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Fertilization levels with NPK in bush pea (*Pisum sativum* L.) genotypes under Andisol soil

Niveles de fertilización NPK en genotipos de arveja arbustiva (*Pisum sativum* L.), bajo un suelo Andisol

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ABSTRACT

Pea (*Pisum sativum* L.) farmers in Colombia, especially in Nariño, lack knowledge about the appropriate fertilizer dosage needed to achieve optimal crop yields, resulting in reduced product competitiveness in the market. The objective was to evaluate the effect of six levels of NPK fertilization on yield components of four promising lines of bush pea with the afila gene in four municipalities in the Nariño department. A split-plot design with three replications was used in the experiment. The principal plot corresponded to the four promising lines of bush pea with the afila gene, and the subplot corresponded to six levels of fertilization. The results showed differential responses of the genotypes to different levels of fertilization. Based on the number of pods per plant, within the ARB15 line in Yacuanquer and ARB16 in Pasto, the result of the 120-16-56 fertilization level was higher than the recommended level based on soil analysis. In number of grains per pod, fertilization based on soil analysis showed similar results to the other five fertilization levels that were evaluated within the four pea lines in the different locations, except in Pasto within the ARB12 line, where 7.45 grains per pod were obtained, being lower than that obtained by the 120-6-56 level, which was 9.02. In terms of yield, the lines ARB2, ARB12, and ARB16 did not present a superior response to the fertilization level applied based on soil analysis. The best yield for ARB15 was obtained with a fertilization level of 90-12-42 in two locations.

Keywords: fertility; grain; legumes; locations; pods; yield

RESUMEN

En Colombia, los agricultores de arveja (*Pisum sativum* L.) carecen de conocimientos sobre las dosis adecuadas de fertilizante para lograr rendimientos óptimos, dando como resultado la baja rentabilidad del cultivo. El objetivo fue evaluar el efecto de seis niveles de fertilización NPK sobre los componentes del rendimiento de cuatro líneas promisorias de arveja con gen afila en cuatro municipios del departamento de Nariño. El diseño experimental utilizado fue de parcelas divididas con tres repeticiones. La parcela principal correspondió a las líneas con gen afila y la subparcela a seis niveles de fertilización. Los resultados mostraron respuestas diferenciales de los genotipos a diferentes niveles de fertilización. El número de vainas por planta de la línea ARB15 en

Yacuanquer y ARB16 en Pasto, con una fertilización 120-16-56, fue superior al nivel recomendado con base en análisis de suelo. En número de granos por vaina, la fertilización con base en el análisis de suelo mostró resultados similares a los otros niveles de fertilización evaluados en las diferentes localidades, excepto en Pasto, donde la línea ARB12 obtuvo 7.45 granos por vaina, valor inferior al obtenido por el nivel 120-6-56 que fue de 9.02. En cuanto al rendimiento, las líneas ARB2, ARB12 y ARB16 no presentaron una respuesta superior al nivel de fertilización aplicado con base en el análisis de suelo. El mejor rendimiento para ARB15 se obtuvo con un nivel de fertilización de 90-12-42 en dos localidades.

Palabras clave: fertilidad; grano; leguminosas; localidades; rendimiento; vainas

INTRODUCTION

In some areas of the Nariño department, which were previously cereal-growing regions, regional varieties of untrained climbing peas with low yields and poor grain quality are cultivated due to the lack of improved genotypes of bush peas. The Andean Crops Research Group at the University of Nariño has developed lines of bush pea with the afila gene, which replaces leaves with tendrils and could be a viable, productive alternative. However, these improved lines still lack management recommendations, particularly regarding fertilization.

Farmers typically fertilize peas based on recommendations for other crops, ignoring the specific requirements for peas (Ruano, 2001), who indicates that 5-2-7 kg ha-1 of NPK are required per ton of pea produced, without considering the limitations of different soil types that affect nutrient utilization efficiency. Thus, applications made by farmers are not appropriate for the proportions required by the crop to obtain a high yield and good quality of the final product.

Andisol derived from volcanic ash is known to be moderately to extremely acidic and highly phosphorus-fixing, forming compounds that impede the decomposition of organic matter (Instituto Geográfico Agustín Codazzi-IGAC, 2004). As a result, they exhibit low efficiency in responding to NPK fertilization, and the crop response generally does not correlate with soil analysis information (Valverde *et al*., 2006; Múnera & Meza, 2012; Checa *et al*., 2021).

