Org. Agr.
https://doi.org/10.1007/s13165-025-00506-8

RESEARCH

Check for updates

Fertilization with fermented composts improves agroeconomic performance and sustainability in organic lettuce and forage sorghum cropping systems in Northwestern Minas Gerais, Brazil

Ana Amélia dos Santos Cordeiro · Luiz Fernando de Sousa Antunes · Giulia da Costa Rodrigues dos Santos · José Guilherme Marinho Guerra · Ricardo Luiz Louro Berbara · Ednaldo da Silva Araújo · José Antonio Azevedo Espindola

Received: 11 February 2025 / Accepted: 26 May 2025

Abstract The study was carried out at the Federal Institute of Northern Minas Gerais—IFNMG, in Arinos-MG, to evaluate the effect of sources and doses of fermented vegetable composts such as "bokashi" on the agroeconomic performance of the succession of curly lettuce and forage sorghum under organic management. The treatments that formed the plots consisted of two formulations of fermented bran composts containing mixtures of raw materials with low (↓) and high (↑) C/N ratios: castor bean bran (CAB↓) + wheat bran (WHB↑) and cottonseed bran (COB↓) + passion fruit peel bran (PFPB↑), applied at doses equivalent to 0, 50, 100 and 200 kg N ha^{-1}. Parameters such as shoot diameter, fresh and dry mass production, productivity, accumulation of N, P, K, Ca and Mg in lettuce and sorghum were evaluated, as well as the economic analysis. There was no interaction between source and dose for the phytotechnical variables. The CAB + WHB treatment resulted in greater K accumulation in the lettuce. Increasing the dose of N increased the commercial fresh mass yield of lettuce by up to 148% at the highest dose. However, the N content was higher in the CAB + WHB treatment, with no significant difference for the other variables. The use of agro-industrial vegetable waste, such as passion fruit peel and cottonseed bran, proved to be a viable alternative for replacing conventional raw materials in the formulation of fermented composts, helping to increase sustainability and reduce financial costs in organic farming units.

Keywords Olericulture · Agroecology · Organic compost type"bokashi" · Passion fruit peel bran · Cottonseed bran

Introduction

Lettuce (*Lactuca sativa*) is a herbaceous vegetable, native to southern Europe and Western Asia

A. A. dos Santos Cordeiro ·
G. da Costa Rodrigues dos Santos · R. L. Louro Berbara
Federal Rural University of Rio de Janeiro,
Seropédica-RJ 23890-000, Brazil
e-mail: anadossantoscordeiro@gmail.com

G. da Costa Rodrigues dos Santos
e-mail: giuliarodrigues.ufrrj@gmail.com

R. L. Louro Berbara
e-mail: rberbara@hotmail.com

L. F. de Sousa Antunes (✉)
Federal Rural University of the Semiarid, Mossoró,
Rio Grande Do Norte 59625-900, Brazil
e-mail: fernando.ufrrj.agro@gmail.com

J. G. Marinho Guerra · E. da Silva Araújo ·
J. A. Azevedo Espindola
National Center for Research in Agrobiology,
Seropédica-RJ 23890-000, Brazil
e-mail: guilherme.guerra@embrapa.br

E. da Silva Araújo
e-mail: ednaldo.araujo@embrapa.br

J. A. Azevedo Espindola
e-mail: jose.espindola@embrapa.br

Published online: 18 June 2025

(Filgueira 2012), it is a source of minerals, vitamins and fiber(Vilar et al. 2019). Its cultivation generates an average of five jobs per hectare (Sala and Costa 2012) and in 2018, it occupied an area of 15,136 hectares (Hortifruti Brasil 2018). It has a short cycle (2 to 3 months) with high production capacity per area and nutrient extraction from the soil (Yuri et al. 2016). Nitrogen (N), the second most required nutrient by this species (Trani et al. 2014), when made available in adequate doses, favors vegetative development, so it is necessary to frequently replace it in the soil, as it is very dynamic and undergoes chemical and biological transformations(Malavolta 1980).

Consumer awareness of the impacts caused by conventional food production has led to the search for agricultural systems based on the principles of environmental, social and economic sustainability. The principles of sustainability are highlighted worldwide by the Sustainable Development Goals (SDGs) (ONU 2015). These systems adopt practices aimed at taking advantage of local resources, implementing polycultures, using bio-inputs that protect and promote plant growth, using organic fertilizers, green manure species and soil cover.

It is common to overdose the fertilizers in order to meet the nutritional requirements of lettuce, which can sometimes result, in addition to losses in product quality (Filgueira 2012), waste of financial resources, contamination of groundwater (Varnier et al. 2019), with the possibility of ammonia volatilization (Rocha 2019) and nitrate accumulation(Barros Júnior et al. 2020), with serious consequences for human health (Keszei et al. 2013), although nitrate accumulation in vegetables is lower in those grown in the organic production system (Gomiero 2018).

Among the various fertilization alternatives, the application of organic waste stands out, and in recent years the use of and research into fermented composts has grown, which in addition to resolving the potential pollutants of organic waste (Wijayanto et al. 2016), can offer considerable levels of nutrients, especially N, which makes this practice particularly important in organic production systems (Oliveira et al. 2014), as well as for promoting an increase in production and organic matter (Lasmini et al. 2018; Xavier et al. 2019).

Studies with a formulation containing 40% castor bean bran (CAB) and 60% wheat bran (WHB), in a ratio of 60:40, considered it to be a Fermented Compost Analogous to the Standard (Goulart 2020; Souza Júnior 2020; Pian et al. 2023). It is, prepared under anaerobic conditions inoculated with the compost accelerator Embiotic®, which contains *Lactiplantibacillus plantarum*, a lactic acid bacterium (LAB) used as a silage inoculant (Liu et al. 2016; Silva et al. 2016, 2018), for promoting lactic fermentation, reducing the pH value and inhibiting the development of enterobacteria and butyric acid-producing bacteria, and the yeast *Saccharomyces cerevisiae*, used in the fermentation of foods and drinks (Parapouli et al. 2020).

Fermented composts can increase the organic matter content in the soil and promote improvements in its chemical, physical and biological properties (Higa and Parr 1994; Nishio 1996; Xu et al. 2000; Homma 2005; Murillo-Amador et al. 2015; Wijayanto et al. 2016; Nikitin et al. 2018; Pian et al. 2023) and in the production of vegetables (Cordeiro 2012; Condé et al. 2017; Goulart et al. 2018; Xavier et al. 2019). However, at the Brazilian level, these studies have been primarily limited to the Baixada Fluminense region, particularly under the tropical humid climate conditions of the Fazendinha Agroecológica km 47 in Seropédica, Rio de Janeiro, Brazil. Established in 1993 through an interinstitutional partnership among the Federal Rural University of Rio de Janeiro (UFRRJ), Embrapa Agrobiology, and Agricultural Research Corporation of the State of Rio de Janeiro, this pioneering initiative—officially named the Integrated Agroecological Production System (SIPA)—was conceived as a research, teaching, and training hub to advance agroecology and organic agriculture through systemic approaches and scientific methodologies. The site's distinct climate (average winter temperatures > 20 °C, summer peaks exceeding 40 °C, and 1,300 mm annual rainfall (Neves et al. 2012) has shaped its role as a national reference. Nevertheless, broader studies are needed to evaluate how diverse compost formulations enhance soil quality and crop yields across Brazil's heterogeneous agroecological zones, production systems, and climatic conditions. crop yields.

Among the most widely grown cereals globally, sorghum (*Sorghum bicolor* (L.) Moench) stands out, ranking fifth in production in Brazil, with great importance in off-season crops and in semi-arid regions (Rosa 2012). Its wide adaptability is attributed to advantageous physiological and morphological mechanisms, including xerophytic characteristics that confer greater tolerance to water stress (Andrade Neto et al. 2010; Rodrigues 2015). In addition, it is a crop that is easy to manage and has a short cycle. It is widely used for human and animal food, in agro-industry and as a soil cover, due to its high quality straw and slow decomposition (Queiroz et al. 2014; Guimarães and Landau 2015). In addition, its allelopathic properties can help control spontaneous plants(Recalde et al. 2015), making it a promising alternative for sustainable agricultural systems.

Sorghum's ability to adapt to different soil and climate conditions, combined with its productive potential, makes it a cultural strategy for regions such as the northwest of Minas Gerais, which is part of the Cerrado biome. Its cultivation helps to diversify agricultural production, improve soil fertility and control flexibility and disease when used in crop rotations. In addition, the growing demand for products derived from sorghum, both for human consumption and animal feed, is driving its expansion. In the northwest of Minas Gerais, the state's main grain producer (SEAPA-MG 2017), sorghum cultivation has been consolidated as a viable alternative for the second crop, and is usually planted after the harvest of early soybeans, summer corn or water beans (Rosa 2012; Rodrigues 2015).

Therefore, the general objective of this study was to evaluate the contribution of fertilization with fermented branny composts based on agro-industrial plant residues on the agroeconomic performance of curly lettuce and forage sorghum grown in succession under organic management, evaluating production, productivity, nutrient content and accumulations in curly lettuce and forage sorghum, as well as their economic viability. Specifically, we addressed: (1) whether fermented branny composts improve crop productivity and soil quality compared to conventional organic fertilization and which compost formulation optimizes cost–benefit ratios. Our hypotheses: Will fermented mashed composts increase productivity by improving nutrient availability? Will they reduce production costs and be able to replace conventional raw materials? Will they sustain soil fertility, making lettuce-sorghum succession a viable model for organic agriculture in the Northwest of Minas Gerais?

