SOIL FERTILITY AND GENOTYPE AFFECT YIELD COMPONENTS AND MINERAL GRAIN CONCENTRATION OF COMMON BEANS (*Phaseolus vulgaris* L.) †

[LA FERTILIDAD DEL SUELO Y EL GENOTIPO AFECTAN LOS COMPONENTES DEL RENDIMIENTO Y CONCENTRACIÓN MINERAL DE GRANOS EN FRIJOLES COMUNES (*Phaseolus vulgaris* L.)]

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SUMMARY

Background: The common bean (*Phaseolus vulgaris* L.) crop is grown all over the world, in cropping systems with a wide range of technology use. These differences lead to interactions between genotype and environment, resulting in yield variations when the crop is submitted to different environmental conditions. Low use of fertilizers and other inputs in crops managed by undercapitalized farmers significantly reduce yield potential of common beans. **Objective:** The objective of this work was to assess agronomic parameters and foliar and mineral composition of common bean cultivars planted under two contrasting soil fertility levels. **Methodology:** The experiment was conducted in a greenhouse with four common bean varieties: BRS Pontal, BRS Agreste, BRS Ametista, and BRS Estilo. The plants were grown in low and high fertility soils. **Results:** Several parameters were affected by soil fertility, including foliar and grain mineral concentration. The cultivars BRS Pontal and BRS Agreste showed overall higher iron content and grain yield. **Implications:** The use of fertilizers is widespread as a key practice to achieve higher yields, but as shown in this work, adequate fertility is also important to obtain higher concentrations of essential nutrients in grains. **Conclusions:** Considering that common beans are a staple crop in many regions around the world, providing optimal soil fertilization is fundamental not only to deliver higher yields but also to produce beans with high nutritional levels.
Keywords: Essential nutrients; nutrition; genotype-environment interaction; micronutrients.

RESUMEN

Antecedentes: El cultivo del frijol común (*Phaseolus vulgaris* L.) se cultiva en todo el mundo, en sistemas de cultivo con una amplia gama de uso tecnológico. Estas diferencias conducen a interacciones entre el genotipo y el medio ambiente, lo que resulta en variaciones de rendimiento cuando el cultivo se somete a diferentes condiciones ambientales. El bajo uso de fertilizantes y otros insumos en cultivos manejados por agricultores subcapitalizados reduce significativamente el potencial de rendimiento del frijol común. **Objetivo:** El objetivo de este trabajo fue evaluar los parámetros agronómicos y la composición foliar y mineral de los cultivares de frijol plantados bajo dos niveles contrastantes de fertilidad del suelo. **Metodología:** El experimento se realizó en un invernadero con cuatro variedades comunes de frijol: BRS Pontal, BRS Agreste, BRS Ametista y BRS Estilo. Las plantas se cultivaron en suelos de baja y alta fertilidad. **Resultados:** Varios parámetros fueron afectados por la fertilidad del suelo, incluyendo la concentración de minerales en granos y hojas. Los cultivares BRS Pontal y BRS Agreste mostraron en general un mayor contenido de hierro y rendimiento de grano**. Implicaciones:** El uso de fertilizantes está muy extendido como clave para asegurar mayores rendimientos, pero como se muestra en este trabajo, la fertilidad adecuada también es importante para obtener una mayor concentración de nutrientes esenciales en los granos. **Conclusiones:** Teniendo en cuenta que los frijoles comunes son un cultivo básico en muchas regiones del mundo, proporcionar una fertilización óptima del suelo es fundamental no solo para ofrecer mayores rendimientos, sino también frijoles con altos niveles nutricionales.
Palabras clave: Nutrientes esenciales; nutrición; interacción genotipo-ambiente; micronutrientes.

INTRODUCTION

Common bean is a key crop to maintain food security in many regions over the world. Beans are sources of proteins and micronutrients such as iron, helping to prevent iron deficiency caused the lack of diversity in starch-based diets (Larochelle & Alwang, 2014, Larochelle *et al*., 2016). The common bean crop

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ISSN: 1870-0462.