Therefore, the objective of this research was to evaluate the effect of six levels of fertilization with nitrogen, phosphorus, and potassium on the yield components (number of pods, pod weight with grain, yield) of four genotypes of afila-leafed bush pea (*Pisum sativum* L.) and their respective interactions to obtain an approximation of the fertilizer recommendation for optimal response.

MATERIALS AND METHODS

The research was carried out in the municipalities of Pasto, Guaitarilla, Tangua, and Yacuanquer, which are part of the zone that was dedicated to grain production in the department of Nariño. The edaphoclimatic conditions of the four experimental sites are recorded in Table 1.

Table 1. *Soil orders and physical-chemical characteristics of the four evaluation zones of bush pea lines*

Municipality	Soil order	pH	Organic matter %	N kg ha^{-1}	P kg ha^{-1}	K kg ha^{-1}	Texture	Apparent density kg dm_3^{-1}
Pasto	Vitric Hapludands		4.14	62.10	31.63	530	Sandy loam	1.02
Guaitarilla	*Typic haplustalfs*	5.56	4.50	67.50	55.28	1500	Sandy loam	1.06
Yacuanquer	*Pachic melanudands*	5.73	9.30	139.50	95.17	819	Sandy loam	1.06
Tangua	*Typic haplustalfs*	4.92	4.35	62.25	43.82	211	Sandy loam	1.03

Experimental design.

In each of the four municipalities, a split-plot design and four replications were used. The principal plot corresponded to four genotypes of bushy pea with the afila gene *(af)* described in Table 2.The control treatment was established based on the deficiencies recorded in the soil analysis to meet the central or 100% requirement. The fertilization levels were established to produce 8 t ha-1. In this case, the phosphorus and potassium levels recorded in the soil analysis (Table 1) exceeded the crop requirements.

Table 2. *Identification and description of the genealogy of the evaluated genotypes*

Genotypes	Father 1	Father 2	Genealogy
ARB2	Sindamanoy	Line ILS3575	F1, SM (F2F3F4), SI (F5P1)
ARB12	Sindamanoy	Line ILS3575	F1RC1 (Sindamanoy), SM (F2RC1), SI (F3RC1P12), SM (F4RC1, F5RC1)
ARB15	Sindamanoy	Line ILS3575	F1, SM (F2,F3,F4), SI(F5P6)
ARB16	San Isidro	Line Dove	F1RC1 (SanIsidro), SM (F2RC1), SI (F3RC183), SI (F4RC1L83P1), SM(F5RC1)

The subplot corresponded to the levels of NPK, calculated based on the requirements per ton of pea produced per hectare, established by Alarcón (1997), which are 15-2-7 kg ha-1 of NPK. This requirement was taken as the central level or 100%, from which levels with 25% and 50% above and below were evaluated. The control treatment was established based on the deficiencies recorded in the soil analysis to meet the central or 100% requirement. The fertilization levels were set to produce 8 t ha-1. In this case, the levels of phosphorus and potassium recorded in the analysis exceeded the crop requirements (Table 3). To achieve the established fertilization levels, a complete triple 15 fertilizer commonly used by the producer, along with urea and KCl, was applied.

Table 3. *Levels of NPK fertilization for the cultivation of bush pea to produce 8 t ha-1*

Percentage	N	P	K
	kg ha^{-1}		
150%	180	24	84
125%	150	20	70
100%	120	16	56
75%	90	12	42
50%	60	8	28
Analysis*	0 - 93	0	0

* Fertilization level calculated in each of the four locations based on soil analysis.

In each locality, the treatment corresponding to fertilization levels based on soil analysis was determined according to the NPK contents of the respective soil analysis (Table 1), being zero for phosphorus and potassium in all localities and 93 kg ha-1 of nitrogen for Tangua, 90 for Guaitarilla, and zero for Yacuanquer.

The experimental unit consisted of 5 rows, 3m long, with a distance of 1.20m between rows and 0.1 m between sites, one seed per site. The evaluated variables included yield components, such as the number of pods per plant, determined by counting the pods in the useful plot and dividing the total by the number of harvested plants. Pod weight with grain was obtained from the average weight of 20 pods from the useful plot. Green or fresh pod yield was measured by weighing the harvested pods in each plot and converting the result to t ha-1 (Checa *et al.,* 2021).

