



Agroeconomic viability of grape-common bean intercropping

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Abstract

The intercropping of agricultural crops aims to increase the profitability and the sustainability of the production systems. The objective of this study was to evaluate the agroeconomic viability of the intercropping of grape with common bean grown at different planting densities and weed management. The experimental design adopted was randomized blocks in a split-plot scheme. Treatments in the plots consisted of weed managements, mowing and chemical, and, in the subplot, the intercropping of grape with 0, 4, 8 and 12 common bean plants/linear meter. Grape-common bean intercropping and weed management did not influence the performance of grape crop. Regarding the agronomic characteristics of common bean, the highest values of plant height and yield were found with 8 and 12 plants/linear meter. Plant dry mass was higher when the common bean was intercropped with 4 plants, compared to 12 plants. For the agroeconomic indicators, land use efficiency index, monetary advantage and corrected monetary advantage, the best results were found with the intercropping with 8 bean plants, while the best results for gross income and net income were found under intercropping with 12 plants. Chemical and mowing weed managements can be recommended for the grape-common bean intercropping because they are efficient and do not affect the performance of the intercropped crops. The intercropping of grape with common bean is feasible because the gross and net income increase up to the density of 12 plants of common bean/linear meter and the intercropping with 8 plants/linear meter resulted in higher values of land use efficiency and monetary advantage.

Keywords: agricultural intercropping, weed management, viticulture, common bean crop

Introduction

Intercropping cultivation demonstrates every day that it is possible to improve agricultural practices in order to make agricultural investment a sustainable practice, significantly benefiting producers of small farms, where the absolute majority has limited physical area for their crops (Vieira et al., 2014; Brito et al., 2017). Factors such as tolerance to competition for vegetative growth, time of associations, arrangements and management used and, finally, the quantity and value of the product harvested will influence the financial results of intercropped crops (Brito et al., 2018).

In the process of choosing the species to be intercropped, it is necessary to have a good capacity for interspecific combination, which consequently will lead to higher production and agroeconomic efficiency in intercropped systems (Camili et al., 2013). Thus, the intercropping of grape cv. 'Niagara Rosada' (*Vitis*

labrusca L.) with common bean (*Phaseolus vulgaris* L.) presents itself as another alternative to make grape cultivation sustainable, promoting the generation of an extra source of income and optimization of family labor, in addition to provide nutrients to the intercropping through biological nitrogen fixation.

Due to physiological and management characteristics in grape cultivation, areas below the canopy can be exploited through the intercropping with annual and/or perennial crops. The sowing of common bean intercropped with other crops is a common practice in Brazil, being carried out mainly by small farmers (Albuquerque et al., 2012). Common bean is one of the agricultural products of greatest economic and social importance, especially due to the labor employed during its cycle (IBGE, 2006).

For the producer to be successful in the implementation of an agricultural activity, it is necessary

to keep in mind that there are factors which can directly interfere in the success of the business, especially weed management. To reduce yield losses, it is necessary to develop environmentally sustainable weed management practices (Frenda et al., 2013). In vineyards, management is a practice carried out along the entire year, and the most used methods are mowing and chemical control. The easy aspect of mowing is the use of a mower only, but its difficulty is the great need for labor. The chemical method becomes more interesting due to its ease, but this method requires more rigor and knowledge about the products registered for the crop and may have greater environmental impact if performed incorrectly. It is known that incorrect weed management may result in imbalance in grapevine growth, which may lead to low yield and lower fruit quality, affecting crop profitability. It would be ideal to use an effective management method in all vineyards (Susaj et al., 2013).

The objective of this study was to evaluate the agroeconomic viability of the intercropping of grape with common beans grown at different planting densities, using different weed managements.

Material and Methods

The experiment was carried out from July/2018 to June/2019 in the "Sítio Cedro" farm, located in the municipality of Santa Teresa-ES, *Central Serrana* region of Espírito Santo, Brazil, at 20° 0' 17.4024" South latitude, 40° 34' 20.0172" West longitude, with an altitude of 806 m above the sea level. According to Köppen's classification, the climate is Cfb, characterized as a humid temperate climate with temperate summer (Alvares et al., 2013). The climatic data of the experimental period were recorded using an MX2301 Data Logger Thermo-hygrometer and a rain gauge (Figure 1).