(*Phaseolus vulgaris* L. - Fabaceae) was domesticated in Central America and it is now grown extensively from 52°N to 32°S latitude, in elevations ranging from zero to 3000 meters (Graham & Ranalli, 1997, Pickersgill & Debouck, 2005, Schoonhoven & Voysest, 1991). This plant can be grown in different systems, including mono, mixed or intercropping systems, under variable plant populations and pest management regimes, resulting in a range of crop yields (Carbonell *et al*., 2004, Graham & Ranalli, 1997). Specific varieties are more adapted to some production systems, as some varieties are used in low technological agriculture while others are adjusted to fully mechanized systems.

The genetic diversity of common bean, associated with a range of environments where the crop is grown, leads to high variations in yield across fields (Barili *et al*., 2015, Carbonell *et al*., 2004, Faria *et al*., 2009, Gomes *et al*., 1999). Soil fertility is the environmental factor that most influences bean yield (Graham *et al*., 2003). In low fertility soils, yields can potentially be improved with the application of moderate levels of chemical fertilizers (Oliveira *et al*., 1998, Ndakidemi *et al*., 2006, Pauletti *et al*. 2010), but since this crop is commonly grown by under-capitalized and low technology use farmers, these inputs are rarely used either due to high cost, the lack of awareness of the economic returns from such cultural practices, or both (Coêlho, 2017, Oliveira *et al*., 1998, Ndakidemi *et al*., 2006, Smith *et al*., 2001).

Genetic breeding for new varieties with an emphasis on tolerance to edaphic soil constraints, such as low fertility and acidity is necessary to improve bean yield (Goettsch *et al*., 2017, Graham & Vance, 2003). Varieties with improved stability across environments will improve yields of farmers using different levels of technology. In fact, genotype x environment (GEI) interaction affects not only yield, but also grain composition of several crops, including corn (Oikeh *et al*, 2004), grain millet (Pucher *et al*., 2014) and wheat (Oury *et al*., 2006). Grain composition is affected not only by genetics, but also by environmental factors. Smith *et al*. (2019) demonstrated how drought significantly impacted foliar and grain concentration of mineral nutrients and amino acids, whereas Gomes *et al*. (2017) indicated weeds affecting the mineral concentration of common beans. Currently, several cultivars are available in the market, with different agronomic characteristics and grain composition. Since grain mineral composition can be affected by genetics, environmental factors and GEI, and common bean crop is cultivated under low fertility and technology levels, it is important to understand how interactions between soil fertility and common bean cultivar affect plant development and grain quality.

The objective of this work was to analyze plant growth and grain mineral composition of common bean cultivars planted in soils with contrasting levels of fertility. This research will address if cultivars bred for higher concentrations of minerals would outperform regular cultivars even in low fertility soils.

MATERIAL AND METHODS

The experiment was conducted in a greenhouse located in the College of Agricultural Sciences and Engineering - Federal University of Espírito Santo (CCAE-UFES), city of Alegre, Espírito Santo, Brazil. The elevation in the area is approximately 250 meters above sea level, with coordinates of -20.76187242 S, -41.53600216 W. According to Köppen's classification, the climate is classified as *Cwa* type, with hot humid summer and dry winter (Alvares *et al*., 2013).

The experiment was established in a 2x4 factorial design. The first factor was soil fertility level, and the second factor was 4 common bean cultivars: BRS Pontal, BRS Agreste, BRS Ametista, and BRS Estilo. The experiment was carried out in a completely randomized design with 5 replications, with a total of 40 experimental units.