Statistical Model

$$Y_{ijk} = \mu + a_i + Y_k + (a\ Y)_{ik} + \beta_j + (\beta Y)_{jk} + (a\beta)_{ij} + (a\ \beta\ Y)_{ijk} + \mathcal{E}i_{ijk}$$

Where: μ = overall mean; αi = effect of the i-th level of the principal plot factor (Pea Genotypes); ϒk = effect of the k-th level of factor Y (Block); (αϒ) ik = interaction effect between the principal plot (Pea Genotypes) and block in combination ik (A error); βj = effect of the subplot factor (Fertilization) at level j; (βϒ)jk = interaction effect between the subplot (Fertilization) and block in combination jk; (αβ)ij = interaction effect between the principal plot (Pea Genotypes) and subplot (Fertilization) in combination ij; (αβϒ)ijk = interaction effect among the principal plot (Pea Genotypes), subplot (Fertilization), and block in combination ijk (B error); Ɛijk = random error in cell ijk.

The data obtained were subjected to Analysis of Variance (ANOVA), and the means of the simple and interaction effects were compared with the Tukey's test. The assumptions of the ANOVA were previously verified. The SAS statistical package version 9.1 was used.

RESULTS AND DISCUSSION

Significant differences were found for the interaction between genotype and fertilization level in the number of pods in Guaitarilla, Pasto, and Yacuanquer; in the weight of pod with grain in Pasto, Tangua, and Yacuanquer; and in the yield in all four localities ($p \leq 0.05$, $p \leq 0.01$) (Table 4).

Table 4. *Mean square of yield components of four pea genotypes under different levels of NPK fertilization in four municipalities of Nariño*

		Number of pods		
Source	***Guaitarilla***	***Pasto***	***Tangua***	***Yacuanquer***
Genotype	143.40*	24.14*	70.67**	48.54*
Error a	6.07	3.16	3.96	6.65
Fertilization	165.07**	11.26**	15.09**	14.99*
G* F	70.36**	6.51	17.12**	29.00**
Error b	0.81	4.53	2.77	4.73
CV	14.23	14.57	18.18	10.84
		Pod weight with grain		
Source	***Guaitarilla***	***Pasto***	***Tangua***	***Yacuanquer***
Genotype	3.09*	9.36**	7.72**	5.50*
Error a	0.38	0.15	0.42	0.62
Fertilization	0.64*	0.72*	0.18	0.20ns
G* F	0.52	0.57*	0.28*	0.54*
Error b	0.21	0.23	0.13	0.26
CV	10.83	6.21	5.91	7.78
		Yield		
Source	***Guaitarilla***	***Pasto***	***Tangua***	***Yacuanquer***
Genotype	71.75*	2.81	48.93**	11.92*
Error a	5.98	0.76	1.08	1.13
Fertilization	58.09**	2.33*	2.19*	25.43**
G* F	33.94**	4.13**	2.75**	14.93**
Error b	3.92	0.64	0.86	2.95
CV	17.22	8.08	20.23	12.29

*Significance at 0.05 level. **Significance at the 0.01 level.

Number of pods per plant. In Pasto, no interaction was found in genotypes and fertilization levels, and the number of pods of the simple effect was similar for all fertilization levels, with averages between 13.98 and 15.84 pods per plant. Due to the previous information, the results discussion in this variable will be focused only on those localities that presented statistical differences in the interaction number of pods per plant and fertilization levels.

Within the ARB2 line in Guaitarilla, the level determined by soil analysis of 90-0-0 kg ha-1 NPK stood out with an average of 30.58 pods plant-1, surpassing the high levels of 180-24-84 and 120-16-56 kg ha-1 NPK. In contrast, in ARB12, the levels of 90-12-42, 120-16-56, and 180-24-84 with averages between 31.43, 30.51, and 29.2 pods plant-1, surpassed the level determined by soil analysis, which obtained an average of 18.83. In the ARB15 line, the level of fertilization from soil analysis showed similar results to those obtained with the other five levels of fertilization evaluated, and in ARB16, the level of 120-16-56 with 36.4 pods plant-1 surpassed the other levels of fertilization, including the level from soil analysis, with values between 15.07 and 21.08 pods plant-1 (Table 5).

