BIOSCIENCE JOURNAL

EFFECTS OF ALTERNATIVE FERTILIZATION ON COMMON BEAN CROPS REGARDING PRODUCTIVITY AND NUTRITIONAL LEVELS

Tiago Silveira da SILVA[1], Ivan Ricardo CARVALHO[2], Murilo Vieira LORO[3], Leonardo Cesar PRADEBON[1], Helaine Claire de ALMEIDA[4], Leonir Terezinha UHDE[2]

[1] Agronomy Course, Universidade Regional do Noroeste do Estado do Rio Grande do Sul, Ijuí, Rio Grande do Sul, Brazil.
[2] Department of Agrarian Studies, Universidade Regional do Noroeste do Estado do Rio Grande do Sul, Ijuí, Rio Grande do Sul, Brazil.
[3] Graduate Program in Agronomy, Universidade Federal de Santa Maria, Santa Maria, Rio Grande do Sul, Brazil.
[4] Postgraduate Program in Genetics and Breeding, Universidade Federal de Viçosa, Viçosa, Minas Gerais, Brazil.

Corresponding author:
Ivan Ricardo Carvalho
ivan.carvalho@unijui.edu.br

How to cite: SILVA, T.S., et al. Effects of alternative fertilization on common bean crops regarding productivity and nutritional levels. *Bioscience Journal*. 2024, **40**, e40019. https://doi.org/10.14393/BJ-v40n0a2024-63214

Abstract
Considering the need for more information about productivity increases and nutritional improvement of soils, the present study evaluated the effects of alternative fertilization on grain yield and nutritional levels of bean crops. It was a randomized block study with four treatments and five replicates. The treatments were the absence of nitrogen fertilization, fertilizer use, chicken litter, and cattle manure. Organic fertilization provided lower variations in soil water availability during flowering and grain filling and increased nutrient concentrations, especially phosphorus and potassium. Chicken litter promoted the highest means for the number of legumes, the number of legumes on branches, the number of six-grain legumes, the mass of a thousand grains, grain mass per plant, and the normalized green-red difference index. However, the two organic fertilizers had significantly higher differences from chemical and no fertilization, showing that organic fertilizer applications must occur when nutrient availability coincides with the phenological stages essential for producing these fertilizers. High yields combined with favorable rainfall conditions occurred during crop development, as high soil moisture allowed faster mineralization of essential organic fertilizer nutrients, directly affecting yield. Pearson's linear correlation allowed a better understanding of the participation of each plant trait in productivity, and the highest grain yield occurred with organic fertilization.

Keywords: Crop practice adjustments. Optimized environments. *Phaseolus vulgaris* L. Sustainable management.

1. Introduction

The common bean (*Phaseolus vulgaris* L.) is a species of the Fabaceae family and is vital for human nutrition, providing high levels of vitamins, iron, calcium, carbohydrates, fibers, and proteins. It is a relevant agricultural activity in Rio Grande do Sul, Brazil, presented in almost all state municipalities. This species stands out for its predominantly family farming cultivation and economic and social relevance in producing regions (Demari et al. 2015).

This legume is extensively consumed across Brazil, mainly by low-income populations, as it is an inexpensive protein source. The current cultivated area (2020/2021) in Brazil is 2.93 million hectares, yielding approximately 3.0 million tons of grains, considering the data from the 1st, 2nd, and 3rd crop seasons (CONAB, 2021). However, Brazil imports around 150 thousand tons of grains annually to supply internal market demands, with most black beans coming from Argentina. In Rio Grande do Sul, the average cost of a 60-kg sack of type I black beans received by the producer was R$295.00 (in Brazilian Reais) in the 2018 crop season, considering the state consumption corresponds to 90% of the produced volume.

As this is mainly a family crop, it uses a low technological level for cultivation. Therefore, the production potential of beans decreases because the absence of adequate base fertilization and favorable water conditions drastically reduce productivity. Beans are sensitive to soil moisture and temperature, and in many cases, their crops are located in unfavorable environmental conditions. Thus, the crop is subjected to different factors (drought, salinity, high temperatures, and low nutrient availability), described as the main production limitations (Mittler 2006). This culture has a more superficial root system, and prolonged stress may hinder plant recovery. Water supply reductions, for instance, during flowering and grain filling, drastically affect productivity. However, genetic breeding programs have been continuously searching for more adaptive and productive cultivars that are less susceptible to biotic and abiotic stresses and capable of supplying the consumer market (Carvalho et al. 2020). Thus, this breeding process has released various cultivars that succeeded in traits such as plant architecture, disease tolerance, and commercial grain type associated with high yields (Melo et al. 2007).

Grain yield (GY) reductions in the common bean crop occur mainly due to lower nutrient availability in the soil. It is predominantly cultivated by small producers, most of whom do not invest in fertilizers because industrialized mineral fertilizers are expensive, making their purchase unfeasible. Therefore, low-cost organic fertilizers are alternatives to reduce production costs, promoting higher yields with lower financial investments. Among organic fertilizers, chicken litter and cattle manure from the compost barn system stand out for their low cost. Cardoso and Mancio (2010) found that producing cattle manure or chicken litter in farms allows the reduction or elimination of external inputs, such as fertilizers, increasing the autonomy of farming families relative to the market.