Material and methods

The experiment was set up at the Federal Institute of Education, Science and Technology of Northern Minas Gerais—IFNMG, Arinos Campus, in Arinos—MG, located at latitude 15° 92'S, longitude 46° 13'W Grw and altitude 520 m, with a climate classified by Köppen as Aw (Oliveira and Oliveira 2019). Although the crops were not grown organically, the area had been fallow for 8 years and the experimental management prioritized practices recommended in the organic farming legislation (Brasil 2003).

Before setting up the experiment in the field, soil was collected from the experimental area, classified as red latosol (Ferralsols), loamy texture (Santos et al. 2018). The samples were collected at a depth of 0—0.20 m and sent to Nativa Laboratório de Análises Agrícolas for chemical characterization: P, K, Ca and Mg, according to the methodology recommended by Embrapa (1997).

The soil was prepared by plowing, harrowing and lifting the beds with a mechanical tiller. The results of soil analysis at 0–20 cm depth (Teixeira et al. 2017) showed: pH in water: 5.7; Al^{+++}: 0.01 $cmol_c$ dm^{-3}; Ca^{++}: 3.61 $cmol_c$ dm^{-3}; Mg^{++}: 1.08 $cmol_c$ dm^{-3}; available P: 7.54 mg dm^{-3}; K^{+}: 162 mg dm^{-3}; organic matter: 2.7 g kg^{-1}. The results showed no need to correct the acidity or recommend potassium fertilization, according to the Manual of Recommendations for the use of correctives and fertilizers in the state of Minas Gerais, Brazil (Ribeiro et al. 1999). A dose equivalent to 2.47 t ha^{-1} of magnesium thermophosphate was incorporated into the soil.

Two formulations of fermented organic bran composts were made: 40% of the mass with a raw material with a low C:N ratio (castor bean bran—CAB), mixed with 60% of the mass with a raw material with a high C:N ratio (wheat bran—WHB), forming the CAB + WHB compost; 40% of the mass with raw material with a low C:N ratio (cottonseed bran—COB), mixed with 60% of the mass with raw material with a high C:N ratio (passion fruit peel bran—PFPB), forming the COB + PFPB compost. These formulations were prepared in larger volumes according to Siqueira and Siqueira (2013), and applied to the beds with the subsequent cultivation of curly lettuce. The chemical analyses of the fermented branny composts are presented in Table 1.

Table 1 Total nutrient content present in raw materials and fermented bran composts

Fermented branny composts	pH	Electrical conductivity (mS m^{-1})	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})	Ca (g kg^{-1})	Mg (g kg^{-1})	C:N ratio
CAB + WHB	4.75	3.59	53.95	12.33	15.10	5.80	6.38	7.78
COB + PFPB	4.62	3.36	30.43	4.48	27.19	3.18	3.58	13.65

Chemical analyses performed according to the methodology proposed by Teixeira et al. (2017)

The fermented branny composts were applied on July 14, 2020, after which the Samira cultivar curly lettuce seedlings were transplanted 6 days later into a 200-cell styrofoam tray filled with organic commercial substrate (Biomix®), a substrate suitable for seedlings and certified for organic production systems, composed of coconut powder or fiber, crushed and composted pine bark, and Bokashi. After 30 days of sowing, the seedlings were transplanted to the field. The randomized block design, with three replications, was divided into plots with two fertilizer sources (CAB + WHB and COB + PFPB) in the plot and four N doses (0, 50, 100 and 200 kg ha^{-1}) in the sub-plots.

The lettuce was harvested on August 25, 2020, when the production of fresh and dry mass was quantified. The yield of curly lettuce was obtained by multiplying the total fresh mass of the aerial part of the lettuce by the plant population extrapolated to one hectare of beds. Sub-samples of the lettuce were predried and sent to an oven with a temperature of 65 ºC and forced air circulation for 48 h. The dry mass was determined and then passed through a Willey-type mill with a mesh opening of 20 meshes, and sent to the Agricultural Chemistry Laboratory at Embrapa Agrobiologia for determination of the N, P, K, Ca and Mg contents.

Agroeconomic indicators were used to estimate the economic viability of using fermented organic compost as a fertilizer for growing curly lettuce and sorghum in succession. The values used as a basis for calculating production costs were obtained from the family farming market in Arinos—MG, and from the food acquisition program—PAA, run by the National Supply Company *(Companhia Nacional de Abastecimento (CONAB)*. The price paid by consumers at the Arinos Family Farmers' Market was BRL2.00 per lettuce plant, and the National School Feeding Program—PNAE/National Fund for the Development of Education—FNDE/Urucuia City Hall, a municipality next to Arinos, paid BRL 2.00 per lettuce plant. To make it easier to interpret the data, the calculations were made for an area of one hectare and one square meter. The calculations were based on the optimum dose of fertilizer.

The gross income (GI), net income (NI) and profitability index (PI) gauges were used for the calculation. Gross income (GI) was calculated taking into account the productivity of the crop, by the verified value of the product paid to the producer. Net income (NI) was calculated by subtracting production costs (C) (inputs and services used) from gross income. The costs were calculated on the basis of one hectare of curly lettuce. The profitability index (PI) was calculated from the ratio between NR and BR, with the result expressed as a percentage.

Hybrid forage sorghum (*Sorghum bicolor*), SHS 570 Astral, was grown in succession to the curly lettuce, following the same experimental design as the previous crop. The first cut was made 63 days after sowing and the second cut was made 33 days after the first cut. Plant height, number of leaves, stem diameter, aerial phytomass productivity, N content and accumulated amount of N were assessed. The methodology was the same used for lettuce.

In this study, the results obtained were subjected to analysis of variance, with significance assessed by the F test ($p \leq 0.05$). Tukey's test was used to compare the means at a 5% probability level. These analyses were carried out using the SISVAR program, version 5.6 (Ferreira 2014). The doses were analyzed using the ANOVA F-test, linear regression analysis was used, and the variables used in this analysis were fresh shoot mass production (g $plant^{-1}$) and fresh shoot mass productivity (Mg ha^{-1}).

Results and discussion

There were no significant effects of fertilizer sources or interactions between fertilizer sources *and* nitrogen doses for the variables analyzed (Table 2), except for the diameter of the lettuce aerial part (Table 2). For doses equivalent to 0.0 and 100.0 kg N ha^{-1}, the two fertilizer sources were similar, while for doses of 50.0 and 200.0 kg N ha^{-1}, the CAB + WHB source showed higher values compared to COB + PFPB. When unfolding each fertilizer source, the CAB + WHB source at doses of 200.0 and 100.0 kg N ha^{-1} resulted in similar values, and at a dose of 200.0 kg N ha^{-1}, the diameter was greater when compared to the doses of 0.0 and 50.0 kg N ha^{-1}. The COB + PFPB source, at doses of 200.0 and 100.0 kg N ha^{-1} resulted in diameters that were similar and statistically superior to the diameters observed at doses of 0.0 and 50.0 kg N ha^{-1} (Table 2).

As for the doses of fermented branny composts, it was observed that as the incorporated dose increased, so did the values for fresh and dry mass production (Fig. 1-A and Fig. 1-B), the quadratic models best describing these responses. The maximum estimated production of fresh and dry matter was 230.5 and 11.82 g $plant^{-1}$ respectively, at a dose equivalent to 187.4 kg N ha^{-1}. These results corroborate Oliveira (2015), Pian et al. (2023) and Souza Júnior (2020), who found the same behavior when evaluating the effect of increasing doses of fermented bran composts formulated from vegetable bran on the cultivation of rocket, rocket and American lettuce, respectively.

The quadratic polynomial model was also reported by other authors studying the effects of aerobic organic composts on lettuce. Yuri et al. (2004) in American lettuce cultivation, observed an estimated maximum production of 634.3 $plants^{-1}$ at a dose equivalent to 561.0 kg of N ha^{-1} contained in organic composts. Oliveira et al. (2006) estimated that the maximum production of curly lettuce fertilized with increasing doses of poultry litter containing 3.53% N was 348 g $plant^{-1}$, at a dose equivalent to 23 Mg ha^{-1}. Steiner et al. (2012), comparing fertilization with a synthetic source (urea) and doses of pig manure and poultry litter, obtained maximum yields of 216.0; 200.0 and 207.0 g $plant^{-1}$, with the application of 180.0; 200.0 and 230.0 kg of N ha^{-1}, respectively.

Maass (2016) reported that increasing doses of fermented bran compost resulted in an increase in the chlorophyll content of parsley (*Petroselinum crispum*). N is an element that is part of the chlorophyll molecule, responsible for photosynthesis (Taíz and Zeiger 2013), essential for plant growth, mass accumulation and increased leaf area. However, there are still few quantitative experimental studies involving doses of fermented branny composts in vegetable crops, in order to enable studies to predict the response to fertilization, except in the soil and climatic conditions of the Baixada Fluminense (Lima 2018; Xavier et al. 2019; Souza Júnior 2020; Pian et al. 2023).

The fresh mass productivity values are equivalent to the average production multiplied by the surface area unit of the planting plot. The doses of 200 and 100 kg of N ha^{-1} showed higher productivity values when compared to the doses of 50 and 0 kg of N ha^{-1}. These data fitted better to the quadratic model, with a maximum estimated value of 45.6 Mg ha^{-1}, at a dose of 184.2 kg of N ha^{-1} (Fig. 1-I). This behavior was also observed by Pian et al. (2023) with maximum rocket productivity at a dose of 385.00 kg of N ha^{-1} contained in fermented compost based on WHB, CAB and coffee husks, and 232.00 kg of N ha^{-1} contained in fermented compost based on CAB, WHB and elephant grass.