In Tangua, the ARB2 line showed uniformity in the number of pods per plant with no differences between the studied fertilization levels, presenting averages between 9.51 and 12.63 pods plant-1. In the ARB12 line, the soil analysis level (93-0-0 of NPK) with 9.37 pods per plant exceeded the levels of 60-8-28, 90-12-42, and 180-24-84 of NPK with averages between 5.88 and 4.48, while in ARB15, the fertilization level of 180-24-84 stood out with an average of 16.11 pods plant-1, exceeding the other evaluated levels including that of soil analysis. Finally, in the ARB16 genotype, the levels of 60-8-28, 120-16-56, and 180-24-84 of NPK, with averages between 10.04 and 13.27 pods plant-1 showed statistical differences with fertilization according to soil analysis (93-0-0 of NPK), which obtained 5.64 pods plant-1 (Table 5).

Table 5. *Comparison of means for the genotype by fertilization interaction in the variable number of pods per plant in three locations of Nariño*

Guaitarilla				
Fertilization Level	**ARB2**	**ARB12**	**ARB15**	**ARB16**
180-24-84	21.78 b	29.2 a	22.24 ab	18.85 bc
150-20-70	26.06 ab	23.76 ab	15.97 b	15.07 bc
120-16-56	16.13 b	30.51 a	28.75 a	36.4 a
90-12-42	24.86 ab	31.43 a	24.39 a	13.01 c
60-8-28	24.51 ab	22.53 b	15.90 b	18.74 bc
Soil Analysis 90-0-0	30.58 a	18.83 b	23.23 ab	21.08 b
DMS Tukey (*p*<0.05) =7.79				
Tangua				
Fertilization Level	**ARB2**	**ARB12**	**ARB15**	**ARB16**
180-24-84	9.51 a	4.48 b	16.11 a	13.27 a
150-20-70	10.81 a	5.88 ab	8.12 b	8.34 bc
120-16-56	12.63 a	8.25 ab	9.02 b	10.49 ab
90-12-42	10.03 a	5.45 b	8.71 b	7.24 bc
60-8-28	12.36 a	5.29 b	8.06 b	10.04 ab
Soil Analysis 93-0-0	11.65 a	9.37 a	8.89 b	5.64 c
DMS Tukey (*p*<0.05) = 3.87				
Yacuanquer				
Fertilization Level	**ARB2**	**ARB12**	**ARB15**	**ARB16**
180-24-84	19.29 a	22.14 a	15.99 c	15.30 b
150-20-70	20.28 a	16.42 b	25.17 a	17.20 ab
120-16-56	23.85 a	16.49 b	18.03 c	20.51 a
90-12-42	22.17 a	19.74 ab	24.97 ab	17.73 ab
60-8-28	20.26 a	15.76 b	25.95 a	19.13 ab
Soil Analysis 0-0-0	21.63 a	21.64 a	19.93 bc	21.55 a
DMS Tukey (*p*<0.05) = 5.06				

In Yacuanquer, for the ARB2 line, the averages ranged from 19.29 to 21.63 pods plant-1, being similar for all fertilizer treatments studied, including the zero-application corresponding to soil analysis. For the ARB12 line, the zero-level determined by soil analysis obtained 21.54 pods plant-1, surpassing the treatments of 60-8-28, 150-20-70, and 120-16-56 with averages between 15.76 and 16.49 pods plant-1. Likewise, in the ARB16 line, the level corresponding to soil analysis (0-0-0) with 21.55 pods plant-1 showed a higher average compared to the level of 180-24-84 (15.30) and was equal to the other fertilization levels evaluated.

In the ARB15 line, the treatments of 150-20-70 and 60-8-28 with 25.95 and 25.17 pods plant-1, respectively, showed a higher number compared to the level determined by soil analysis (0-0-0) and to the NPK levels of 120-16-56 and 180-24-84, which ranged between 19.93 and 15.80 pods plant-1 (Table 5). In Pasto, the number of pods per plant1 did not show interaction between genotypes and fertilizer levels.

Overall, the results suggest that for the ARB2 line, fertilization based on soil analysis was the most appropriate in Guaitarilla, Tangua, and Yacuanquer municipalities, while for ARB12, fertilization based on soil analysis was appropriate in Tangua and Yacuanquer but not in Guaitarilla, where levels such as 90-12-42, 120-16-56, and 180-24-84 achieved a better response.