Organic fertilizer use has been extensively researched to provide the required nutrients for crop development and productivity. However, this fertilizer type is abundant compared to mineral fertilizers (Pereira et al. 2013; Silva et al. 2015) because the chemical composition of organic fertilizers highly varies. Also, the application doses to meet the nutritional requirements of vegetables depend on mineralization conditions, residue nutrient concentrations, soil fertility, and vegetable species. Considering the need for more information about productivity increases and nutritional improvements of soils, the present study evaluated the effects of alternative fertilization on grain yield and nutritional levels of bean crops.

2. Material and Methods

Experiment description

This study was developed at the Regional Institute for Rural Development of the Regional University of Northwestern Rio Grande do Sul, municipality of Augusto Pestana, Brazil, located at 28°26’0’’ LS and 54°00’ 58’’ LW, and an altitude of 301 meters. According to the Köeppen climate classification, the regional climate is Cfa (wet subtropical) with hot summers and no prolonged droughts.

The experimental design was a randomized block with four treatments (compost barn manure, chicken litter, chemical fertilizer, and no fertilizer) and five replicates, totaling 20 experimental units to evaluate macronutrients. Compost barn manure yielded 2.1% nitrogen (N), 1.3% phosphorus (P), 3.3% potassium (K), 1.6% calcium (Ca), and 1.1% magnesium (Mg); chicken litter had 4.24% N, 1.60% P, 3.41% K, 1.84% Ca, and 1.37% Mg; and the chemical treatment was 10-20-20 (N-P_2O_5-K_2O). Soil fertility was diagnosed at a 0-20 cm depth, and after ending the crop cycle, another soil collection was performed to analyze the2 treatment effects on soil fertility. The Soil Laboratory of the Regional University of Northwestern Rio Grande do Sul performed both analyses.

Chicken litter and compost barn manure were the organic fertilizers used in the trials. These fertilizers stayed under sunlight for a few days for “tanning” for pH adjustments, odor reduction, and handling improvement. After this process, they were bagged, transported to the farm, and applied by spreading 83 days before bean sowing. Chemical fertilization occurred on the day of sowing – December 16, 2020. The used species were common black beans with an initial density of ten plants per linear meter, and sowing was aided by a tractor fertilizer seeder with seven rows spaced 0.40 m apart. The treatments were chemical fertilization with the 10-20-20 formula (N-P2O5-K2O), organic fertilization with chicken litter and compost barn manure, and no fertilization in a total experimental area of 20m x 20 m (400 m²), and each experimental unit measured 5 m x 4 m, with 20 m². The trial used 400 kg ha^{-1} of chemical fertilizer, 3.5 Mg ha^{-1} of chicken litter, and 30 Mg ha^{-1} of compost barn manure, totaling 0.800 kg, 7 kg, and 60 kg per plot, respectively. The doses were adjusted for equivalence regarding the acquisition costs of fertilizer sources. Thus, 40 kg ha^{-1} of N and 80 kg ha^{-1} of P and K were added through the chemical fertilizer. The concentrations per hectare with chicken litter application were 148.4 kg of N, 56 kg of P, and 119.35 kg of K, and cattle manure fertilization provided 630 kg ha^{-1} of N, 390 kg ha^{-1} of P, and 990 kg ha^{-1} of K.

Assessments and collections

Soil moisture content was measured from crop flowering to physiological maturity using an HFM2030-Hidrofarm electronic meter inserted at a 0-20 cm depth. The evaluations started immediately after crop implantation to define the traits of agronomic interest, determining the useful area of each experimental unit. The evaluations were the chlorophyll index (CI) using portable electronic equipment; the chlorophyll-Falker index (CFI) in the vegetative stage R5 with five plants per plot; initial plant stand (IS) per linear meter 21 days after sowing; the green leaf index (GLI), the normalized green-red difference index (NGRDI), and the blue-green pigment index (BGI), determined by collecting ten leaves in each treatment.

Next, pictures were taken with the help of a digital camera in the visible range, later capturing multispectral images. The final plant stand (FS) was determined two days before harvesting. Plant height at flowering (PHF) was measured with a measuring tape from the ground level to the plant apex, with results in cm, and plant height at maturity (PHM) used the same procedure. The insertion of the first legume (IFL) was measured from the ground level to the first viable plant legume, with results in cm, and the number of legumes per plant (NLP) was the individual count of legumes in the evaluated plants.

The number of legumes in the main stem (NLMS) was the total of productive legumes in the main plant stems, with results in units. The number of legumes on branches (NLB) were the vegetables on all plant branches. The number of branches (NB) considered those over 10 cm. The number of one-grain legumes (NL1), two-grain legumes (NL2), three-grain legumes (NL3), four-grain legumes (NL4), five-grain legumes (NL5), six-grain legumes (NL6), seven-grain legumes (NL7), and eight-grain legumes (NL8) were counted from the 200 plants evaluated and their respective viable grains in each legume. The number of grains per plant (NGP) originated from a random selection of ten plants per experimental unit.