In a study investigating the performance of iceberg lettuce fertilized with different organic composts, Sediyama et al. (2016) reported that doses close to 800 kg N ha^{-1} resulted in maximum productivity of 70 Mg ha^{-1}. Brzezinski et al. (2017) evaluating two cropping systems, at a dose of 80 kg N ha^{-1} in the form of urea, achieved yields for Angelina cultivar of 35 Mg ha^{-1}.

Lettuce is a species that responds well to organic fertilization. Based on the equations in Fig. 1, it is estimated that, on average, for each kg of N applied, contained in the fermented bran compost, there is an increase of 0.247 Mg of curly lettuce. It should be noted that the dose of 184.2 kg of N ha^{-1} is equivalent to 409.0 kg of urea ha^{-1}, bearing in mind that the use of synthetic and highly soluble fertilizers is not permitted in organic farming (Brasil 2003). The use of renewable sources, enabling the cycling of nutrients obtained on the farm or locally, is an important strategy that can make fertilization viable on production units, while also making it possible to save money on the purchase or production of these organic fertilizers.

It should be emphasized that soil organic matter must be managed not only to promote increased productivity, but also its increase in the soil, an especially difficult task in tropical regions, where its degradation

Table 2 Phytotechnical variables of curly lettuce, subjected to fertilization with fermented branny composts in increasing doses, in the conditions of Northwest Minas Gerais. 2020

Variable	Fermented compost	Doses of N ha^{-1}				Average
		0	**50**	**100**	**200**	
Diameter (cm plant^{-1})	CAB + WHB	17.2 Ac	22.9 Ab	24.6 Aba	26.3 Aa	22,8 A
	COB + PFPB	18.0 Ac	19.91 Bbc	22.6 Aab	23.4 Ba	21,0 A
	Average	17,6 c	21,4 b	23,6 a	24,9 a	
Fresh mass of the whole plant (g plant^{-1})	CAB + WHB	91.3 Ac	168.1 Ab	213.3 Aba	242.9 Aa	178,9 A
	COB + PFPB	94.2 Ac	142.9 Abc	188.7 Aba	216.7 Aa	160,6 A
	Average	92,7 c	155,5 b	201,0 a	229,8 a	
Whole plant dry mass (g plant^{-1})	CAB + WHB	4.8 Ac	8.4 Ab	10.9 Aba	12.5 Aa	9,1 A
	COB + PFPB	4.9 Ac	7.5 Abc	10.3 Aba	12.3 Aa	8,8 A
	Average	4,9 d	7,9 c	10,6 b	12,4 a	
Productivity (Mg ha^{-1})	CAB + WHB	18.2 Ac	33.6 Ab	42.7 Aba	48.6 Aa	35,8 A
	COB + PFPB	18.8 Ac	28.6 Acb	37.7 Aba	43.3 Aa	32,1 A
	Average	18,5 c	31,1 b	40,2 a	45,9 a	
N content (g kg^{-1})	CAB + WHB	25.1 Ab	24.5 Aba	31.1 Aba	35.3 Aa	29,0 A
	COB + PFPB	24.2 Aa	25.4 Aa	30.1 Aa	30.1 Aa	27,4 A
	Average	24,6 b	24,9 b	30.6 ba	32,7 a	
Accumulated N (kg ha^{-1})	CAB + WHB	23.9 Ab	41.6 Ab	68.4 Aa	88.1 Aa	55,5 A
	COB + PFPB	23.8 Ab	38.0 Ab	62.2 Aa	72.7 Aa	49,2 A
	Average	23,8 b	39,8 b	65,3 a	80,4 a	
P content (g kg^{-1})	CAB + WHB	6.6 Aa	7.2 Aa	7.2 Aa	7.5 Aa	7,1 A
	COB + PFPB	5.8 Aa	6.1 Aa	6.7 Aa	6.7 Aa	6,3 A
	Average	6,2 a	6,6 a	6,9 a	7,1 a	
Cumulative P (kg ha^{-1})	CAB + WHB	6.3 Ac	12.1 Ab	15.7 Aba	18.9 Aa	13,2 A
	COB + PFPB	5.7 Ac	9.2 Acb	13.9 Aba	16.2 Aa	11,3 A
	Average	6,0 c	10,6 b	14,8 a	17,6 a	
K content (g kg^{-1})	CAB + WHB	42.8 Aa	48.0 Aa	57.0 Aa	57.6 Aa	51,4 A
	COB + PFPB	42.8 Aa	54.9 Aa	57.3 Aa	64.6 Aa	54,9 A
	Average	42,8 a	51,5 a	57,4 a	60,8 a	
Accumulated K (kg ha^{-1})	CABWHB	42.58 Ac	80.3 Acb	114.4 Aba	158.6 Aa	97,9 A
	COBPFPB	41.5 Ac	80.8 Acb	126.3 Aba	142.9 Aa	99,0 A
	Average	42,00 c	80,6 b	120,35 a	150,8 a	
Ca content (g kg^{-1})	CAB + WHB	12.3 Aa	12.3 Aa	11.3 Aa	12.1 Aa	12,0 A
	COB + PFPB	13.3 Aa	11.8 Aa	11.9 Aa	11.4 Aa	12,1 A
	Average	12,8 a	12,0 a	11,6 a	11,7 a	
Accumulated Ca (kg ha^{-1})	CAB + WHB	11.8 Ab	20.6 Aba	24.4 Aa	30.2 Aa	21,8 A
	COB + PFPB	13.3 Ab	17.6 Aba	25.3 Aba	28.2 Aa	21,1 A
	Average	12,55 c	19.1 bc	24.9 ba	29,2 a	
Mg content (g kg^{-1})	CAB + WHB	3.2 Aa	4.3 Aa	3.9 Aa	3.5 Aa	3,7 A
	COB + PFPB	3.5 Aa	3.0 Ab	3.1 Aa	2.8 Aa	3,1 A
	Average	3,4 a	3,7 a	3,5 a	3,2 a	
Accumulated Mg (kg ha^{-1})	CAB + WHB	3.0 Ab	7.4 Aba	8.3 Aa	8.8 Aa	6,9 A
	COB + PFPB	3.5 Aa	4.5 Aa	6.5 Aa	6.9 Aa	5,4 A
	Average	3,3 b	6.0 ba	7,4 a	7,9 a	

Different lower-case letters in the rows and upper-case letters in the columns are statistically significant according to Tukey's test at the 5% probability level ($p \leq 0.05$). CAB + WHB—Fermented compost based on castor bean bran (CAB) and wheat bran (WHB). COB + PFPB—Fermented bran compost based on cottonseed bran (COB) and passion fruit peel bran (PFPB).

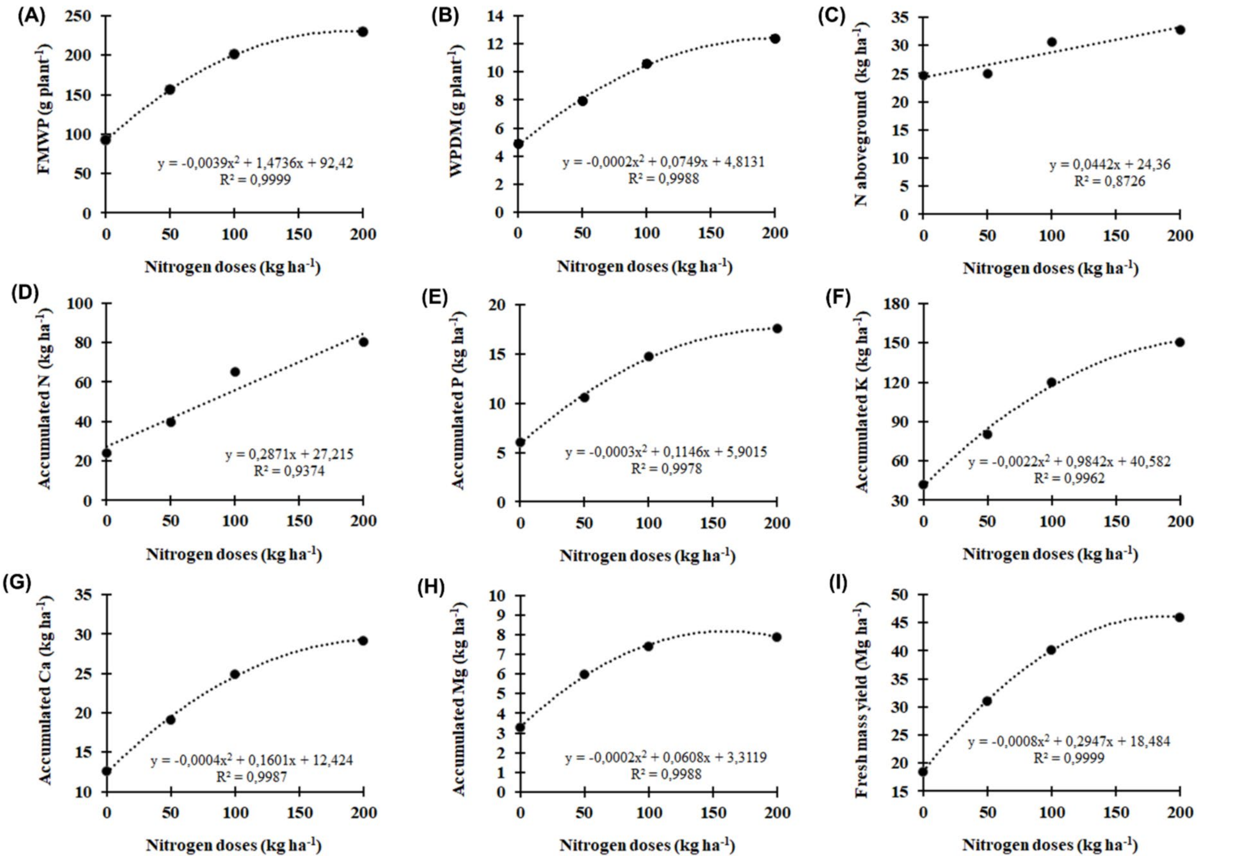

Fig. 1 Regression analysis of nitrogen dose effects from CAB +WHB (castor bean +wheat bran) and COB +PFPB (cottonseed +passion fruit peel bran) fermented branny composts on curly lettuce (Samira cultivar) fresh mass (**A**), dry mass (**B**), N content (**C**), cumulative N (**D**), P (**E**), K (**F**), Ca (**G**), Mg (**H**), and yield (**I**) under Arinos-MG conditions (2020 season)

is accelerated. However, increasing the input of soil organic matter stimulates microbial activity and the mechanisms involved in this process are called the *priming* effect, which is the microbial decomposition of native soil organic matter as a result of fresh carbon inputs, which is a key component of the global cycle (Guenet et al. 2018; Sayer et al. 2021). While the introduction of easily assimilated organic C sources may have no effect on the mineralization of MOS, more recalcitrant C source materials may have a *priming* effect (Bastida et al. 2019).