On the other hand, the fertilizer recommendation according to soil analysis showed the best response for ARB15 only in Guaitarilla and for ARB16 only in Yacuanquer. From this, it can be deduced that nutritional requirements are not the same for the different pea genotypes evaluated and that there is a strong genotype-environment interaction that leads to differential behavior of genotypes through the evaluated fertilizer levels and the locations where the experiments were established (Checa-Coral & Rodríguez-Rodríguez , 2015), (Checa *et al.*, 2021).

The character number of pods per plant is of quantitative inheritance (Ligarreto *et al.*, 2009) governed by many genes with small contributions to its expression and with strong interaction with the environment where the plant develops. Fertilization is part of the environment that is offered to the plant for its productive process; therefore, it is understandable that different genotypes have a differential response to the evaluated levels of fertilization. Following the results presented here and taking into consideration the plant-fertilization material relationship, the results can also be explained through phenotypic plasticity, which concept as described by Gianoli (2001), states that genetically identical plants can exhibit variable responses due to environmental factors like fertilization rates. These rates, in turn, are influenced by the soil and climatic conditions of the growing area. The four locations were influenced by soil moisture regimes and their physical-chemical conditions, which markedly affected nutrient uptake by the pea crop. This is evidenced by the differential response obtained by the genotypes evaluated in the different environments (Table 5), results that can be explained and corroborated by what has been proposed by various authors, working in different environments with pea crops and other legumes; as proposed by Zhang *et al.* (2021), Abou Seeda *et al.* (2020), Singh (2017), Santana *et al.* (2008), Gadissa & Chemeda *et al.* (2009), Endres, *et al.* (2010), Carvalho *et al.* (2004).

Pod weight with grain. In this variable, greater uniformity was observed between fertilization levels within the four evaluated lines. In Pasto, for the ARB2 line, the 60-8-28 treatment with 7.54g exceeded the 90-12-42 of NPK (6.35g); however, no differences were observed between the applied level according to soil analysis and the other evaluated fertilization levels. For the ARB12 line, the level of 120-16-56 exceeded the level applied according to soil analysis (93 0 0 of NPK). For ARB15, the levels of 90-12-42 and 60-8-28 exceeded the 150 20 70 of NPK, and none of the fertilization levels exceeded the level applied based on soil analysis. On the other hand, the ARB16 line had averages for pod weight with grain between 6.05 and 6.57g without differences between the evaluated fertilization levels (Table 6).

In Tangua, the ARB2, ARB15, and ARB16 lines obtained similar averages for pod weight with grain for all fertilization levels, including the level determined by soil analysis (90-0-0 of NPK), with averages between 5.17 and 7.13 g, while in the ARB12 line, the 120-16-56 NPK level with 5.75 g exceeded the 60-8-28 and 180-20-70 NPK levels with averages of 4.89 and 4.90 g and the level applied according to soil analysis showed no differences with the other evaluated fertilization levels (Table 6).

Table 6. *Comparison of means for the genotype by fertilization interaction in the variable pod weight with grain (g) for the locations of Pasto, Tangua, and Yacuanquer.*

Fertilization Level	Pasto			
	ARB2	ARB12	ARB15	ARB16
180-24-84	6.87 ab	8.04 ab	8.28 a	8.62 a
150-20-70	6.49 ab	8.23 ab	6.8 b	8.38 a
120-16-56	6.47 ab	9.02 a	7.52 ab	8.55 a
90-12-42	6.35 b	7.82 b	8.07 a	8.39 a
60-8-28	7.54 a	8.06 ab	8.13 a	8.65 a
Soil Analysis 93-0-0	6.93 ab	7.45 b	7.77 ab	8.08 a
DMS Tukey (p<0.05) =1.11				
Fertilization Level	**Tangua**			
	ARB2	**ARB12**	**ARB15**	**ARB16**
180-24-84	5.72 a	4.90 b	6.81 a	6.05 a
150-20-70	5.89 a	5.45 ab	6.93 a	6.35 a
120-16-56	5.82 a	5.75 a	6.35 a	6.51 a
90-12-42	5.30 a	5.62 ab	7.13 a	6.54 a
60-8-28	5.88 a	4.89 b	6.62 a	6.57 a
Soil Analysis 90-0-0	5.17 a	5.43 ab	6.61 a	6.45 a
DMS Tukey (p<0.05) =0.835				
Fertilization Level	**Yacuanquer**			
	ARB2	**ARB12**	**ARB15**	**ARB16**
180-24-84	5.81 a	6.48 a	7.11 a	6.62 b
150-20-70	5.88 a	6.58 a	6.30 a	7.14 ab
120-16-56	6.12 a	6.24 a	6.77 a	6.71 b
90-12-42	6.10 a	6.96 a	6.40 a	7.19 ab
60-8-28	5.57 a	7.07 a	6.31 a	8.10 a
Soil Analysis 0-0-0	5.75 a	6.35 a	7.15 a	7.55 ab
DMS Tukey (P<0.05) =1.18				