Soils used for this experiment were collected from the top layer (0-20 cm) of a production field in the CCAE-UFES University Farms, located in Rive Village, Alegre – Espírito Santo. Both soils were classified as red oxysol, clay texture (Santos *et al*., 2013). These fields are experimental plots and over the years displayed contrasting fertility levels in soil tests. Crop rotation in the area include corn, common beans and pineapple. Fields selected for soil sampling are approximately 100 meters apart, separated by a topographic barrier (hill), since the area is characterized by rolling hills. From each field, 20 soil cores were collected in a zigzag pattern covering the entire area. Litter, leaves, weeds and decomposing material were removed from soil surface before collecting samples. Cores were mixed forming a composite sample, following the Espírito Santo State soil sampling and fertilization guide. (Prezoti, 2007). Samples were sent to a commercial laboratory for chemical and physical analysis, with results shown in Table 1. Based on field fertility history and after comparing soil chemical analysis results with State’s fertility recommendations for common bean, soil 1 was designated as high fertility (HF) and soil 2 as low fertility (LF). Soil chemical and physical analysis results are presented in Table 1.

Table 1. Chemical and physical analysis of the soils used in the experiment. Soil 1 was designated high fertility soil and soil 2 low fertility.

Parameter	**pH[1]**	**P[2]**	**K**	**Ca**	**Mg**	**Al**	**H + Al**	**CEC**	**T**	**BS**
Unit		(mg dm^{-3})	----------------- $cmol_c$ dm^{-3}---------------------							(%)
Soil 1 (HF)	6	16	150	2.5	1.2	0	2.1	4.1	6.2	66
Soil 2 (LF)	5.4	10	83	1.5	0.4	0.3	2.4	2.4	4.5	46.8
Normal range[5]	5.0-5.9	20-40	60-150	1.5-4	0.5-1	< 0.3	< 2.5	2.5-6.0	7.4-10	50-70

Parameter	**m**	**S**	**B**	**Fe**	**Cu**	**Mn**	**Zn**	**OM[3]**	**Clay[4]**	**Silt[4]**	**Sand[4]**
Unit	(%)	(mg dm^{-3})	dg Kg^{-1}	-------------- g Kg^{-1} --------------							
Soil 1 (HF)	0	5	0.29	90	2	93	2.6	3.1	670	60	270
Soil 2 (LF)	12	6	0.21	61	1.5	47	2.9	1.4	740	40	220
Normal range[5]	< 20	5.0-10	0.3	20-45	0.8-1.8	5-12	1.0-2.2	>2.0	-	-	-

[1]H_2O, [2] Mehlich, [3]Organic matter, [4] Pipette method: Sand (Ø > 0.05 mm), Silt (Ø de 0.05 – 0.002 mm), Clay (Ø < 0.002 mm) (EMBRAPA,1997), [5]Average values found in soils of Espirito Santo state (Prezotti *et al*., 2007). CEC (cation exchange capacity), T (CEC at pH7), V (total base saturation), m (aluminum saturation).

In a standard germination test performed before the greenhouse experiment, seeds of all cultivars reached germination rates >90% following the standard germination test published by the Brazilian Ministry of Agriculture (Brazil, 2009). For each treatment, five 8 L pots were filled with sieved soil collected from top layer (0-20 cm) of fields previously described. Two seeds were planted per pot, and ten days after planting, extra plants were removed to maintain only one per pot. Plants were watered daily, maintaining soil close to water holding capacity.

The following plant variables were assessed: stem diameter (SD – 50 DAE - days after emergence) using a digital caliper, number of leaves (NL – 65 DAE) and pods per plant (NP – 65 DAE). Average seed weight (ASW), number of seeds per plant (NS) and grain yield per plant (GYP) were assessed at the end of the experiment, Grains were placed on paper bags and dried in an oven for 72 hours at 60 °C, and then ground into a fine powder. Grain mineral concentration was estimated using the methodology described by Malavolta (1997), for N, P, K, Ca, Mg, Mn, Fe, and Zn. The same methodology was used to assess foliar concentrations of N, P, K, Ca, Mg, Mn, Fe, and Zn at flowering.

