N doses, this calculation is presented in Table 3. It is observed that AE_N is reduced as the doses of N increase, in consequence, it is possible to use a graphic method to find the AE_N in the point of the curve in which this starts to decrease in a clear form, this point is the interception of the yield curve according to N doses with the $AE_{N.}$ curve. The graphic representation of the association between the yield and the AE_N for the Superchola variety is presented in the Figures 5 and 6, and for the INIAP Natividad variety in the Figures 7 and 8.

Table 3. Yield and nitrogen agronomic efficiency of the Superchola and INIAP-Natividad varieties in the localities of Cortijo Bajo and Chañag, Quimiag, Chimborazo, 2016.

Doses of N kg ha^{-1}	Cortijo Bajo		Chañag	
	Yield kg potato ha^{-1}	AE_N kg potato ha^{-1}	Yield kg potato ha^{-1}	AE_N kg potato ha^{-1}
Superchola				
0	38.610		36.890	
60	47.430	147	47.270	173
120	54.600	133	53.390	138
180	55.710	95	57.200	113
240	58.270	82	59.540	94
INIAP-Natividad				
0	46.120		32.150	
60	54.030	132	41.900	163
120	58.020	99	49.070	141
180	64.730	103	56.360	135
240	66.550	85	60.100	116

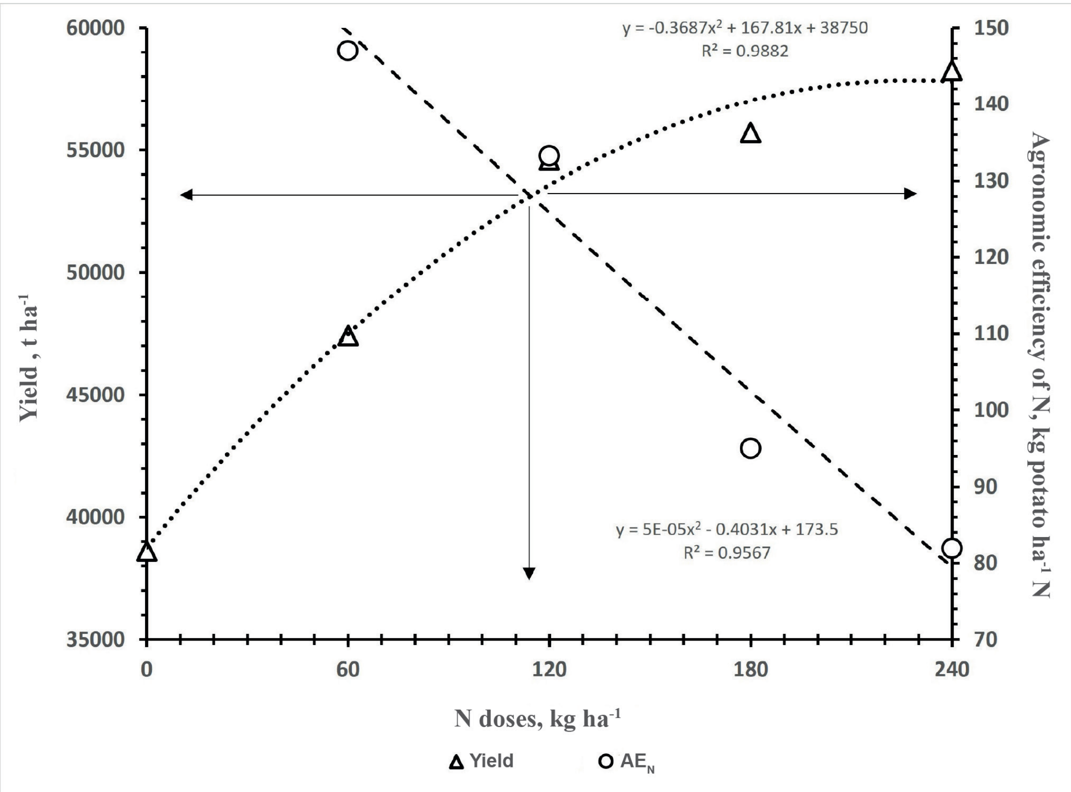

Figure 5. Tuber yield and N agronomic efficiency in response to increasing N doses of the Superchola variety in Cortijo Bajo, Quimiag, Chimborazo.