In Yacuanquer, for the ARB2, ARB12, and ARB15 lines, similar averages were obtained at all fertilization levels, including the level determined by soil analysis (0-0-0), with averages between 5.75 and 7.55 g. In the ARB16 line, the zero-application level determined by soil analysis showed no differences with any of the other evaluated fertilization levels, while the 60-8-28 level with an average of 8.10 g exceeded the 120-16-56 NPK level (6.71 g) (Table 6).

Analyzing the experiments from the three locations where there was a significant genotype by fertilization interaction (Pasto, Tangua, and Yacuanquer) together, it was observed that in the ARB2, ARB15, and ARB16 lines, the fertilization treatment based on soil analysis did not show differences with the other levels of fertilization evaluated. Meanwhile for the ARB12 line, the same result was obtained in Tangua and Yacuanquer but not in Pasto, where the 120-16-56 level showed a better response than the soil analysis level. This suggests that for most of the evaluated pea genotypes, applying fertilization levels above what is required according to soil analysis did not increase pod weight with grain. However, there are genotypes such as ARB12 that do achieve a better response with higher applications in some environments.

Yield. In Guaitarilla, the ARB2 line showed yields between 12.19 and 15.96 t ha-1, with no differences between the evaluated fertilization levels, including the level corresponding to soil analysis (93-0-0 NPK), while the ARB12 line presented the lowest yields (4.2 and 2.14 t ha-1) in the two highest NPK levels (180-24-84 and 150-20-70). In ARB15 the fertilization level of 120-16-56 had the lowest average with 5.32 t ha-1, being surpassed by the other fertilization levels that obtained averages above 11 t ha-1. In the ARB16 line, the level of soil analysis exceeded 150-20-70 and was similar to the other NPK evaluated levels (Table 7).

In Pasto, ARB2 with the fertilizer level of 150-20-70 produced 12.39 t ha-1, surpassing the other evaluated levels, including the level corresponding to soil analysis (93-0-0 NPK), which had the lowest average with 7.76 t ha-1. In the ARB12 line, the same previous level (150-20-70), with 10.91 t ha-1, surpassed 120-16-56 NPK, and there were no differences between the other evaluated levels. In ARB15, the level 150-20-70 of NPK, with an average of 8.25 t ha-1, had the lowest yield, being lower than the soil analysis level (93-0-0 NPK), which obtained 10.46 t ha-1. In the ARB16 line, the level 180-24-84 with 11.73 t ha-1 was superior to the level 60-8-28 (8.25 t ha-1); however, it did not show differences with the soil analysis level, which was similar to the other evaluated levels (Table 7).

Table 7. *Comparison of means for the genotype by fertilization interaction on yield (t ha-1) in four locations in Nariño*

Fertilization Level	Guaitarilla			
	ARB2	ARB12	ARB15	ARB16
180-24-84	14.90 a	4.2 c	11.18 a	11.94 a
150-20-70	12.19 a	2.14 c	10.27 a	5.45 b
120-16-56	13.60 a	14.64 a	5.32 b	14.29 a
90-12-42	14.96 a	8.86 b	14.82 a	9.83 ab
60-8-28	14.30 a	12.48 ab	11.17 a	14.4 a
Soil Analysis 90-0-0	15.96 a	15.26 a	11.79 a	10.53 a
DMS Tukey $p<0.05$) = 4.59				