Data were analyzed using a two-way ANOVA to search for effects of each factor (Fertility; Genotype) and factorial interaction (Fertility*Genotype). When factorial interaction was not significant, factors were studied separately. When effects of factors were significant, means were separated using Tukey HSD ($p \leq 0.05$). All statistical analyses were performed using JMP®, Version 14.0 (SAS Institute Inc., Cary, NC, 1989-2020).

RESULTS AND DISCUSSION

Effects of each factor (Fertility; Genotype) and factorial interaction (Fertility*Genotype) are presented in Table 1. Data indicates factorial interaction influencing number of leaves (F: 3.3; P: 0.0335), pods (F: 4.2; P: 0.0335) and seeds per plant (F: 4.7; P: 0.0078). Factorial interaction also affected foliar nitrogen (F: 3.2; P: 0.0361) and iron (F: 4.8; P: 0.0069), and grain concentrations of nitrogen (F: 4.8; P: 0.0069) and iron (F: 4.8; P: 0.0069).

When analyzing factors separately, soil fertility affected stem diameter (F: 27.6: P<.0001), number of leaves (F: 29.4; P<.0001), pods (F: 72.5; P<.0001), and seeds per plant (F: 58.3; P<.0001). Soil fertility also influenced foliar concentrations of zinc (F: 8.1: P: 0.0077), nitrogen (F: 6.6; P: 0.0152), and iron (F: 13.6; P:0.0008), in addition to grain concentrations of zinc (F: 9.5; P: 0.0041), nitrogen (F: 22.8; P<.0001) and iron (F: 13.6; P: 0.0008).

Cultivar selection affected all variables, with exception to foliar nitrogen (F: 0.8; P: 0.5118), manganese (F: 1.2; P: 0.3331, and calcium (F: 1.1; P: 0.3711), and grain concentrations of nitrogen (F: 0.3; P: 0.8495) and manganese (F: 1.2; P: 0.3331). When comparing foliar and grain concentrations for iron, magnesium and manganese, readings were close, with some differences in the third decimal, resulting in similar results when expressed with two decimals.

Table 2. Analysis of variance indicating the effects of soil fertility and cultivar on agronomic variables, foliar and seed composition of common beans.

AGRONOMIC VARIABLES

	SD		**NL**		**NP**		**ASW**		**NS**		**GYP**	
Source	F	P>F	F	P>F	F	P>F	F	P>F	F	P>F	F	P>F
Fertility	27.6	<0.0001	29.4	<0.0001	72.5	<.0001	1.32	0.25	58.3	<.0001	29.4	<.0001
Cultivar	6.1	0.002	0.2	0.89	5.0	0.006	1.86	0.15	13.3	<.0001	2.9	0.048
F*C	1.0	0.41	3.3	0.034	4.2	0.013	1.60	0.21	4.7	0.008	0.36	0.78

FOLIAR CONCENTRATIONS

	N		**P**		**K**		**Ca**		**Mg**		**Mn**		**Fe**		Zn	
Source	F	P>F	F	P>F	F	P>F	F	P>F	F	P>F	F	P>F	F	P>F	F	P>F
Fertility	6.6	0.015	0.3	0.61	0.7	0.42	0.2	0.64	0.0	0.87	1.2	0.29	13.6	0.0008	8.1	0.008
Cultivar	0.8	0.51	6.1	0.002	6.7	0.001	1.1	0.37	3.2	0.04	1.2	0.33	6.9	0.001	9.0	0.0002
F*C	3.2	0.04	0.5	0.68	0.5	0.68	0.1	0.97	2.8	0.055	1.2	0.34	4.8	0.007	0.5	0.70

GRAIN CONCENTRATIONS

Source	F	P>F	F	P>F	F	P>F	F	P>F	F	P>F	F	P>F	F	P>F	F	P>F
Fertility	22.8	<0.0001	1.3	0.26	0.7	0.42	0.1	0.79	0.0	0.87	1.2	0.29	13.6	0.0008	9.5	0.004
Cultivar	0.3	0.85	9.1	0.0002	6.7	0.001	3.6	0.023	3.2	0.037	1.2	0.33	6.9	0.001	7.6	0.0006
F*C	4.8	0.007	0.4	0.75	0.5	0.68	2.7	0.064	2.8	0.055	1.2	0.34	4.8	0.007	0.4	0.78