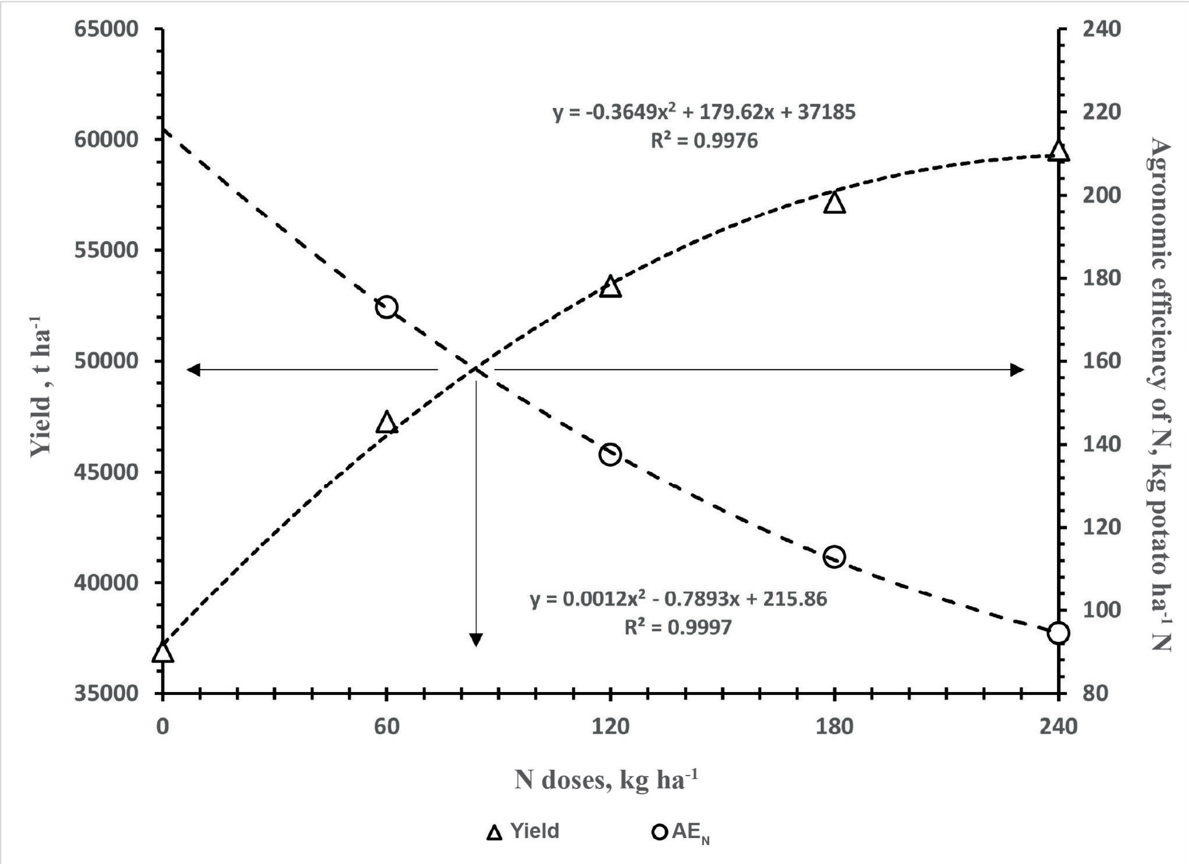

Figure 6. Tuber yield and N agronomic efficiency in response to increasing N doses of the Superchola variety in Chañag, Quimiag, Chimborazo. Y-axis: Yield kg ha-1.