Fertilization Level	Pasto			
	ARB2	**ARB12**	**ARB15**	**ARB16**
180-24-84	9.87 b	9.66 ab	9.28 ab	11.73 a
150-20-70	12.39 a	10.91 a	8.25 b	10.06 ab
120-16-56	7.76 c	9.06 b	10.51 a	10.11 ab
90-12-42	9.07 bc	9.84 ab	10.59 a	10.88 ab
60-8-28	9.87 b	10.39 ab	9.79 ab	9.74 b
Soil Analysis 93-0-0	7.76 c	9.15 ab	10.46 a	9.93 ab
DMS Tukey p<0.05) = 1.85				
Fertilization Level	**Tangua**			
	ARB2	**ARB12**	**ARB15**	**ARB16**
180-24-84	5.49 b	1.85 a	4.56 b	3.86 b
150-20-70	7.72 a	1.99 a	4.25 b	4.59 ab
120-16-56	7.37 a	2.35 a	3.49 b	5.23 ab
90-12-42	5.44 b	3.23 a	7.26 a	4.89 ab
60-8-28	6.27 ab	2.09 a	4.66 b	6.12 a
Soil Analysis 90-0-0	5.80 ab	2.67 a	4.29 b	4.51 ab
DMS Tukey p<0.05) = 2.15				
Fertilization Level	**Yacuanquer**			
	ARB2	**ARB12**	**ARB15**	**ARB16**
180-24-84	13.17 a	11.80 b	12.48 b	11.15 c
150-20-70	14.60 a	9.42 b	13.69 b	12.46 bc
120-16-56	16.93 a	11.48 b	14.41 b	17.54 a
90-12-42	13.19 a	17.29 a	19.62 a	13.70 abc
60-8-28	13.11 a	12.52 b	14.68 b	15.46 ab
Soil Analysis 0-0-0	13.61 a	14.32 ab	12.09 b	16.99 a
DMS Tukey p<0.05) = 3.99				

In Tangua, the lowest yields were obtained, with lower averages of 7.3 t ha-1. In this location, there were environmental limitations due to deteriorated soils, excess moisture in the early stages of cultivation, and drainage deficiencies. Consequently, there were greater difficulties in expressing the productive potential of the evaluated line. However, in the ARB2 line, all fertilization levels had similar yields to the level applied based on soil analysis. The treatments 150-20-70 and 120-16-56 outperformed 180-24-84 and 90-12-42. On the other hand, in ARB12, yields were similar for all fertilization levels, including the level determined by soil analysis, with averages ranging from 1.85 to 3.23 t ha-1. In the ARB15 line, the level of 90-12-42 NPK with 7.26 t ha-1 outperformed the other fertilization levels with averages lower than 4.67 t ha-1, and in the ARB16 line, the level of 60-8-28 NPK with 6.12 t ha-1 outperformed the level of 180-24-84 NPK, which obtained 3.86 t ha-1. The soil analysis level (90-0-0) was similar to the other fertilization levels evaluated (Table 7).

In Yacuanquer, the ARB2 line showed similar averages for all levels of fertilization, including the level determined by soil analysis, which was zero application of NPK, with averages ranging from 13.11 to 16.93 t ha-1. In the ARB12 line, the 90-12-42 treatment with 17.29 t ha-1 outperformed the other fertilization levels except for the treatment based on soil analysis. The ARB15 line had the best performance with the 90-12-42 NPK level of 19.62. Meanwhile, ARB16 showed the lowest average yields with the two highest levels of fertilization, 180-24-84 y 150-20-70 N-P-K, with yields of 11.15 and 12.46 t ha-1, respectively (Table 7).

When analyzing the behavior of the lines concerning the levels of fertilization applied in the four localities, it can be observed that for ARB2, the level applied according to soil analysis showed no differences with the other levels in Guaitarilla, Tangua, and Yacuanquer. For ARB12, the level applied based on soil analysis surpassed the high levels of 180-24-84, 150-20-70, and 90-12-42 in Guaitarilla, while in Pasto, Tangua, and Yacuanquer, it registered similar yields to the other evaluated levels. The fertilization level corresponding to soil analysis produced similar yields to those of the other evaluated levels in Guaitarilla, surpassed the level of 150-20-70, equaled the other evaluated levels in Pasto, and was surpassed by the level of 90-12-42 in Tangua and Yacuanquer. Finally, for ARB16, the level applied according to soil analysis surpassed the level of 150-20-70 and equaled all other levels in Guaitarilla, Pasto, and Tangua, and surpassed l80-24-84 and 150-20-70 in Yacuanquer.