The mass of a thousand grains (MTG) was obtained by sampling eight subsamples of 100 grains each, which were determined, counted, and transformed into grams (g). Grain mass per plant (GMP) was weighed with a precision scale. Grain yield (GY) used the total grain mass of each plot and later corrected it to 13% humidity with population adjustments in each experimental unit by converting productivity into kg ha^{-1}.

Finally, the ratio between the number of grains and mass (NGxM) and the ratio of grains per area (GxA) were calculated. Meteorological data recordings for rainfall (mm), air temperature (°C), and relative air humidity (%) used the IRDeR meteorological station approximately 250 meters away from the trial. They were determined every hour of the day, defining a daily average.

Statistical analysis

The statistical analysis used ANOVA at 5% significance to verify trait variabilities and the significance of each treatment, followed by Tukey's test at 5% significance to verify the means of each treatment. Pearson's linear correlation was performed at 5% significance by the t-test, and the analyses used R software to understand the linear relationships between the evaluated traits.

3. Results

The meteorological data (Figure 1) collected during the trial showed that rainfall levels remained satisfactory from sowing to harvest, with the highest volumes concentrated in emergence periods until 30 days after sowing; thus, rainfall was 61 mm on the first three days. Water volumes were within the normal range, as quantities from 300 mm to 500 mm are more than enough to obtain satisfactory results. Air temperature during the vegetative period (0-40 DAS) varied between 22 and 31°C.

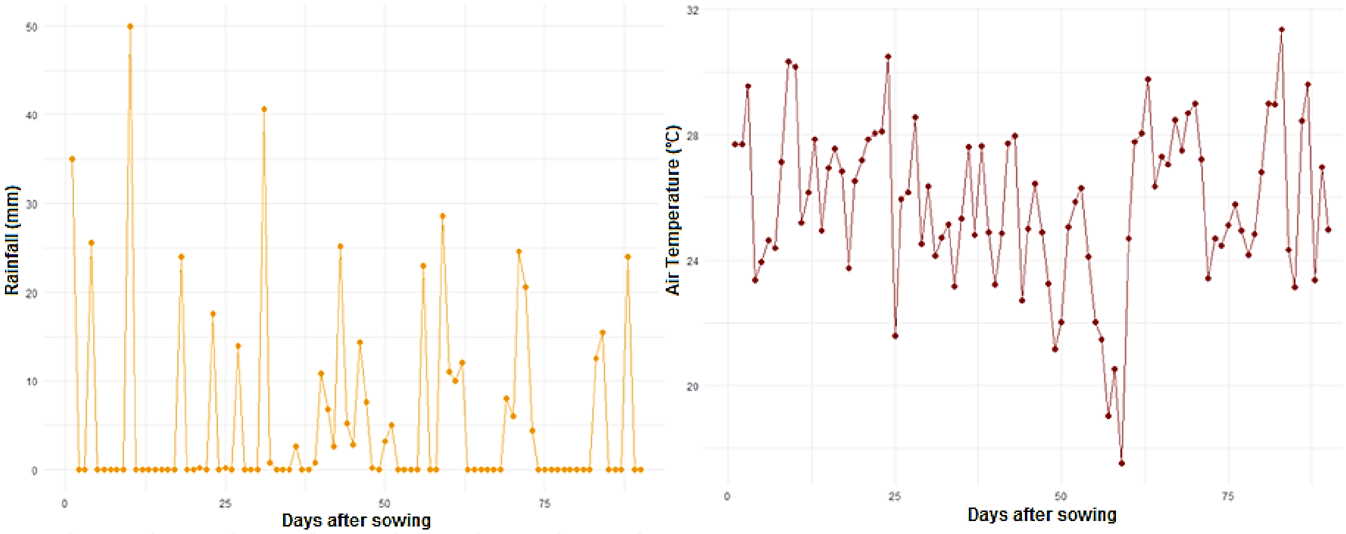

Figure 1. Description of meteorological variables during the trial. Rainfall (mm); Air Temperature (°C). Meteorological Station of the Regional Institute for Rural Development (IRDeR) - UNIJUÍ.

Figure 2 refers to soil moisture conditions during flowering and grain filling, one of the most critical crop phases, directly impacting yield. The data shows that chemical fertilization promoted soil moisture with higher variability than the other treatments but with higher levels reaching 58%.

Table 1. Results of the soil analysis carried out before and after crop implantation in each one of the treatments used.