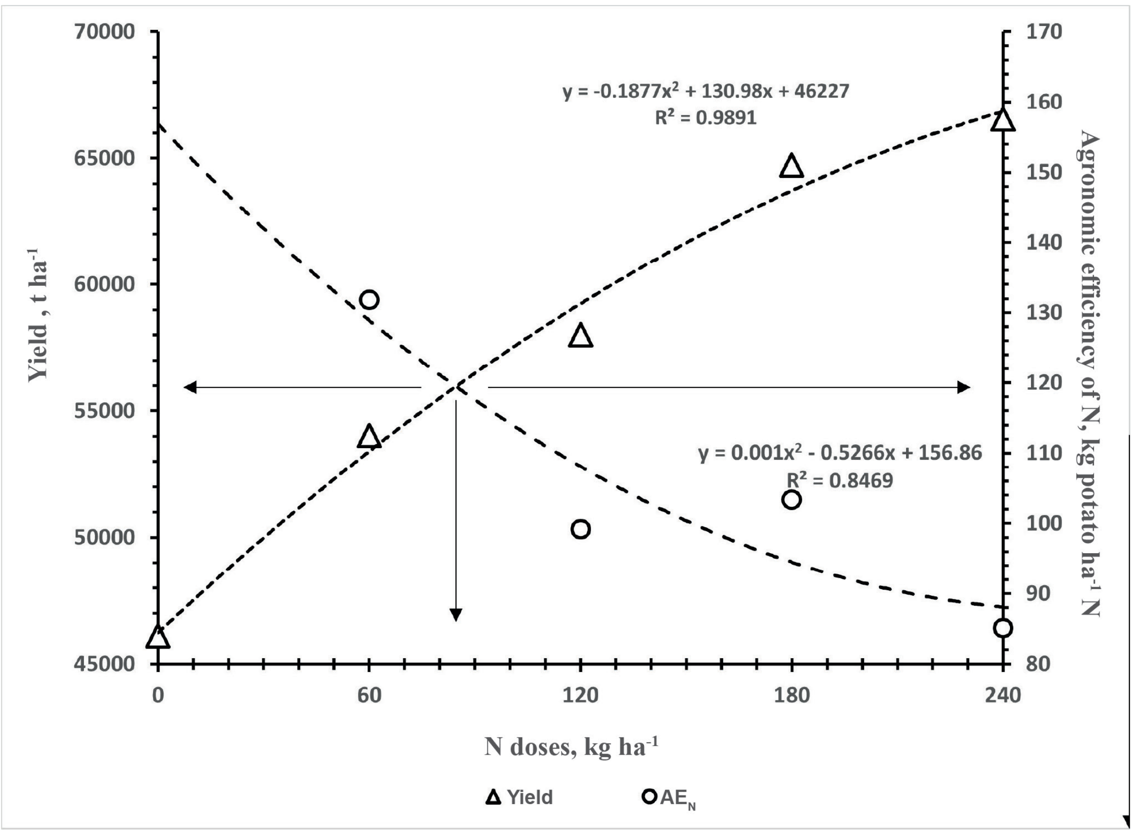

Figure 7. Tuber yield and N agronomic efficiency in response to the application of increasing N doses of the INIAP Natividad variety in Cortijo Bajo, Quimiag, Chimborazo.

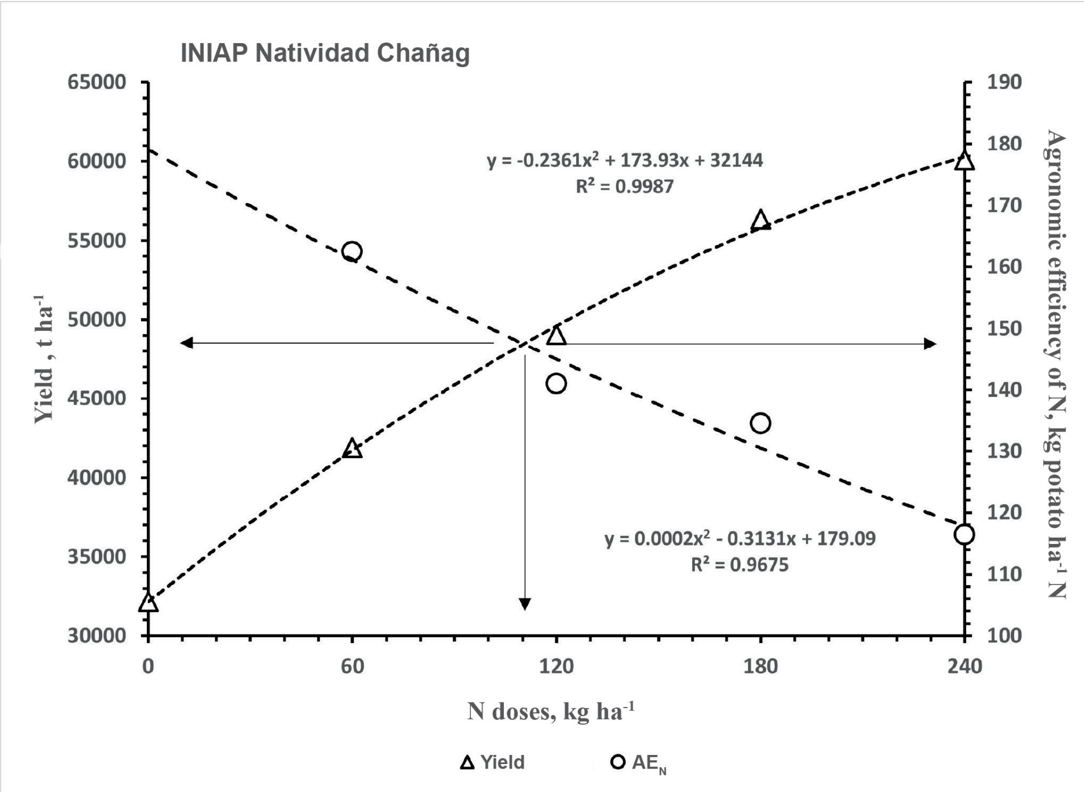

Figure 8. Tuber yield and N agronomic efficiency in response to the application of increasing N doses of the INIAP Natividad variety in Chañag, Quimiag, Chimborazo.

From Figure 5, it can be observed that the target yield for the Superchola variety in Cortijo Bajo should be around 55,000 kg ha^{-1}, the AE_N 130 kg of potato kg^{-1} of N and the recommended N dose for the next sown in the site should be 120 kg N ha^{-1}.