The response of the yield components of these bush pea lines to different levels of fertilization under these conditions was differential according to genotype. Fertilization, especially with phosphorus, is one of the aspects to take into account in soils of volcanic origin (Andisols) with high levels of fixation of this important element. Therefore, a response to fertilization may occur even though the analysis indicates a sufficient amount of nutrients in the soil to satisfy the crop's requirements. This was observed in the ARB2 line in the locality of Pasto and the ARB15 line in Yacuanquer. On the other hand, a lower yield response was observed with fertilization applications higher than those recommended by soil analysis in Alfisol soils, such as in Guaitarilla, where none of the evaluated lines responded to higher doses than those indicated by the soil analysis.

Some important characteristics of Andisols (of volcanic origin) are their high capacity for phosphate fixation and anion exchange, which are responsible for the high contents of allophane, this clay is an amorphous mineral that has high aluminum contents; Another characteristic of these soils is that much of the total potassium is organic, because mineralization is very low. In Yacuanquer, despite being an Andisol, there was no response to fertilization levels higher than those determined by soil analysis in three of the four evaluated lines, probably due to the previous crop being a potato. This confirms in some way what was noted by Múnera & Meza (2012), who affirm that in Andisols the residual effect of high phosphorus application is variable or erratic due to the high capacity for fixation of this element and the difficulty in predicting all of the fixation power and because crops have different critical levels of P in the same Andisol.

It is important to note that according to other fertilization studies in vining pea in the region, the response of pea yield components to fertilization is related to the limitations presented by soil types for the efficiency and utilization of NPK, as noted by Checa *et al.* (2021) and Valverde et al., (2006). They report a response to high doses of fertilization in Andisols, even if the analysis registers enough amounts to meet the crop's requirements, due to the high capacity of phosphorus fixation by soil acidity and the presence of allophanic materials.

Andisols in their original state present a moderately to strongly acidic reaction, high amounts of organic matter, organic complexes strongly resistant to microbial destruction, and a very high capacity for phosphorus fixation (IGAC, 2004). Andisols are incorporated into agriculture with adequate mechanization, with fertilizations high in phosphorus and potassium; However, these nutrients have low diffusion coefficient values (2×10-11 and 2×10-7), which gives them low mobility in the soil. They can accumulate in the surface horizon, due to its low use by the crop; this is also directly influenced by the texture of the soil and its humidity regime (Intagri, 2022). Due to the aforementioned difficulties, the amount of Phosphorus in these soils in limited. In this regard, Sharma *et al.* (2000) and Singh (2017) note that increases in phosphorus supply improved the number of pods per plant, grains per pod, and grain weight, probably as a result of greater chlorophyll synthesis, accumulation of carbohydrates and proteins, and their translocation to reproductive organs, which in turn increased the number of pods and other yield components. These results are consistent with those of Patel *et al.* (2012), Khatkar (2007), Saket *et al.* (2014), and Singh (2017).

CONCLUSIONS

Differential behavior of genotypes was observed in the variables pods per plant, pod weight with grain, and yield across the different fertilization levels evaluated at the locations where the study was conducted. In terms of pods per plant, the ARB15 pea line showed a better response to high fertilization levels of 180-24-84 and 150-20-70 kg ha-1 NPK than those recommended by soil analysis in two of the four locations evaluated. The same occurred for ARB16 with the high levels of 180-24-84 and 120-16-56 kg ha-1 NPK in two locations and for ARB12 in one location. In contrast, for the ARB2 line, the best response was obtained with the Fertilizer application based on soil analysis. In pod weight with grain, ARB12 showed a better response in Pasto with the 120-16-56 level, while in ARB2, ARB15, and ARB16, the recommended level based on soil analysis was the most favorable treatment. The yield of lines ARB12 and ARB16 did not present a superior response to the level of fertilization applied based on soil analysis. The best yield for ARB15 was obtained with a fertilization level of 90-12-42 in two locations and at the 150-20-70 level within ARB2 in one location.

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CONFLICT OF INTEREST

The manuscript was prepared and reviewed with the participation of all authors, who declare that there is no conflict of interest that would jeopardize the validity of the presented results.

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