When analyzing the effects of the doses of fermented branny composts on the N content in the dry matter of the aerial part of curly lettuce, regression analysis showed that the best fit was the increasing linear model, with a maximum value of 33.2 g kg^{-1} (Fig. 1-C). Oliveira (2015), when assessing the N content in the dry matter of rocket fertilized with CAB +WHB fermented branny composts, observed a quadratic behavior of the data. According to Trani et al. (2014) the appropriate range for N in lettuce leaves varies from 30 to 50 g kg^{-1}, and it is the second most demanded nutrient by the lettuce crop, behind K. In lettuce cultivation, its management requires special attention due to the risk of leaching as a result of its high solubility, added to the fact that it is absorbed in greater quantity in the final phase of the cycle (Yuri et al. 2016).

When interpreting the effects of the doses of organic fertilizers on the accumulated amount of nutrients in the dry matter of the aerial part of curly lettuce, significant differences were observed for the variables: accumulated amounts of N, P, K, Ca and Mg. The highest accumulated amounts of P, Ca and K were observed at a dose of 200.0 kg N ha^{-1}. For the accumulated amount of N and Mg, the doses of

100 and 200 kg N ha^{-1} obtained higher values than the others (Table 2).

For the accumulated amount of N in the aerial part of the curly lettuce, the regression analysis showed that the best mathematical fit was the increasing linear model, with a maximum value of 84.6 kg N ha^{-1} (Fig. 1-D). For the accumulated amounts of P, K, Ca and Mg, the regression analysis showed that the best fit was the quadratic polynomial model, with 16.8 kg P ha^{-1}, 135.7 kg K ha^{-1}, 28.4 kg Ca ha^{-1} and 7.93 kg Mg ha^{-1} for the doses of 191.0; 194.7; 135.7; 200.0 and 152.0 kg N ha^{-1}, respectively (Figs. 1-E, 1-F, 1-G, 1-H and 1-I). The quadratic model was also reported by Souza Júnior (2020), when investigating the maximum accumulated amount of nutrients in American lettuce fertilized with compost containing castor bean bran, which was 167.0 kg N ha^{-1}, 35.0 kg P ha^{-1}, 355 kg K ha^{-1}, 63.0 kg Ca ha^{-1} and 16.0 kg Mg ha^{-1}, for doses of 343.0, 283.0, 207.0, 229.0 and 251.0 kg N ha^{-1}, respectively.

Significant amounts of N are exported from the soil, especially in vegetable-growing areas, where cultivation is intensive, with several harvests per year per unit area, requiring regular additions of this nutrient, in addition to its high dynamism in the soil, with various chemical and biological transformations, resulting in losses (Malavolta 1980). K is the nutrient most exported by lettuce plants(Trani et al. 2014), it is related to product quality, photosynthetic and enzymatic processes, osmotic control, carbohydrate transport and the opening and closing of stomata (Mota and Cano 2016).

The application of organic fertilizers can be a good alternative, resulting in similar or even higher yields for lettuce crops (Hernández et al. 2016). Organic fertilizers can also have beneficial effects on the physical and microbiological properties of the soil, influencing crop production (Hernández et al. 2014) and reducing the leaching of nutrients beyond the reach of the root system (Liang et al. 2013).

It is important to note that the local sources used as raw materials for making fermented brany compost, cottonseed bran, a by-product of processing plants, are easily found in the northwest region of Minas Gerais, and passion fruit peel bran, a by-product of the fruit processing agroindustry, installed on the premises of the IFNMG—Arinos, proved to be just as effective as the sources traditionally used to make this type of fermented brany compost, castor bean and wheat bran, which can both reduce the cost of organic fertilization and make it easier for farmers to access raw materials.

When analyzing the agronomic performance of forage sorghum grown in succession to curly lettuce, there was no interaction between the type of organic compost and the dose for fresh and dry mass yield, N, P, K, Ca and Mg content and accumulated amounts. For this crop, no fertilization was carried out and the plants developed only with the residual effect of the fertilization carried out in the previous crop.

With regard to sorghum fresh mass productivity, the results for both the sources and doses of total N showed average values of 36.15 Mg ha^{-1}, similar according to the F test of the analysis of variance (Table 3). This value is close to that obtained by Gontijo Neto et al. (2019) who evaluated forage sorghum intercropped with Marandu grass in the municipality of Unaí, in the northwest of Minas Gerais, and found fresh mass productivity of 35.5 Mg ha^{-1} in a single cut, in a situation of indian summer during the growing season. It is possible to achieve yields of around 30 t ha^{-1} of fresh matter in one cut, with a potential of up to 90 Mg ha^{-1} in three cuts (Embrapa 2008). Ferreira et al. (2012) obtained fresh mass yields of 42.9 Mg ha^{-1} in Areia, Paraíba, Brazil, under rainfed conditions.

For sorghum dry mass productivity (t ha^{-1}), the N doses did not result in an increase promoted by the residual effect of the fermented brany composts. Pian et al. (2023) also found no residual effect of fermented composts based on castor bean and wheat bran; wheat bran, coffee husks and gliricidia; and wheat bran, elephant grass and gliricidia, on the performance of curly lettuce. The average yield was 5.7 Mg ha^{-1}, close to that reported by Torres et al. (2005) of 4.0 Mg ha^{-1}, when cut at the flowering stage, and by Torres and Pereira (2008), of 4.0 and 7.1 Mg ha^{-1}, in two consecutive cycles, in Uberaba, Minas Gerais, Brazil. Other authors have reported values ranging from 4.5 to 21 Mg ha^{-1}(Rodrigues Filho et al. 2006; Embrapa 2008; Albuquerque et al. 2013), to 50 Mg ha^{-1} (Parrella 2011).

Albuquerque et al. (2013) evaluating the performance of different forage sorghum cultivars in Nova Porteirinha, in the semi-arid region of Minas Gerais, Brazil, obtained dry matter yields of between 9.74 and 14.69 Mg ha^{-1}, under base fertilization of 350 kg ha^{-1} of the 04–30-10 formula and top dressing

Table 3 Effects of compost type and N doses on productivity, nutrient content, and accumulation in forage sorghum (first and second cuts) after lettuce

Treatments	Doses of N (ha^{-1})				Average
	0	**50**	**100**	**200**	
Fresh mass yield (Mg ha^{-1})					
CAB + WHB	27.9 Aa	38.3 Aa	40.4 Aa	44.8 Aa	37,9 A
COB + PFPB	28.1 Aa	32.7 Aa	35.3 Aa	41.7 Aa	34,4 A
Average	28,0 a	35,5 a	37,8 a	43,3 a	
Dry mass productivity (Mg ha^{-1})					
CAB + WHB	4.2 Aa	6.0 Aa	6.1 Aa	6.9 Aa	5,8 A
COB + PFPB	4.3 Aa	5.7 Aa	5.8 Aa	6.7 Aa	5,6 A
Average	4,3 a	5,8 a	6,0 a	6,8 a	
N content (g $plant^{-1}$)					
CAB + WHB	13.3 Aa	14.3 Aa	14.6 Aa	16.9 Aa	14,8 A
COB + PFPB	13.4 Aa	12.8 Aa	13.8 Aa	12.8 Ba	13,2 B
Average	13,4 a	13,6 a	14,2 a	14,8 a	
P content (g $plant^{-1}$)					
CAB + WHB	2.4 Aa	2.2 Aa	2.1 Aa	1.8 Aa	2,1 A
COB + PFPB	2.7 Aa	2.5 Aa	2.3 Aa	2.3 Aa	2,4 A
Average	2,6 a	2,3 a	2,2 a	2,1 a	
K content (g $plant^{-1}$)					
CAB + WHB	35.6 Aa	33.0 Aa	31.7 Aa	30.7 Aa	32,8 A
COB + PFPB	33.2 Aa	32.3 Aa	36.0 Aa	33.6 Aa	33,8 A
Average	34,4 a	32,7 a	33,8 a	32,1 a	
Ca content (g $plant^{-1}$)					
CAB + WHB	3.0 Aa	2.8 Aab	2.4 Ab	2.7 Aab	2,75 A
COB + PFPB	2.9 Aa	2.8 Aa	2.8 Aa	2.8 Aa	2,8 A
Average	2,9 a	2,8 a	2,6 a	2,6 a	
Mg content (g $plant^{-1}$)					
CAB + WHB	3.2 Aa	3.2 Aa	2.6 Aa	2.7 Aa	2,9 A
COB + PFPB	2.6 Ba	2.6 Ba	2.48 Aa	2.5 Aa	2,5 A
Average	2,9 a	2,9 a	2,5 a	2,6 a	
Accumulated quantity of N (Mg ha^{-1})					
CAB + WHB	56.0 Ab	89.1 Aab	89.9 Aab	115.5 Aa	87,6 A
COB + PFPB	57.7 Aa	73.3 Aa	80.1 Aa	86.1 Aa	74,3 A
Average	56,9 a	81,6 a	84,6 a	100,8 a	
Accumulated quantity P (Mg ha^{-1})					
CAB + WHB	10.3 Aa	12.9 Aa	12.3 Aa	12.6 Aa	12,0 A
COB + PFPB	11.5 Aa	14.0 Aa	13.8 Aa	15.5 Aa	13,7 A
Average	10,9 a	13,5 a	13,0 a	14,1 a	
Accumulated quantity K (Mg ha^{-1})					
CAB + WHB	156.3 Aa	197.2 Aa	192.1 Aa	211.3 Aa	189,2 A
COB + PFPB	144.2 Aa	184.3 Aa	211.0 Aa	224.8 Aa	191,0 A
Average	150,2 a	190,7 a	201,5 a	218,0 a	
Accumulated quantity Ca (Mg ha^{-1})					
CAB + WHB	13.1 Aa	17.0 Aa	14.8 Aa	18.9 Aa	15,9 A
COB + PFPB	12.5 Aa	16.2 Aa	15.9 Aa	18.7 Aa	15,8 A
Average	12,7 a	16,6 a	15,1 a	17,7 a	
Accumulated quantity Mg (Mg ha^{-1})					
CAB + WHB	14.1 Aa	18.2 Aa	15.7 Aa	18.4 Aa	16,6 A
COB + PFPB	11.3 Aa	14.9 Aa	14.5 Aa	16.9 Aa	14,4 B
Average	12,7 a	16,6 a	15,1 a	17,7 a	