Sample	Clay (%)	pH	SMP	P	K	OM	Al	Ca	Mg	H+Al	CEC pH 7	Effective CEC	CEC Sat pH 7.0 per bases (%)	Effective CEC Sat by aluminum (%)	Cu	Zn	Mn	S
				mg. dm³		%				Cmol. dm³						mg. dm³		
Pre-Sowing	50	5.0	6.1	21.5	166.0	2.8	0.3	4.8	2.8	6.9	14.9	-	71.7	3.6	6.4	2.6	55.6	11.6
Compost barn	43	6.0	6.5	60.3	448.0	3.5	0.0	6.5	3.5	2.5	13.6	11.1	81.9	0.0	9.1	6.0	22.4	7.2
Chicken Litter	51	5.5	6.1	49.1	280.0	3.1	0.3	6.4	2.9	3.9	13.9	10.0	72.0	2.5	7.8	4.4	47.1	24.6
Chemical	51	5.7	6.5	19.4	150.0	2.6	0.2	5.8	2.7	2.5	11.4	9.1	78.4	2.2	10.7	2.2	37.3	27.1
Absence	51	5.6	6.2	39.3	151.0	2.6	0.7	5.2	2.5	3.5	11.6	8.8	70.0	7.6	8.8	3.2	43.5	10.0

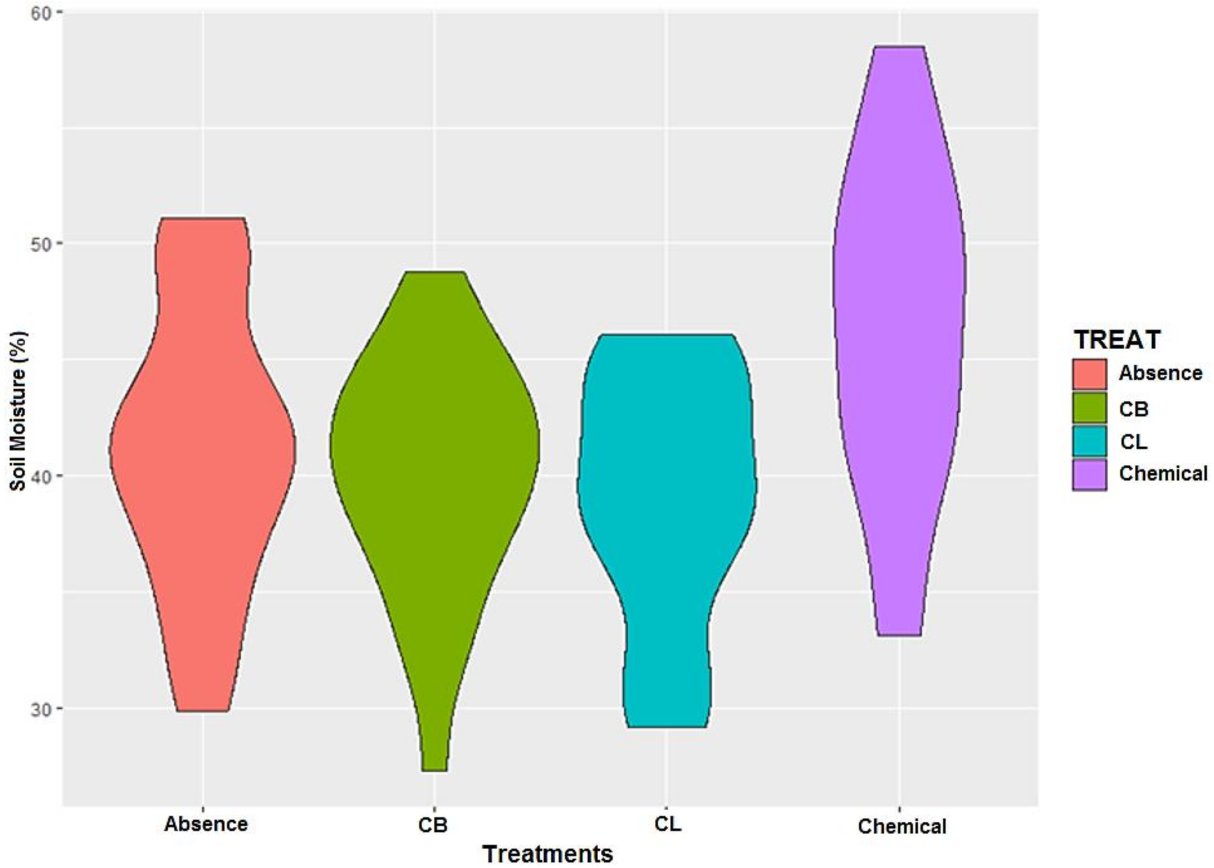

Figure 2. Data regarding the soil moisture content (%), in the 0-20 cm layer, during the flowering and grain filling phases, carried out during the trial bed. US (%): soil moisture; A: absence of fertilization; CB: compost barn bed; CL: chicken litter; C: chemical.

Table 2 summarizes the analysis of variance (ANOVA) for the evaluated variables. The treatments statistically differed regarding NLP, NLB, NB, NL6, NL8, NGP, MTG, GMP, GY, NGxM, GxA, NGRDI, and BGI. Blocks also significantly differed regarding CI and PHM.

The data in Table 2 concerning the mean comparison test performed with Tukey's test demonstrates that the chicken litter treatment had significantly higher means than the other treatments for NLP (26.45), NLB (18.86), NL6, MTG (201,593), GMP (35,495), and NGRDI (0.440). The lowest coefficient of variation (CV) among these mean values was MTG of 3.77%, considered very low and representative. The highest CV was NL8 of 21.89%, considered an average value.