SD- Stem diameter, NL- number of leaves, NP- number of pods, ASW- average seed weight, NS- number of seed, GYP, grain yield per plant, N- Nitrogen, P-Phosphorus, K- Potassium, Ca- Calcium, Mg- Magnesium, Mn- Manganesium, Fe- Iron, Zn- Zinc

Table 2. Effect of cultivar and soil fertility on stem diameter (SD), seed weight (SW), foliar and grain concentrations of phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and zinc (Zn), and foliar concentration of manganese (Mn) in common beans. All foliar and grain concentration results are expressed in $mg\ Kg^{-1}$.

Parameter	**Factor 1: Cultivar**				**Factor 2: Soil Fertility**		**CV%**[3]
	BRS Pontal	BRS Agreste	BRS Ametista	BRS Estilo	HF Soil[1]	LF Soil[2]	
SD[4]	3.88 b	4.50 a	4.68 a	4.75 a	4.87 a	4.03 b	11.39
SW[5]	0.28b	0.27b	0.33 a	0.33 a	0.30 a	0.30 a	9.23
Foliar P	5.93 a	4.59 b	6.50 a	5.64 ab	5.75 a	5.58 a	18.06
Foliar K	19.24 a	15.05 c	18.70 ab	15.92 bc	17.56 a	16.90 a	14.62
Foliar Ca	1.89 a	1.47 a	1.55 a	1.64 a	1.60 a	1.68 a	33.31
Foliar Mg	2.53 a	1.91 b	2.26 ab	2.19 ab	2.21 a	2.23 a	20.08
Foliar Mn	13.61 a	12.09 a	13.45 a	13.56 a	13.54 a	12.81 a	16.10
Foliar Zn	24.49 bc	22.90 c	27.08 a	25.96 ab	25.97 a	24.25 b	7.63
Grain P	3.75 a	2.76 b	3.91 a	3.39 ab	3.55 a	3.35 a	15.53
Grain K	19.24 a	15.05 c	18.70 ab	15.92 bc	17.56 a	16.90 a	14.62
Grain Ca	1.72 ab	1.33 b	1.55 ab	1.85 a	1.63 a	1.59 a	23.03
Grain Mg	2.53 a	1.91 b	2.26 ab	2.19 ab	2.21 a	2.23 a	20.08
Grain Zn	24.72 ab	23.08 b	27.08 a	25.96 a	26.17 a	24.25 b	7.81

For each factor, means followed by the same letter in rows are not statistically different using Tukey's test (p=0.05). [1]High fertility soil; [2]Low fertility soil; [3]Coeficient of variation.

Table 3. Effect of factorial interaction (cultivar*soil fertility) on number of leaves (NL), pods (NP) and seeds (NS) per plant, foliar and grain concentration on N and Fe and grain concentration of manganese in common beans. All foliar and grain concentration results are expressed in mg Kg^{-1}.