The target yield of the Superchola variety in Chañag (Figura 6) should be around 50,000 kg ha^{-1}, the AE_N should be 160 kg of potato kg^{-1} of N and the recommended N dose for the next sown in the site should de 80 kg N ha^{-1}. In the Figure 8, it is observed that the target yield for the INIAP-Natividad variety in Chañag is around 50,000 kg ha^{-1}, the AE_N is 150 kg of potato kg^{-1} of N, and the recommended N dose for the next sown in the site should be 110 kg N ha^{-1}.

These results agreed with Gutiérrez et al. (2018), who obtained the best AE_N with doses of 70 and 140 kg N ha^{-1} in oat crop. However, with higher doses of kg N ha^{-1} the AE_N decreases. On the other hand, Marouani & Harbeoui (2016) reported higher yields and extracted N from tubers with the highest doses of N (200 kg ha^{-1}).

In Table 4, a comparison between the data of the agronomic evaluation found during this experiment and the data from the economic analysis is presented. It is observed that the doses obtained by the graphic method are close to the ones obtained by the better economic return through the method of Perrin et al. (1983), conducted with the response data to the application of N doses in the two varieties and two sites of the evaluation.

The obtained AE_N during this experiment can be used to calculate the required dose of N to reach the target yield of the potato crop in the recommended domain (zone where the clime and soil conditions are the same) of potato production in Quimiag. The target yield (potato yield that the environment allows with the best agronomic management known and with the more efficient dose of N), so the required (Y_{+N}, and for the calculation as well, was stablished by the experiment. In this manner, the dose of N is determined for each production cycle. Once it is obtained and tried, the dose can improve the AE_N. It means higher yield with the same N dose through agronomic management (better forms to localize the N in the soil, different N sources, careful fractioning of the doses, better pest and irrigation management, among others). The data of this experiment shows that the environment could allow the production of 70,000 kg ha^{-1} of tubers and with a better agronomic management this could be the new target yield for the recommendation domain. With this method, the plant only allows to determine the N dose required to reach the targeted yield and make a more efficient use of N. This strategy is easy to implement and manage by the farmers.

Table 4. Comparison of agronomic efficiency and the corresponding nitrogen application doses obtained by the graphical method and the nitrogen doses that produced the best economic response of the Superchola and INIAP Natividad varieties in Cortijo Bajo and Chañag, Quimiag, Chimborazo, 2016.

Site	Agronomic assessment			Economic assessment	
	Target yield	**Doses**	**AE_N**	**Net Benefit**	**Doses**
Superchola					
	kg ha^{-1}	kg ha^{-1}	kg potato kg^{-1} N	US $ ha^{-1}	kg ha^{-1}
Cortijo Bajo	55.000	120	130	12.294	120
Chañag	50.000	80	160	12.831	60
INIAP-Natividad					
Cortijo Bajo	55.000	80	120	8.630	120
Chañag	50.000	110	150	10.268	120

4. Conclusions

The experiments conducted in Cortijo Bajo and Chañag in Quimiag, Chimborazo, allowed to determine that the AE_N of the variety Superchola varied between 130 and 160 kg of potato kg^{-1} of applied N, while the AE_N of the INIAP-Natividad variety varied between 120 and 150 kg of potato kg^{-1} of applied N. These values allowed to determine the required dose of N that is necessary to apply in the next sown cycle of Superchola and INIAP Natividad potato in the respective domain of recommendation. With this, the EU_N could be improved for the potato crop of the two varieties. The recommendation of the doses of N application obtained with the agronomic evaluation (120 and 80 kg ha^{-1} for Superchola and INIAP Natividad in Cortijo; while 80 and 110 kg ha^{-1} for the same varieties in Chañag) can be compared with the doses that get the best return in the economic evaluation of the yield (120 kg ha^{-1} for the two varieties in Cortijo Bajo; while 60 and 120 kg ha^{-1} for Superchola and INIAP Natividad; respectively in Chañag). On the other hand, it is evident that N extraction does not serve as an only guide for future recommendations of fertilization because the analysis could lead to over-fertilization to reach the target yield of the crop.

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Contributor roles

- Fátima Gaibor: investigation, data curation, methodology, formal analysis, writing – original draft.
- José Espinosa: visualization, supervision, investigation, writing – review & editing.
- Yamil Cartagena: methodology, formal analysis.
- Rafael Parra: methodology, data curation, investigation.
- Cristhian Torres Carrera: methodology, data curation, investigation.
- Soraya Alvarado-Ochoa: conceptualization, funding acquisition, project administration, supervision, investigation, data curation, visualization, writing – original draft, writing – review & editing.

Ethical Implications

Ethics approval not applicable.

Conflicts of Interest

The authors declare that they have no affiliation with any organization with a direct or indirect financial interest that could have appeared to influence the work reported.

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