The highest significant means of the compost barn manure treatment were NL8 of 2.59, NGxM of 0.196, and GxA of 0.0049 (Table 2). GY was higher in compost barn manure, with 3,971 kg ha^{-1}. Pereira et al. (2013) studied organic fertilization with cattle manure in Vigna beans, obtaining a GY of 1,563 kg ha^{-1}. Conversely, the treatment with the lowest average was chemical fertilization, presenting the lowest mean for the number of legumes (17.9), NLB, and GY. The compost barn manure did not statistically differ from the highest mean (chicken litter) and the absence of fertilization.

4. Discussion

Hence, the soil had good water storage, an optimal condition for seed absorption, and more uniform germination. Water deficit during germination is one of the most sensitive crop development phases, and water availability in the soil is among the environmental factors that most affect crop yield by reducing germination rates, as water is responsible for metabolism reactivation and other steps in the germination process (Garcia et al. 2012; Silva et al. 2013).

Other critical crop stages are flowering and grain filling, as the studied species has little tolerance to water stress, and 60% of its global cultivation is subjected to this factor. Therefore, water scarcity is the highest productivity reducer (Duarte et al. 2013). Baptista and Berlato (2012) stated that water deficit during flowering causes abortion and flower losses, reducing the number of pods per plant and fructification (grain filling) and affecting grain formation and weight. However, Cunha et al. (2013) found that the yield of bean crop plants subjected to 21 and 37% water deficits, respectively, in the vegetative and reproductive phases decreased by 29%, and a 22% water deficit in the reproductive phase reduced bean crop yield by 15%. Carvalho et al. (2013) showed that beans require a tropical climate with an average temperature of 25°C (18 to 30°C) and scattered monthly rains of 100 mm.

Soil moisture levels reached 53% without fertilization but with lower variability, remaining between 38 and 44% (Figure 2). Conversely, compost barn manure had the lowest moisture variation, remaining between 45 and 48%, with a small drop of 27%, probably due to the lack of rainfall for a few days. The moisture in the soil that received chicken litter showed a low variation of around 37 to 45%. Chicken litter is a soil temperature regulator, reducing moisture lost to the environment, delaying mineral phosphorus fixation, concomitantly promoting the structure, aeration, and compression of soil water conservation, and favoring plant development.

Table 2. Summary of the analysis of variance (Anova) and comparison of Tukey means for the components of bean crop yield.

Sources of Variation	DF	IS	FS	CLO	PHF	PHM	IFL	NL	NLMS	NLB	NB	NDL1	NDL2	NDL3	NDL4
Treat	3	0.367	0.064	0.875	0.071	0.658	0.510	0.0005	0.352	0.001*	0.003*	0.935	0.991	0.393	0.288
Blocks	4	0.998	0.762	0.028*	0.161	0.021*	0.548	0.129	0.100	0.463	0.115	0.920	0.644	0.554	0.195
CV (%)		19.45	21.66	2.65	10.42	4.09	7.21	11.01	12.35	19.09	6.38	31.97	31.18	31.42	22.10

Sources of Variation	DF	NDL5	NL6	NL7	NL8	NGP	MTG	GMP	GY	NGxM	G x A	GLI	NGRDI	BGI
Treat	3	0.159	0.019*	0.238	0.025*	0.001*	4.3e-5*	1.7e-5*	0.001*	2.2e-4*	2.2e-4*	0.057	0.027*	8.3e-4*
Blocks	4	0.694	0.365	0.964	0.744	0.559	0.083	0.138	0.423	0.192	0.192	0.553	0.440	0.360
CV (%)		24.93	17.01	30.43	21.89	13.20	3.77	13.89	11.28	4.16	4.16	6.53	12.33	2.05

Comparison of Tukey Means

Treatment	NLP	NLB	NB	NL6	NL8	NGP	MTG
Compost b.	24.5^{ab}	16.848^{ab}	3.683^{a}	6.3^{ab}	2.59^{a}	130.488^{a}	178.6^{b}
Chicken Litter	26.4^{a}	18.865^{a}	3.681^{a}	6.68^{a}	2.28^{ab}	139.191^{a}	201.593^{a}
Chemical	17.9^{c}	9.995^{c}	3.10^{6b}	4.44^{b}	1.93^{ab}	90.12^{b}	175.975^{b}
Absence	20.3^{bc}	12.54^{bc}	3.382^{ab}	5.88^{ab}	1.58^{b}	110.12^{ab}	169.15^{b}

Treatment	GMP	GY	NGxM	G x A	NGRDI	BGI
Compost b.	25.53^{b}	3.971^{a}	0.196^{a}	0.0049^{a}	0.328^{ab}	0.398^{b}
Chicken Litter	35.495^{a}	3.722^{a}	0.178^{b}	0.0044^{b}	0.44^{a}	0.489^{a}
Chemical	17.48^{c}	2.719^{b}	0.174^{b}	0.0043^{b}	0.198^{b}	0.436^{a}
Absence	21.076^{bc}	3.278^{ab}	0.165^{b}	0.0041^{b}	0.271^{ab}	0.311^{c}