Different lower-case letters in the rows and upper-case letters in the columns are statistically significant according to Tukey's test at the 5% probability level ($p \leq 0.05$). CAB + WHB—Fermented compost based on castor bean bran (CAB) and wheat bran (WHB). COB + PFPB—Fermented bran compost based on cottonseed bran (COB) and passion fruit peel bran (PFPB).

with 200 kg ha^{-1} of N (urea) and 120 kg ha^{-1} of K_2O (potassium chloride). It should be noted that the yield values for forage sorghum reported above were not obtained under residual fertilization, unlike the present work.

Sorghum is a species of agronomic interest that can grow well when temperatures are higher in the northwest of Minas Gerais, Brazil. It should also be noted that its root system explores different soil depths, and the aerial part can be used both for ground cover and for animal fodder, fed raw in the trough or in the form of hay and silage, making it an alternative for the dry season.

Considering that a yield of 6.0 Mg ha^{-1} of dry straw mass provides adequate soil cover (Darolt 1998), only the doses of 100 and 200 kg N ha^{-1} met this premise, although they did not differ from the other doses. Sorghum is a species that is widely used as a ground cover plant, especially in crop rotation systems with other species, in addition to its advantages such as rusticity, low production costs and the possibility of producing a large amount of biomass (Magalhães et al. 2015).

The low N levels are explained by the large export of N by the main crop, plus the possibility of losses of this nutrient through leaching and volatilization(Malavolta 1980). Fracetto (2009), studying the emission of N_2O in castor bean bran applied to the soil under laboratory incubation conditions, found a cumulative emission of approximately 600 mg N-N_2O m^2 of soil h^{-1} in the first 15 days after fertilization. Silva et al. (2017) reported a greater loss of nitrate through leaching in soil fertilized with castor bean bran when compared to fertilization with dairy cattle wastewater. As for P, at the time the area was prepared for growing the main crop, it was at average levels, and no planting fertilizer was applied, nor was fertilizer applied when sorghum was grown. No differences were observed in the N, P, K, Ca and Mg levels for the N doses.

The average values obtained for N, P, K, Ca and Mg were 80.95, 12.85, 190.1 and 15.85 kg ha^{-1} respectively (Table 3). Silva (2002) reported accumulated amounts of N, P, K, Ca and Mg in the aerial part of sorghum at a similar age to this study, of 101.1, 29.5, 133.3, 38.0 and 33.4 kg ha^{-1} respectively. Padovan et al. (2016) in an experiment in Dourados – Mato Grosso do Sul, Brasil, reported accumulated amounts of 100.5, 11.2, 129.8, 29.2 and 40.7 kg ha^{-1} of N, P, K, Ca and Mg, respectively. The removal of the aerial biomass of sorghum promotes a large export of nutrients from the soil, especially N and K (Albuquerque et al. 2013).

When analyzing the data obtained from the forage sorghum regrowth, it was observed that there was no interaction between the types of fertilizers ×doses, there was no difference between the N sources or the fertilizer doses in terms of fresh and dry matter productivity, N content and accumulated amount of N (Table 4). The average fresh mass yield was 13.60 Mg ha^{-1}, 37.60% of the average value obtained in the first cut. While the average dry matter yield was 2.05 Mg ha^{-1}, 36.0% of that obtained in the first cut.

Sorghum's ability to regrow is due to its high capacity to actively preserve its root system (Rezende et al. 2011). Its regrowth potential depends on the health of the plant, the genetic material, the number of tillers formed, water availability and the environment. Productivity varies between 40 and 60% of the productivity obtained in the first cut (Magalhães et al.

Table 4 Effects of compost type and N doses on sorghum regrowth productivity and N dynamics following curly lettuce. IFNMG—Arinos, 2020

Treatments	Doses of N (ha^{-1})				Average
	0	**50**	**100**	**200**	
Fresh mass yield (Mg ha^{-1})					
CAB + WHB	13.7 Aa	13.1 Aa	14.9 Aa	12.7 Aa	13,6 A
COB + PFPB	13.2 Aa	12.3 Aa	13.9 Aa	15.1 Aa	13,6 A
Average	13,5 a	12,7 a	14,4 a	13,9 a	
Dry mass productivity (Mg ha^{-1})					
CAB + WHB	2.1 Aa	2.0 Aa	2.2 Aa	2.0 Aa	2,1 A
COB + PFPB	1.9 Aa	1.8 Aa	2.0 Aa	2.1 Aa	2,0 A
Average	2,0 a	1,9 a	2,1 a	2,1 a	
N content (g kg^{-1})					
CAB + WHB	13.5 Aa	13.3 Aa	12.7 Aa	14.3 Aa	13,4 A
COB + PFPB	13.5 Aa	12.2 Aa	11.8 Aa	11.7 Aa	12,3 A
Average	13,5 a	12,8 a	12,2 a	13,0 a	
Accumulated quantity of N (kg ha^{-1})					
CAB + WHB	27.3 Aa	27.0 Aa	27.8 Aa	29.0 Aa	27,8 A
COB + PFPB	25.2 Aa	22.5 Aa	24.8 Aa	24.9 Aa	24,4 A
Average	26,2 a	24,8 a	26,3 a	26,9 a	

Different lower-case letters in the rows and upper-case letters in the columns are statistically significant according to Tukey's test at the 5% probability level ($p \leq 0.05$). CAB + WHB—Fermented compost based on castor bean bran (CAB) and wheat bran (WHB). COB + PFPB—Fermented bran compost based on cottonseed bran (COB) and passion fruit peel bran (PFPB).

2015; Paula 2016), some hybrids, this percentage can exceed 90% of the productivity of the first cut (Tomich et al. 2003). Sorghum regrowth is mainly used as soil mulch in the no-till system (Foloni et al. 2008).

The analysis of the agroeconomic viability of curly lettuce fertilized with the CAB +WHB compost showed that this fertilizer burdened production by 40.00% of the total production cost, followed by the costs of seedling production, at 25.77%, labor costs, at 21.62%, and the rental of machinery and implements for soil preparation, at 6.30%. These values are close to those observed by Lima (2018), who reported the cost of fertilization with the CAB +WHB compost in carrot cultivation, at 48% of the total cost. When analyzing the agroeconomic viability of the treatment fertilized with the COB +PFPB compost, it is observed that this fertilizer represented 28.75% of the total cost, behind the cost of producing lettuce seedlings, with 30.60% of the total value, labor costs represented 25.7% of the total value and the rental of machinery and implements for soil preparation represented 7.49% of the total costs (Table 5).

The lettuce culture is an activity recognized for its ability to employ rural labor (Sala and Costa 2012), especially in organic production systems, Miguel et al. (2010) reported a relative production cost of 30.6% for labor. According to Barros Júnior et al. (2020) the cost of producing curly lettuce was 32.6% for labor, 28.1% for the purchase of seedlings, 16.2% for machinery and implements, 8.0% for mineral fertilizers and 6.9% for pesticides.