Parameter	Soil	Common bean cultivar				CV%[3]
		BRS Pontal	BRS Agreste	BRS Ametista	BRS Estilo	
Nº Leaves	HF Soil[1]	16.60 aB	22.00 aA	18.40 aAB	17.60 aB	14.3
	LF Soil[2]	14.20 aA	11.60 bA	13.20 bA	14.00 bA	
Nº Pods	HF Soil	15.60 aB	20.60 aA	14.00 aB	14.40 aB	17.22
	LF Soil	10.40 bA	9.80 bA	8.40 bA	11.20 bA	
Nº Seeds	HF Soil	78.20 aA	92.40 aA	60.20 aB	57.00 aB	16.17
	LF Soil	58.00 bA	50.60 bAB	38.00 bB	47.20 aAB	
Foliar N	HF Soil	1.78 bA	2.02 aA	1.88 bA	2.29 aA	19.01
	LF Soil	2.38 aA	2.08 aA	2.72 aA	2.13 aA	
Grain N	HF Soil	1.43 bA	1.62 aA	1.50 bA	1.61 aA	8.37
	LF Soil	1.90 aA	1.66 aA	1.73 aA	1.70 aA	
Foliar Fe	HF Soil	66.65 aA	65.46 aA	49.47 aB	51.55 aB	12.04
	LF Soil	49.65 bA	52.77 bA	44.99 aA	55.14 aA	
Grain Fe	HF Soil	66.64 aA	65.46 aA	49.47 aB	51.55 aB	12.04
	LF Soil	49.64 bA	52.76 bA	44.99 aA	55.14 aA	
Grain Mn	HF Soil	14.3 bA	16.2 aA	15.0 bA	16.1 aA	8.37
	LF Soil	19.0 aA	16.6 aA	17.3 aA	17.0 aA	

For each parameter, means followed by same uppercase letter in rows or same lowcase in columns are not statistically different using Tukey's test (p=0.05). [1]High fertility soil; [2]Low fertility soil; [3]Coeficient of variation.

The effects of cultivar and soil fertility on stem diameter, seed weight, foliar and grain concentrations of phosphorus, potassium, calcium, magnesium, and zinc, and foliar concentration of manganese are presented in Table 3. Factorial interaction (Fertility*Cultivar) impact on number of leaves, pods and seeds per plant, foliar and grain concentration on nitrogen and iron and grain concentration of manganese is displayed in Table 4.

The stem diameter of common bean plants was affected by both soil fertility and cultivar selection. Low fertility can lead to crop lodging at harvest, which is a major limitation for mechanized harvest of common beans (Horn *et al*., 2000). Lodging is caused by a combination of factors, including larger row spacing, lower plant populations, environmental conditions, and cultivar susceptibility (Ball *et al*., 2006, Crook & Ennos, 1995). Ball *et al*. (2006) point out that more vigorous stems build crop canopies capable to prevent and recover from lodging. Seed weight, which was affected only by cultivar, is a stable plant parameter across environments and it is driven mainly by variation within cultivars, having a strong contribution for the genetic dissimilarity between common bean cultivars (Barbosa & Gonzaga, 2012, Martinho Correa & Gonçalves, 2012, Bezerra, Neves, Rocha, & Brito, 2017). Seed weight, combined with qualitative characters, such as color and brightness, will determine commercial acceptance of common bean cultivars (Santos *et al*., 2011).

Overall, all tested cultivars better performed when planted in higher fertility soil. Under low soil fertility, cultivars presented similar results regarding number of leaves and pods, for example, but genotype variations were observed under increased fertility, as cultivars expressed their full growth potential. The number of seeds was significantly enhanced with increased fertility, with exception to BRS Estilo. Overall, BRS Pontal and BRS Agreste produced a higher number of seeds across environments. Together, number of pods, seeds per pod, grain weight, and plant population drive yield in common beans (Szilagyi, 2003). Soils with pH below 5.5 lead to a reduction in the availability of essential nutrients required for plant development. For common beans, ideal pH is close to 6.0, allowing optimal nutrient availability for the crop. In addition, the organic matter content was significantly different between tested soils (55% lower in LF). Organic matter is a key indicator when assessing soil quality, as its interaction with soil components has a direct effect on physical, chemical, and biological characteristics. Organic matter influences the availability of nutrients for plants, cation retention, shaping the availability of air and water to plant roots, playing an important role in soil fertility.