* significant at 5% significance by the F test; DF: degrees of freedom; CV (%): coefficient of variation. Initial Plant Stand (IS), Final Plant Stand (FS), Chlorophyll Index (CLO), Plant Height at Flowering (PHF), Plant Height at Physiological Maturity (PHM), Insertion Height of First Legume (IFL), Number of Legumes per Plant (NLP), Number of Legumes in the Main Stem (NLMS), Number of Legumes in the Branches (NLB), Number of Branches (NB), Number of One-Grain Legumes (NDL1), Number of Two-Grain Legumes (NDL2), Number of Three-Grain Legumes (NDL3), Number of Four-Grain Legumes (NDL4), Number of Five-Grain Legumes (NDL5), Number of Six-Grain Legumes (NDL6), Number of Seven-Grain Legumes (NDL7), Number of Eight-Grain Legumes (NDL8), Number of Grains per Plant (NGP), Grain Yield (GY), Ratio between the Number of Grains and Mass (NGxM), Ratio of Grains by Area (G /A), Green Leaf Index (GLI), Normalized Green-Red Difference Index (NGRDI), Blue Green Pigment IPigment Index (BGI).

Soil moisture is crucial for beans because their underdeveloped root system requires lower water loss to the environment during a dry period. Thus, even if organic fertilizers present a lower moisture concentration in the soil, their variation is lower than chemical fertilization. Organic fertilization increases the soil's water retention capacity, provides higher nutrient availability to plants, and improves soil traits (Pereira et al. 2013). Using organic fertilizers in agriculture is an alternative to meet nutrient demands, especially phosphorus and potassium. Pereira et al. (2013) affirmed that organic fertilization improves the soil's physical, chemical, and biological conditions. Therefore, the immediate conservation of natural resources requires further studies aiming at alternative fertilization to provide higher nutrient availability for plants and improve soil traits (Pereira et al. 2013).

Soil analyses showed that compost barn manure fertilization promoted the highest soil pH increase from five to six (Table 1). Amaral et al. (2004) stated that such an increase is due to ammonia release during decomposition or possibly the Ca and Mg from this residue, neutralizing and displacing elements responsible for acidity, such as H^+. Mello and Vitti (2002) also showed that higher soil organic matter content increases the pH, causing the complexation and precipitation of aluminum from the soil solution.

Soil organic matter contents in compost barn manure and chicken litter treatments increased by 0.7 and 0.3%, respectively, while chemical and no fertilization reduced organic matter levels by 0.2%. It is worth noting that rainfalls during the cycle were essential to increase the speed of organic compound mineralization, promoting rapid nutrient availability for plants. Phosphorus and potassium macronutrient levels increased considerably by 38.8 and 282 mg dm^{-3}, respectively. Likewise, Melo et al. (2007) used an organic fertilizer from cattle manure and obtained similar results for P (200%), K, and Mg levels compared to the soil without an organic fertilizer.

The P, K, and Mg levels in the chemical fertilization treatment show a low significant difference and even a restriction of P compared to the absence of nutrients. That is because nutrient mineralization is faster in mineral fertilization, which may be beneficial for allowing a more vertiginous development due to the quick nutrient supply (Almeida Junior et al. 2011). However, the benefits of organic fertilizers are nutrient provisions and the improvement of base exchange capacity, favoring longer nutrient supply to plants (Dantas, 2014) than chemical fertilization. Among these macronutrients, phosphorus is the most restricting for bean crop yield in Brazilian soils because, when limiting its availability at the beginning of the vegetative cycle, it may present irreversible development problems even if subsequently supplied at adequate levels (Grant et al. 2001). Zucareli et al. (2011) found that plants fertilized adequately and balanced are more resistant to adversity and produce more high-quality seeds. As for potassium, many of its functions in the plant stand out: activating various enzymatic systems that participate in photosynthesis and respiration (Taiz and Zeiger 2013), slower growth in plants deficient of this nutrient, poorly developed roots, weaker stems with higher flexibility and susceptibility to pest attacks and diseases, and effects on the formation of smaller seeds with less intense colors (Ernani et al. 2007).

The analysis also showed higher sulfur levels in the chemical fertilizer and chicken litter treatments than in compost barn manure and the absence of fertilization. That is because chicken litter composition has higher sulfur contents, and this residue is a relevant nutrient source (Broch et al. 2011). Crops require low amounts of micronutrients, but they are essential for full plant development, and their concentrations in the soil vary slightly compared to the absence of fertilizers. Zinc differed the most, increasing 2.8 mg dm^{-3} with compost barn manure and 1.2 mg dm^{-3} with chicken litter. The chemical fertilizer treatment differed the least without fertilizers, probably because plants absorb zinc (Zn) faster than chemical fertilizers, as this micronutrient enhances the production of the growth hormone - auxin (Taiz et al. 2013). The highest Zn, Cu, and Mn concentrations in organic fertilization treatments may be explained by their high concentrations in compost barn manure and chicken litter caused by the supply of unbalanced diets to animals with an excess of these elements.