When analyzing the agroeconomic viability of curly lettuce grown in the absence of fertilization with fermented branny composts, it can be seen that the production of seedlings represents 44.50% of the cost of production, labor represented 37.33% of the

Table 5 Production cost of growing curly lettuce and forage sorghum in succession, subjected to organic management as a function of doses of fermented bran compost. IFNMG—Arinos, 2020

Activity	Lettuce production costs			
	Unit	Unit price (BRL)	Cost m^{-2} (BRL)	Cost ha^{-1} (BRL)
Preparing the area	Machine time^{-1}	140.00	0.182	1,820.00
Seedling production	Tray	6.76	0.7437	7,437.57
Distribution of the compost in the beds	Man day^{-1}	60.00	0.06	600.00
Irrigation installation	Man day^{-1}	60.00	0.024	240.00
Planting	Man day^{-1}	60.00	0.15	1,500.00
Weeding	Man day^{-1}	60.00	0.30	3,000.00
Harvesting	Man day^{-1}	60.00	0.09	900.00
Electricity	Kwh	0.45	0.0315	315.00
Transportation	km	1.00	0.15	1,500.00
CABWHB compost	kg	1.46	1.10	11,547.13
Compost COBPFPB	kg	0.804	0.638	6,988.16
Total cost optimal dose CAB +WHB			2.88	28,859.70
Total cost of optimal dose COB +PFPB			2.43	24,300.73
Control (no fertilization)			1.67	16,712.57
Activity	**Forage sorghum production costs**			
Seed	Package	169.00	0.01	169.00
Planting	Man day^{-1}	60.00	0.06	600.00
Weeding	Man day^{-1}	60.00	012	1,200.00
Harvesting	Man day^{-1}	60.00	0.09	900.00
Electricity	Kwh	0.45	0.018	180.00
Total cost			0.305	**3,049.00**

*0.815 kg m^{-2} of fermented bran compost on a dry basis. CAB +WHB—Fermented compost based on castor bean bran (CAB) and wheat bran (WHB). COB +PFPB—Fermented bran compost based on cottonseed bran (COB) and passion fruit peel bran (PFPB). BRL = Brazilian real

Table 6 Agroeconomic indicators of curly lettuce cultivation subjected to organic management, as a function of doses of fermented organic compost. IFNMG—Arinos, 2020

Treatments	Agroeconomic indicators of lettuce cultivation						
	Cost of production ha^{-1} (BRL)	**[1]Productivity (Mg ha^{-1})**	**[2]GI ha^{-1} (BRL)**	**[3]NI ha^{-1} (BRL)**	**[4]GI m^2 (BRL)**	**[5]NI m^{-2} (BRL)**	**[6]PI m^2 (%)**
Wholesale sales (BRL 1.7 unit)							
CAB + WHB*	28.859,70	45.6	110.742,86	81.883,15	11.07	8.18	73
COB + PFPB*	24.300,73	45.6	110.742,86	86.442,12	11.07	8.64	78
Control	16.712,57	18.54	45.025,71	28.313,14	4.50	2.83	62
Retail sales—Family farming fair (BRL 2.0 unit)							
CAB + WHB*	28.859,70	45.60	130.285,71	101.426,01	13.02	10.14	78
COB + PFPB*	24.300,73	45.60	130.285,71	105.984,98	13.02	10.59	81
Control	16.712,57	18.54	52.971,43	36.258,86	5.3	3.62	68
Treatment	**Agroeconomic indicators for forage sorghum** (BRL 240.00 Mg ha^{-1})						
CAB + WHB*	3.049,00	49.75	11,940,00	8.891,00	1.19	0.89	74
COB + PFPB*	3.049,00	49.75	11,940,00	8.891,00	1.19	0.89	74
Control	3.049,00	49.75	11,940,00	8.891,00	1.19	0.89	74

[1]Productivity; [2]Gross income ha^{-1}; [3]Net income ha^{-1}; [4]Gross income m^{-2}; [5]Net income m^{-2}; [6]Profitability index. *: applied at the optimum dose, equivalent to 187.4 kg N ha^{-1}. CAB + WHB—Fermented compost based on castor bean bran (CAB) and wheat bran (WHB). COB + PFPB—Fermented bran compost based on cottonseed bran (COB) and passion fruit peel bran (PFPB). BRL = Brazilian real

total cost of production, followed by the cost of renting machinery to prepare the area, with 10.9%.

In the scenario of selling production to the wholesale market, fertilization with CAB + WHB and COB + PFPB increased net income by 189.2 and 205.3%, respectively, compared to the control, without fertilizer application. Analyzing the possibility of retail sales at the Family Farmers' Market in Arinos – Minas Gerais, Brazil, net income increased by 179.7 to 192.3% compared to the control, without fertilization (Table 6), an average gain of 23.0% compared to sales on the wholesale market.

In terms of the profitability index (PI), it was higher in the retail market scenario at the Family Farming Market in Arinos—MG, with values of 78 and 81 for CAB + WHB and COB + PFPB, respectively. In the wholesale market scenario, these values were 73 and 78 for CAB + WHB and COB + PFPB, respectively. In the absence of fertilization, the PI values were 62 and 68 for the wholesale and retail markets, respectively (Table 6).

As for the agroeconomic evaluation of forage sorghum, obtained by adding the two harvests together, it was not possible to observe an increase in net income ha^{-1}, because there was no residual effect of organic fertilizers on the productivity of this crop. However, sorghum productivity can be considered interesting, despite its lower profitability compared to lettuce, since the biomass produced can be sold, used for animal feed on the farm or used as soil cover, improving the chemical, physical and biological quality of the soil. Increasing organic matter in the soil, especially in tropical soils such as those in the Brazilian cerrado region, deserves attention, especially in areas where vegetables are grown, where high humidity and temperature conditions favor the rapid decomposition of organic matter, as well as the considerable export of nutrients from the soil.

Based on the results of the agroeconomic performance of curly lettuce as a result of fertilization with fermented brany composts, the benefits and feasibility in terms of production costs for the climatic conditions of the semi-arid region of Minas Gerais are clear.

Conclusions

The phytotechnical performance of curly lettuce subjected to organic management, as a result of fertilization with different sources and doses of fermented branny composts formulated with mixtures containing castor bean and wheat bran, and cottonseed bran and passion fruit peel, is influenced by the dose applied, but does not differ in terms of the sources, showing the viability of replacing the commonly used source that is castor bean bran + wheat bran (CAB + WHB), with the source whose acquisition is more economical and easily accessible that is cottonseed bran + passion fruit peel bran (COB + PFPB) for the conditions of the Northwest of Minas Gerais.

There was no residual effect of fertilizing curly lettuce on forage sorghum grown in succession to curly lettuce.

The net economic income from growing curly lettuce is positively influenced by the application of fermented branny compost, with the highest values being obtained when it is sold directly at the Arinos—MG Family Farming Fair, rather than on the wholesale market.

The production cost of COB + PFPB fertilizer represents only 55.3% of the production cost of CAB + WHB compost, and can generate savings of BRL 5,158.97 per hectare.

Authors contribution Ana Amélia dos Santos Cordeiro: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Validation, Writing—original draft. Luiz Fernando de Sousa Antunes: Data curation, Validation, Writing—review & editing. Giulia da Costa Rodrigues dos Santos: Data curation, Writing—review & editing. José Guilherme Marinho Guerra: Conceptualization, Methodology, Visualization, Supervision, Writing—review & editing, Resources, Funding acquisition. Ricardo Luiz Louro Berbara: Conceptualization, Methodology, Visualization, Supervision, Writing—review & editing, Resources, Funding acquisition. Ednaldo da Silva Araújo: Visualization, Writing—review & editing, Resources, Funding acquisition. José Antonio Azevedo Espindola: Visualization, Writing—review & editing, Resources, Funding acquisition.

Funding This work was carried out with the support of the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES)—Financing Code 001, Brazil.

Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interest The authors declare no competing interests.

References

Albuquerque CJB, Jardim RR, Alves DD, Guimarães ADS, Porto EMV (2013) Características agronômicas e bromatológicas dos componentes vegetativos de genótipos de sorgo forrageiro em minas gerais. Revista Brasileira de Milho e Sorgo 12:164–182. https://doi.org/10.18512/1980-6477/rbms.v12n2p164-182

Andrade Neto RC, Miranda NO, Duda GP, Góes GB, Lima AS (2010) Crescimento e produtividade do sorgo forrageiro BR 601 sob adubação verde. Rev Bras Eng Agríc Ambient 14:124–130. https://doi.org/10.1590/S1415-43662010000200002

Barros Júnior AP, Cecílio Filho AB, Rezende BLA, Lins HA (2020) Ntrate accumulation in lettuce and rocket in response to nitrogen fertilization in intercropping. Rev Caatinga 33:260–265. https://doi.org/10.1590/1983-21252020v33n128rc

Bastida F, García C, Fierer N et al (2019) Global ecological predictors of the soil priming effect. Nat Commun 10:3481. https://doi.org/10.1038/s41467-019-11472-7

Brasil H (2018) Anuário 2018/2019. Hortifruti Brasil 17:50

Brasil (2003) Lei nº 10.831 de 23 de dezembro de 2003. Diário Oficial da União, Brasília-DF. http://www.planalto.gov.br/ccivil_03/leis/2003/l10.831.htm

Brzezinski CR, Abati J, Geller A, Werner F, Zucareli C (2017) Produção de cultivares de alface americana sob dois sistemas de cultivo. Rev Ceres 64:83–89. https://doi.org/10.1590/0034-737x201764010012

Condé VF, Oliveira DM, Oliveira JEZ (2017) Incidência e severidade de hérnia das crucíferas em solo tratado com biofertilizante tipo bokashi(plasmodiophora brassicae w.) Em repolho (brassica oleracea l. Var. Capitata). Ciência e Natura 39:07–15. https://doi.org/10.5902/2179460X21445

Cordeiro AAS (2012) Manejo de espécies de cobertura do solo antecedendo o cultivo orgânico de repolho. Dissertação (Mestrado em Fitotecnia), Universidade Federal Rural do Rio de Janeiro, p 70

Darolt MR (1998) Princípios para implantação e manutenção de sistemas. Plantio direto: pequena propriedade sustentável. Instituto de Desenvolvimento Rural do Paraná (IAPAR), Londrina-PR, pp 16–45p

Embrapa (1997) Manual de métodos de análise de solo, 2nd edn. Embrapa Solos, Rio de Janeiro-RJ, p 212