Some nutrients, including foliar and grain nitrogen and grain manganese, had higher concentrations on lower fertility soil. Under reduced plant development, some elements may have increased concentration in leaves due to lower biomass production, which is defined as the dilution effect (Jarrell & Beverly, 1981). Foliar and grain concentrations of iron were correlated. When planted in the low fertility soil, no iron differences were observed between cultivars. In contrast, under higher fertility, BRS Pontal and BRS Agreste developed higher iron concentrations compared to other cultivars. These cultivars were bred to have higher concentrations of essential minerals and to be distributed to small farmers in areas where food insecurity and malnutrition are challenges (Barbosa & Gonzaga, 2012, Petri *et al*., 2015). For these cultivars, iron content shows to be dependent on soil fertility, since the iron concentration was not different under lower fertility. Similar reports in the literature support these findings. Araújo *et al*. (2013) similarly reported GEI driving iron content in common beans. In corn, GEI was the main driver of the total variation in grain zinc (Oikeh *et al*., 2004). GEI similarly influenced Fe and Zn grain densities in pearl millet, highlighting the importance multienvironmental evaluation for identifying stable genotypes (Pucher *et al*., 2014).

The use of correct fertilization, improved cultivars, and crop management practices are strategies used to fight mineral malnutrition globally and may significantly improve nutrition of individuals depending on this crop as a staple food. (Bouis & Welch, 2010, House, *et al*., 2002, White & Broadley, 2009). In order to achieve full yield and grain quality potential and, optimal nutritional requirements should be provided. Nutrients absorbed in larger quantities by the common bean crop are nitrogen (N), potassium (K) and phosphorus (P), followed by sulfur (S), calcium (Ca) and magnesium (Mg), in addition to micronutrients, zinc (Zn), boron (B), copper (Cu), manganese (Mn), iron (Fe) and molybdenum (Mo). Although micronutrients are absorbed in lower amounts, adequate concentrations are essential to achieve higher yields. Due to the superficial root system and the short cycle of common bean, nutrients must be available in adequate depth and vegetative stages (Loosli *et al*., 2017). Since most Brazilian soils have elevated acidity, high levels of exchangeable aluminum and low nutrients availability, a proper fertilization program is essential to improve production systems (Araújo and Camelo, 2015).

Several parameters were affected by soil fertility, including the mineral concentration in grains. Adequate soil fertilization will ensure optimum conditions for crop development, including a more resilient root system, as the cycle of common beans is relatively short (90 to 110 days). During the vegetative and reproductive stage, a large amount of nutrients is absorbed, and adequate fertility is key to obtain higher yields and return profits to growers. The use of fertilizers is widespread as key to assure higher yields, but as shown in this work, adequate fertility is also important to obtain a higher concentration of essential nutrients in common beans grains. Considering that common beans are a staple crop in many regions around the world, providing optimal soil fertilization is fundamental not only to deliver higher yields but also to produce beans with high nutritional levels.

CONCLUSION

Low fertility affected several agronomic variables, including stem diameter, number of leaves, pods, and grains per plant. Mineral concentration was also influenced by soil fertility, as shown by foliar and grain concentration of Zn, N, and Fe and grain concentration of Mn. Genotype influenced all analyzed variables, with exception to foliar N, Mn, and Ca and grain concentration of Ca. Fe concentration shows to be dependent on soil fertility, even for cultivar developed to achieve higher foliar concentrations of Fe. In regions of poor soil fertility and where malnutrition is a problem, implementing common bean cultivars with higher mineral concentration will only be effective if associated with practices to improve soil fertility.

Acknowledgments
The authors are thankful for all the assistance from undergraduate and graduate students conducting all trials. This work is based on first author's undergraduate thesis (Bachelor of Science in Agronomy).

Funding. This study was financed and supported by the Universidade Federal do Espírito Santo (Federal University of Espirito Santo).

Conflict of interest. The authors confirm no known conflicts of interest associated with this publication

Compliance with standards of ethics. The current research hereby reported did not involve animals or humans. The study did not involve endangered or protected species and the study site is not a protected area. No permissions were required for any activity.

Data availability. Data are available upon request via e-mail by contacting the first author (leo.fr8@gmail.com).

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