The base saturation (V) of treatments was higher in compost barn manure (81.9%), followed by the mineral fertilizer and chicken litter, and the latter differed the least from the method without fertilization. Oliveira et al. (2013) presented similar findings, with cattle manure application raising the base saturation index above 60% and improving the organic matter content in the soil. The literature recommends a minimum base saturation of 70% for the soil used in the trial, aiming at good plant development. Organic fertilization is also a lower-cost alternative, allowing producers to use residues from their properties. Therefore, it is essential for small producers as the most common crop fertility provider, considering that incorrectly using chemical fertilization harms the soil biota and promotes salinization, reducing yield.

Studies of Santos et al. (2011) demonstrated that chicken litter increased GY, and Guareschi et al. (2012), working with chicken litter and cattle manure, provided azuki bean grain yields similar to chemical fertilization, making it economically viable.

Oliveira et al. (2000) investigated cowpeas, reporting positive effects of cattle manure on seed production. They attributed this finding to nutrient supply and the improvement of other soil fertility constituents, water supply, structure improvements through humus-clay complex formations, and higher cation exchange capacity (CEC), providing better nutrient use. Reina et al. (2010) reported the same outcomes, attributing the crop yield increase to higher cattle manure doses, probably due to more nutrient availability and water retention capacity under these conditions.

Organic fertilizers showed a higher mean than chemical and no fertilization. A higher NB was among the most relevant traits provided by organic fertilizers to plants compared to the other two treatments. That is essential for productivity because branches have a compensatory effect on plants.

Remarkably, chicken litter stood out in all treatments. The most reasonable explanation for this difference may be the nitrogen concentration in chicken litter compared to compost barn manure, even if the latter was distributed equally on the soil. Raij et al. (1996) found that the nutrients in organic compost, mainly nitrogen and phosphorus, have a slower release than mineral fertilizers, as they depend on organic matter mineralization, providing availability over time, often favoring their use by plants.

Therefore, this difference among treatments was only possible because organic fertilization was applied months before sowing for a gradual nutrient release from the beginning of plant development. If organic fertilization had been performed on the day of sowing, it might not have caused a significant effect. Gerlach et al. (2013) compared organic and chemical fertilization, finding that such availability only occurs close to the reproductive phase. When they applied organic fertilization on the same day as the chemical fertilizer, they did not obtain significant results for NLP, NGP, or the number of grains per legume. Another possibility that may be a determinant for higher yields from chicken litter is the smaller particles than compost barn manure. Hence, soil colloids absorb these nutrients faster and become quickly available at crucial moments for bean crops, especially nitrogen and phosphorus. Demaria et al. (2015) stated that nitrogen presents an agronomic interest for beans, promoting maximum performance.

It is also worth noting that chicken litter presented significantly higher means than the other treatments for NGRDI and BGI. The BGI variable comes from the higher chlorophyll content in plants, having a direct relationship with nitrogen, dry matter production, and yield (Schadchina and Dmitrieva 1995). Rissini et al. (2015) performed studies on wheat crops, directly relating the normalized difference index to higher yields in three evaluated phenological stages. This evaluation method using leaves is imperative to identify the nutritional status of plants and for high-resolution equipment to detect diseases and soil spots, among others. That is vital in agriculture because producers may minimize fertilizer application costs in their crops.

Figure 3 shows Pearson's linear correlation estimates for 11 morphological traits of beans (Pearson's linear correlation coefficients n=1000), significant at 5.00% error probability. It was possible to identify correlations among the analyzed variables, as they range from -1 (strong and negative correlation) to 1 (strong and positive correlation) and 0 (no correlation). Estimating the linear correlation is relevant for genetic improvement, as it allows result applications to indirect selection (Carvalho et al. 2015). Person's linear correlation showed 55 associations among the 11 traits evaluated in the trial, 15 of which were significant. Thus, GLI had a positive correlation coefficient for NL6 (r=0.99), and NB showed a positive correlation for NL6 (r=0.96), NL7 (r=0.96), NGP (0.99), and GY (r=0.98).

NGRDI positively correlated to NLB (r=0.96) and NGP (r=0.95). Studies demonstrated that beans reached higher vigor and development in locations with minimum blue and red absorption and maximum green, mainly in the near-infrared, when bean plants reached maximum development (Luiz et al. 2001). Other authors mentioned that these indexes are related to properties, such as the amount of biomass, the leaf area index, and the photosynthetically absorbed active radiation (Middleton 1991). Reflectance differences may detect physiological changes in leaves, such as moisture loss and chlorophyll degradation. Boechat et al. (2014) found that chlorophyll pigments in healthy plants in the visible region present more absorbed amounts of blue and red spectrum and more reflected green. Also, NL8 positively correlated to

NGxM (r=0.96) and GxA (r=0.96). Kurek et al. (2001) identified NLP as the trait that contributed the most to increasing bean grain yield. Thus, understanding these traits is highly beneficial for plant improvement, and their correlation is significant, as it allows the assessment of the number of changes in one trait that may affect others (Silva et al. 2009).