Embrapa (2008) Sorgo para corte e pastejo: Híbridos de sorgo sudão e sorgo bicolor: alternativas de forrageiras para corte e pastejo. Embrapa Milho e Sorgo, Sete Lagoas-MG, p 2

Ferreira DF (2014) Sisvar: a Guide for its Bootstrap procedures in multiple comparisons. Ciência e Agrotecnologia 38:109–112. https://doi.org/10.1590/S1413-70542014000200001

Ferreira LE, Silva IF, Souza EP, Souza MA, Borchartt L (2012) Caracterização física de variedades de sorgo submetidas a diferentes adubações em condição de sequeiro. Revista Verde De Agroecologia e Desenvolvimento Sustentável 7:249–255

Filgueira FAR (2012) Novo manual de olericultura: agrotecnologia moderna na produção e comercialização de hortaliças, 3rd edn. UFV, Viçosa

Foloni JSS, Tiritan CS, Calonego JC, Dundes LR (2008) Rebrota de soqueiras de sorgo em função da altura de corte e da adubação nitrogenada. Ceres 55(2):102–108

Fracetto FJC (2009) Estoque de carbono e nitrogênio e estrutura da comunidade de diazotróficas em solos de caatinga com plantio de mamona. Dissertação (Mestrado em Agronomia), Escola Superior de Agronomia Luiz de Queiroz - ESALQ, Piracicaba-SP, p 77

Gomiero T (2018) Food quality assessment in organic vs. conventional agricultural produce: Findings and issues. Appl Soil Ecol 123:714–728. https://doi.org/10.1016/j.apsoil.2017.10.014

Gontijo Neto MM, Silva RV, Borghi E, Resende ÁV, Melo CJ, Abreu SC (2019) Alternativas de Integração Lavoura-Pecuária para Produção de Forragens e Recuperação de Pastagens Estudo de caso da Fazenda São Pedro, Unaí-MG. Circular Técnica 257. Embrapa Milho e Sorgo, Sete Lagoas-MG, p 32

Goulart RGT, Santos CA, Oliveira CM, Costa ESP, Oliveira FA, Andrade NF, Carmo MGF (2018) Desempenho agronômico de cultivares de alface sob adubação orgânica em Seropédica RJ. Revista Brasileira de Agropecuária Sustentável 8:66–72. https://doi.org/10.21206/rbas.v8i3.3011

Goulart JM (2020) Estratégias de produção in situ de biomassa de leguminosas arbustivas e arbórea para confecção de compostos fermentados empregados na fertilização de cenoura e alface consorciadas em cultivo orgânico. Dissertação (Mestrado em Fitotecnia), Universidade Federal Rural do Rio de Janeiro, Seropédica-RJ, p 76

Guenet B, Camino-Serrano M, Tifafi PCM, Maignan F, Song JL, Janssens IA (2018) Impact of priming on global soil carbon stocks. Global Change Biology | Environmental Change Journal | Wiley Online Library 24:1873–1883

Guimarães DP, Landau EC (2015) Zoneamento da Cultura do Sorgo. In: Zoneamento da Cultura do Sorgo., 9th edn. In: José Avelino Rodrigues. (Org.). Cultivo do Sorgo - Sistema de Produção., Sete Lagoas: Embrapa Milho e Sorgo, 2015

Hernández T, Chocano C, Moreno J-L, García C (2014) Towards a more sustainable fertilization: combined use of compost and inorganic fertilization for tomato cultivation. Agr Ecosyst Environ 196:178–184. https://doi.org/10.1016/j.agee.2014.07.006

Hernández T, Chocano C, Moreno J-L, García C (2016) Use of compost as an alternative to conventional inorganic fertilizers in intensive lettuce (Lactuca sativa L.) crops—Effects on soil and plant. Soil and Tillage Research 160:14–22. https://doi.org/10.1016/j.still.2016.02.005

Higa T, Parr JF (1994) Beneficial and effective microrganisms for a sustainable agriculture. Internacional Nature Farming Research Center, p 16

Homma SK (2005) Efeito do manejo alternativo sobre a descompactação do solo, fungos micorrízicos arbusculares nativos e produção em poma convencional de tangor "murcott." Dissertação (Mestrado em Ecologia de Agroecossistemas), Escola Superior de Agronomia Luiz de Queiroz - ESALQ

Keszei AP, Goldbohm RA, Schouten LJ, Jakszyn P, van den Brandt PA (2013) Dietary N-nitroso compounds, endogenous nitrosation, and the risk of esophageal and gastric cancer subtypes in the Netherlands Cohort Study. Am J Clin Nutr 97:135–146. https://doi.org/10.3945/ajcn.112.043885

Lasmini SA, Nasir B, Department of Plant Pest and Disease, University of Tadulako, Hayati N, Department of Horticulture, University of Tadulako, Edy N, Department of Plant Pest and Disease, University of Tadulako, Palu - 94117, Indonesia (2018) Improvement of soil quality using bokashi composting and NPK fertilizer to increase shallot yield on dry land. Aust J Crop Sci 12:1743–1749. https://doi.org/10.21475/ajcs.18.12.11.p1435

Liang B, Zhao W, Yang X, Zhou J (2013) Fate of nitrogen-15 as influenced by soil and nutrient management history in a 19-year wheat–maize experiment. https://doi.org/10.1016/J.FCR.2012.12.007

Lima PH (2018) Avaliação da adubação orgânica com composto fermentado aliada a cobertura morta do solo no desempenho agroeconômico de hortaliças em sucessão. Tese (Doutorado em Fitotecnia), Universidade Federal Rural do Rio de Janeiro, Seropédica-RJ, p 156

Liu Q, Li X, Desta ST, Zhang J, Shao T (2016) Effects of Lactobacillus plantarum and fibrolytic enzyme on the fermentation quality and in vitro digestibility of total mixed rations silage including rape straw. J Integr Agric 15:2087–2096. https://doi.org/10.1016/S2095-3119(15)61233-3

Maass V (2016) Bokashi mejorado y su efecto en un cultivo de perejil bajo manejo orgánico en invernadero. Tese (Doutorado em Agronomia), Pontificia Universidad Católica de Chile

Magalhães PC, Souza TC, Schaffert RE (2015) Ecofisiologia. In: Rodrigues JAS (ed) Sistemas de Produção Embrapa: Cultivo do sorgo, 9th edn. Embrapa Milho e Sorgo, Sete Lagoas-MG, pp 105–123

Malavolta E (1980) Elementos de nutrição mineral de plantas. Editora Ceres, São Paulo-SP, p 251

Miguel FB, Grizotto RK, Furlaneto FPB (2010) Custo de produção de alface em sistema de cultivo orgânico. Pesquisa & Tecnologia 7:1–6

Mota CS, Cano MAO (2016) Respostas fotossintéticas e acúmulo de massa em plantas jovens de macaúba submetida ao déficit hídrico cíclico. Revista Caatinga 29:850–858. https://doi.org/10.1590/1983-21252016v29n409rc

Murillo-Amador B, Morales-Prado LE, Troyo-Diéguez E, Córdoba-Matson MV, Hernández-Montiel LG, Rueda-Puente EO, Nieto-Garibay A (2015) Changing environmental conditions and applying organic fertilizers in Origanum vulgare L. Front Plant Sci 6:549. https://doi.org/10.3389/fpls.2015.00549

Neves MCP, GUERRA JGM, Carvalho SR, Ribeiro RLD, Almeida DL (2012) Sistema Integrado de Produção Agroecológica ou Fazendinha Agroecológica do Km 47. In: AQUINO AM, ASSIS RL (eds) Agroecologia: Princípios e Técnicas Para uma Agricultura Orgânica Sustentável, 2nd edn. Embrapa Informação Tecnológica, Brasília-DF, pp 163–195

Nikitin AN, Cheshyk IA, Gutseva GZ, Tankevich EA, Shintani M, Okumoto S (2018) Impact of effective microorganisms on the transfer of radioactive cesium into lettuce and barley biomass. J Environ Radioact 192:491–497. https://doi.org/10.1016/j.jenvrad.2018.08.005

Nishio M (1996) Microbial fertilizers in japan. ASPAC Food & Fertilizer Technology Center, Japan

Oliveira EAG (2015) Formulações tipo “bokashi” como fertilizantes orgânicos no cultivo de hortaliças. Tese (Doutorado em Fitotecnia), Universidade Federal Rural do Rio de Janeiro, Seropédica

Oliveira JÂM, Oliveira CMM (2019) Balanço hídrico climatológico e classificação climática para o município de Arinos – MG. Revista Brasileira De Agricultura Irrigada - RBAI 12:3021–3027

Oliveira NG, De-Polli H, Almeida DL, Guerra JGM (2006) Plantio direto de alface adubada com cama de aviário sobre coberturas vivas de grama e amendoim forrageiro. Hortic Bras 24:112–117

Oliveira LB, Accioly AMA, Santos CLR, Flores RA, Barbosa FS (2014) Características químicas do solo e produção de biomassa de alface adubada com compostos orgânicos. Rev Bras Eng Agríc Ambient 18:157–164. https://doi.org/10.1590/S1415-43662014000200005

ONU (2015) Transforming our world: the 2030 agenda for sustainable development. In: Organização das Nações Unidas. https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf. Accessed 12 Aug 2021

Padovan MP, Carneiro LF, Felisberto G, Nascimento JS, Carneiro DNM (2016) Milho cultivado em sucessão a adubos verdes em sistemas sob bases agroecológicas. Revista Agro@Mbiente On-Line 9:377–385. https://doi.org/10.18227/1982-8470ragro.v9i4.2705

Parapouli M, Vasileiadis A, Afendra A-S, Hatziloukas E (2020) Saccharomyces cerevisiae and its industrial applications. AIMS Microbiol 6:1–31. https://doi.org/10.3934/microbiol.2020001

Parrella RA (2011) Desempenho agronômico de híbridos de sorgo biomassa. Embrapa Milho e Sorgo, Sete Lagoas-MG

Paula ADM (2016) Desempenho agronômico, bromatologico e estabilidade fenotípica de sorgo silageiro em Uberlândia–MG. Dissertação (Mestrado em Fitotecnia), Universidade Federal de Uberlândia

Pian LB, Guerra JGM, Berbara RLL, Jesus MSC, Barbosa Junior J, Araújo ES (2023) Characterization, nitrogen availability, and agronomic efficiency of fermented composts in organic vegetable production. Org Agr 13:461–481. https://doi.org/10.1007/s13165-023-00439-0

Queiroz VAV, Menezes CB, Barros FAR, Martino HSD (2014) O sorgo na alimentação humana. EPAMIG, Belo Horizonte - MG, pp 7–12

Recalde KMG, Carneiro LF, Carneiro DNM, Felisberto G, Nascimento JS, Padovan MP (2015) Weed suppression by green manure in an agroecological system. Rev Ceres 62:546–552. https://doi.org/10.1590/0034-737X201562060006

Rezende GM, Pires DAA, Botelho PRF, Rocha Júnior VR, Sales ECJ, Jayme DG, Reis ST, Pimentel LR, Lima LOB, Kanemoto ER, Moreira PR (2011) Características agronômicas de cinco genótipos de sorgo [Sorghum bicolor (L.) Moench], cultivados no inverno, para a produção de silagem. Revista Brasileira de Milho e Sorgo 10:171–179. https://doi.org/10.18512/1980-6477/rbms.v10n2p171-179

Ribeiro AC, Guimarães PTG, Alvarez VH (1999) 5ª Aproximação: Recomendações para o uso de corretivos e fertilizantes em Minas Gerais. Sociedade Brasileira de Ciência do Solo, Viçosa-MG

Rocha DC (2019) Composição mineral e teor de nitrato em alface hidropônica baby leaf sob diferentes proporções NO3-:NH4+ e concentrações de molibdênio. Dissertação (Mestrado em Ciência do Solo), Universidade Federal do Paraná. Curitiba-PR. 59p.

Rodrigues JAS (2015) Cultivo do Sorgo. Embrapa Milho e Sorgo, Sete Lagoas, MG

Rodrigues Filho O, França AFS, Oliveira RP, Oliveira ER, Rosa B, Soares TV, Mello SQS (2006) Produção e composição bromatológica de quatro hibrídos de sorgo forrageiro [Sorghum bicolor (L.) Moench] submetidos a três doses de nitrogênio. Ciência Animal Brasileira 7:37–48

Rosa WJ (2012) Cultura do Sorgo. Emater-MG, Belo Horizonte - MG

Sala FC, Costa CP (2012) Retrospectiva e tendência da alfacicultura brasileira. Hortic Bras 30:187–194. https://doi.org/10.1590/S0102-05362012000200002

Santos HG, Jacomine PKT, Anjos LHC, Oliveira VA, Lumbreras JF, Coelho MR, Almeida JA, Araújo Filho JC, Oliveira JB, Cunha TJF (2018) Sistema Brasileiro de Classificação de Solos, 5th edn. Embrapa, Brasília, DF

Sayer EJ, Baxendale C, Birkett AJ, Bréchet LM, Castro B, Kerdraon-Byrne D, Lopez-Sangil L, Rodtassana C (2021) Altered litter inputs modify carbon and nitrogen storage in soil organic matter in a lowland tropical forest. Biogeochemistry 156:115–130. https://doi.org/10.1007/s10533-020-00747-7

SEAPA-MG (2017) Projeções do Agronegócio: Minas Gerais – 2017 a 2027. Secretaria de Agricultura, Pecuária e Abastecimento de Minas Gerais, Belo Horizonte - MG

Sediyama MAN, Magalhães IPB bosa, Vidigal SM, Pinto CLO, Cardoso DSCP, Fonseca MCM, Carvalho IPL (2016) Uso de fertilizantes orgânicos no cultivo de alface americana (Lactuca sativa L.) ‘Kaiser.’ Revista Brasileira de Agropecuária Sustentável 6. https://doi.org/10.21206/rbas.v6i2.308

Silva VP, Pereira OG, Leandro ES, Da Silva TC, Ribeiro KG, Mantovani HC, Santos SA (2016) Effects of lactic acid bacteria with bacteriocinogenic potential on the fermentation profile and chemical composition of alfalfa silage in tropical conditions. J Dairy Sci 99:1895–1902. https://doi.org/10.3168/jds.2015-9792

Silva JBG, Martinez MA, Matos AT, Pires CS, Terração G (2017) Mobilidade dos íons nitrato e amônio em área agrícola sob adubação com água residuária de bovinocultura de leite e torta de mamona. Revista Engenharia na Agricultura - Reveng 25:200–211. https://doi.org/10.13083/reveng.v25i3.678

Silva NC, Nascimento CF, Nascimento FA, de Resende FD, Daniel JLP, Siqueira GR (2018) Fermentation and aerobic stability of rehydrated corn grain silage treated with different doses of Lactobacillus buchneri or a combination of Lactobacillus plantarum and Pediococcus acidilactici. J Dairy Sci 101:4158–4167. https://doi.org/10.3168/jds.2017-13797

Silva VV (2002) Efeito do pré-cultivo de adubos verdes na produção orgânica de brócolos (Brassica oleraceae var. Itálica) em sistema de plantio direto. Dissertação (Mestrado em Fitotecnia), Universidade Federal Rural do Rio de Janeiro, Seropédica-RJ, p 80

Siqueira APP, Siqueira MFB (2013) Bokashi: adubo orgânico fermentado. Pesagro-Rio, Niterói-RJ

Souza Júnior JB (2020) Eficiência agronômica da fertilização de alface em sistema de cultivo orgânico com compostos fermentados formulados com farelos de resíduos de cervejaria e de Gliricidia sepium. Trabalho de Conclusão de Curso (Agronomia), Universidade Federal Rural do Rio de Janeiro, Seropédica-RJ, p 35

Steiner F, Echer M, Guimarães V (2012) Produção de Alface "Piraroxa" Afetada pela Adubação Nitrogenada com Fertilizante Orgânico e Mineral. Scientia Agraria Paranaensis 11:77–83. https://doi.org/10.18188/1983-1471/sap.v11n3p77-83

Taíz L, Zeiger E (2013) Fisiologia vegetal, 5th edn. Artmed, Porto Alegre-RS

Teixeira PC, Donagemma GK, Fontana A, Teixeira WG (2017) Manual de métodos de análise de solo, 3rd edn. EMBRAPA Solos, Rio de Janeiro-RJ

Tomich TR, Pereira LGR, Gonçalves LC, Tomich RGP, Borges I (2003) Características Químicas para Avaliação do Processo Fermentativo de Silagens: uma Proposta para Qualificação da Fermentação. Embrapa Pantanal, Corumbá, MS

Torres JLR, Pereira MG (2008) Dinâmica do potássio nos resíduos vegetais de plantas de cobertura no Cerrado. Rev Bras Ciênc Solo 32:1609–1618. https://doi.org/10.1590/S0100-06832008000400025

Torres JLR, Pereira MG, Andrioli I, Polidoro JC, Fabian AJ (2005) Decomposição e liberação de nitrogênio de resíduos culturais de plantas de cobertura em um solo de cerrado. Rev Bras Ciênc Solo 29:609–618. https://doi.org/10.1590/S0100-06832005000400013

Trani PE, Passos FA, Azevedo-Filho JA (2014) Alface, almeirão, chicória, escarola, rúcula e agrião d'agua. Recomendação de adubação e calagem para o estado de São Paulo. Instituto Agronômico de Campinas - IAC, Campinas-SP, pp 1–16

Varnier C, Rocha GA, Campos JE, Albuquerque Filho JL, Simonato M, Hirata R (2019) Nitrato nas águas subterrâneas: desafios frente ao panorama atual. SIMA/IG, São Paulo-SP

Vilar DA, Vilar MSA, Brandão MP, Anjos CJF, Silva AE (2019) Plantas medicinais: um guia prático, 1st edn. Editora do Ifs, Aracaju-SE

Wijayanto T, Tufaila M, Sarman AM, Zamrun MF (2016) Influence of bokashi fertilizers on soil chemical properties, soybean (Glycine max (L.) Merrill) yield components and production. WSEAS Trans Biol Biomed 13:8

Xavier MCG, Santos CA, Costa ESP, Carmo MGF (2019) Produtividade de repolho em função de doses de bokashi. Revista de agricultura neotropical 6:17–22. https://doi.org/10.32404/rean.v6i1.2372

Xu H, Wang R, Mridha AU (2000) Effects of organic fertilizers and a microbial inoculant on leaf photosynthesis and fruit yield and quality of tomato plants. J Crop Prod 3:173–182. https://doi.org/10.1300/J144v03n01_15

Yuri JE, Resende GM, Rodrigues Júnior JC, Mota JH, Souza RJ (2004) Efeito de composto orgânico sobre a produção e características comerciais de alface americana. Hortic Bras 22:127–130. https://doi.org/10.1590/S0102-05362004000100027

Yuri JE, Resende GM, Souza RJ (2016) Nutrição e adubação da cultura da alface. In: Prado RM, Cecílio Filho AB (eds) Nutrição e adubação de hortaliças. FCAV/CAPES, Jaboticabal - SP, pp 559–577