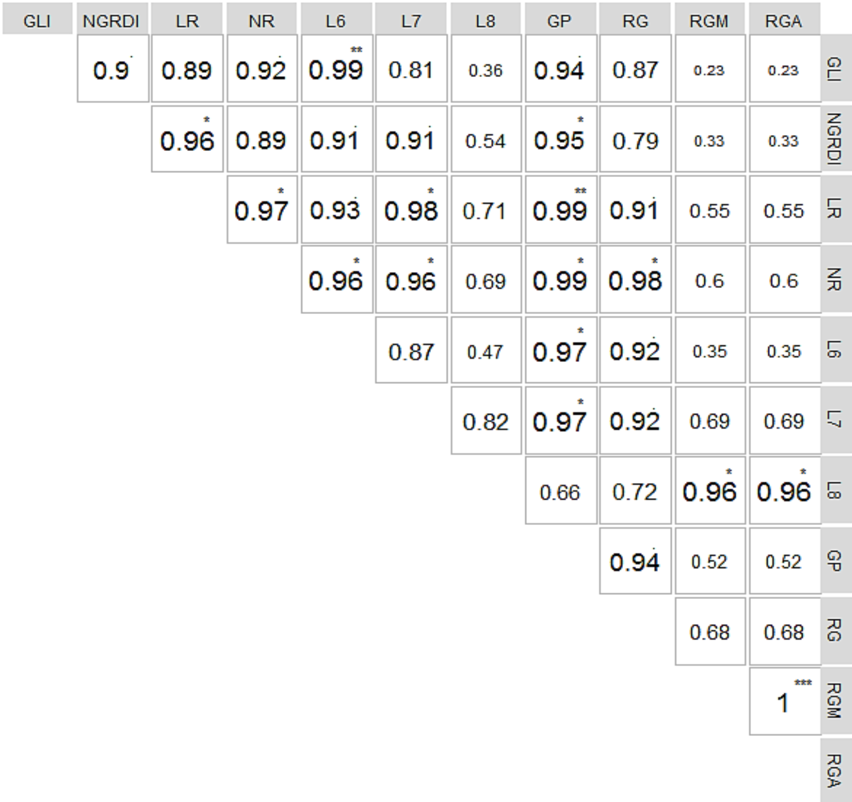

Figure 3. Pearson linear correlation estimates for 11 morphological traits of beans.
* Pearson linear correlation coefficients, significant at 5.00% of probability of error. Initial plant stand (IS), final plant stand (FS), Chlorophyll Index (CLO), Plant Height at Flowering (PHF), Plant Height at Physiological Maturity (PHM), Insertion Height of First Legume (IFL), Number of Legumes per Plant (NLP), Number of Legumes in the Main Stem (NLMS), Number of Legumes in the Branches (NLB), Number of Branches (NB), Number of One-Grain Legumes (NDL1), Number of Two-Grain Legumes (NDL2), Number of Three-Grain Legumes (NDL3), Number of Four-Grain Legumes (NDL4), Number of Five-Grain Legumes (NDL5), Number of Six-Grain Legumes (NDL6), Number of Seven-Grain Legumes (NDL7), Number of Eight-Grain Legumes (NDL8), Number of Grains per Plant (NGP), Grain Yield (GY), Ratio between the Number of Grains and Mass (NGxM), Ratio of Grains by Area (G /A), Green Leaf Index (GLI), Normalized Green-Red Difference Index (NGRDI), Blue Green Pigment Index (BGI).

5. Conclusion

Organic fertilization provided lower variations in soil water availability during flowering and grain filling and increased nutrient concentrations, especially phosphorus and potassium.

Chicken litter promoted the highest means for the number of legumes, the number of legumes on branches, the number of six-grain legumes, the mass of a thousand grains, the grain mass per plant, and the normalized green-red difference index. However, the two organic fertilizers significantly differed from chemical and no fertilization, demonstrating that organic fertilizers must be applied when nutrient availability coincides with the phenological stages, a determinant for high yields. Such a condition combined with rainfall promoted favorable conditions during crop development, considering that high soil moisture allowed faster mineralization of essential nutrients in organic fertilizers, directly affecting productivity.

Pearson's linear correlation allowed a better understanding of the participation of each plant trait in productivity, and organic fertilization provided the highest grain yield.

Authors' Contributions: SILVA, T.S.: conception and design, acquisition of data, analysis and interpretation of data, and drafting the article; CARVALHO I.R.: analysis and interpretation of data, drafting the article, and critical review of important intellectual content; LORO, M.V.: analysis and interpretation of data, drafting the article, and critical review of important intellectual content; PRADEBON, L.C.: analysis and interpretation of data, drafting the article, and critical review of important intellectual content; ALMEIDA, H.C.: analysis and interpretation of data, drafting the article, and critical review of important intellectual content; UHDE, L. T.: analysis and interpretation of data, drafting the article, and critical review of important intellectual content. All authors have read and approved the final version of the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

Ethics Approval: Not applicable.

Acknowledgments: The authors would like to thank the CNPq (National Council for Scientific and Technological Development – Brazil), CAPES (Coordination for the Improvement of Higher Education Personnel - Brazil), and FAPEGRS (Rio Grande do Sul Research Foundation).

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Received: 14 September 2021 | **Accepted:** 31 January 2024 | **Published:** 3 April 2024