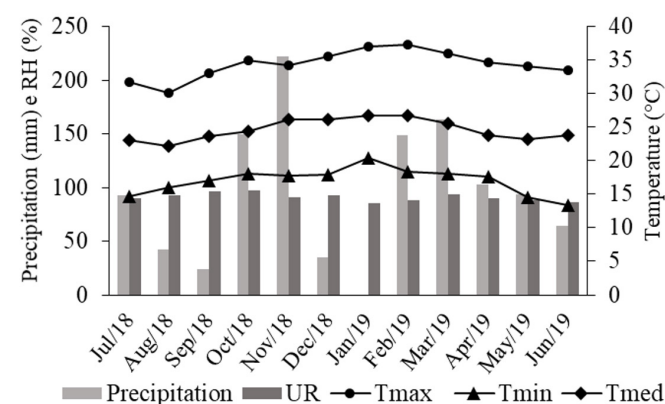


Figure 1. Precipitation (mm), maximum, minimum and average temperatures (°C) and relative humidity (%) recorded along the experiment with intercropping of 'Niagara Rosada' grape with common beans.

In the vineyard where the experiment was conducted, the grape cv. 'Niagara Rosada' is cultivated using as rootstock 'IAC 572 Jales', which is considered a table grape, trained on the trellis system, with 10 years of age and cultivated at the spacing of 3.0 m x 2.0 m. Pruning of production was carried out on August 18, 2018.

The experiment was conducted in a randomized block design (RBD), in a split-plot scheme, with four replicates. The treatments in the plots consisted of weed managements: mowing (M1) and chemical (M2), and in the subplot, the intercropping of grape with 0, 4, 8 and 12 common bean plants per linear meter, cultivated in two rows, each on each side of the grape row, spaced by 0.5 m. In the experimental units, three grape plants were considered usable.

Common bean was sown seven days after grape pruning, using two seeds per pit. The pits were distributed in two rows of 4 linear meters between grape plants, and the spacing was proportional to the number of pits used (0, 2, 4 and 6 common bean pits/linear meter). The common black bean chosen has been cultivated by local producers for several years in the region, has medium cycle and is adapted to the local conditions.

Fertilizing of both crops was carried out according to the results of soil analysis and their respective requirements, following the recommendations of the Manual of Fertilization and Liming of ES - 5th approximation (Prezzotti et al., 2007). Given the satisfactory precipitation for the development of the crops (Figure 1), irrigation was not necessary. Before the common bean sowing, weeds were manually removed from grape rows along a continuous 0.5-m-wide strip in the cultivation row. This procedure was performed in both weed managements and only in the experimental units where common bean was planted. At 25 days after sowing, the soil was piled up around common bean plants.

Two weed managements were used in the interrows: mowing and chemical. In the mowing management, a motorized mower was used to trim the weeds three days before grape pruning and at 73, 102 and 258 days after grape pruning, at approximately 5 cm from the soil. The chemical management was performed using the systemic, non-selective herbicide Crucial, from the substituted glycine chemical group, applying 1400 g of the active ingredient (a.i.) per ha⁻¹ three days before pruning and the non-selective total-action herbicide Finale, from the chemical group of substituted homoalanine, applying 280 g of a.i. ha⁻¹ at 73, 102 and 258 days after pruning. To calculate the spray volume, a backpack sprayer with constant pressure and equipped

with a Teejet DG 110.02 nozzle was calibrated to apply the equivalent of 200 L ha⁻¹ of the mixture. At the time of application at 8 a.m., the temperature was 22.4 °C, with maximum and minimum relative humidity values of 86% and 77%, respectively, and wind speed close to 1.4 m s⁻¹.

At 67 days after grape pruning, when the common bean plants were 60 days old, plant height (cm), stem diameter (mm) and plant dry mass (g) were evaluated considering the average value of 4 plants per experimental unit. Plant height was measured with a tape measure, from the base of the plant to the insertion of the last trifoliate leaf. stem diameter was measured at the base of the plant with a digital caliper. After these evaluations, the plants were uprooted, placed in paper bags, and dried in an oven with forced air circulation at 65 °C until reaching constant weight. After these procedures, the materials were weighed on an electronic scale (0.01 g precision). When common bean plants reached the harvest point (approximately 16% moisture), which occurred at 87 days after sowing, the pods were counted, threshed and weighed on a precision scale to estimate the yield (kg ha⁻¹). Then, 100 seeds were randomly selected and weighed.

From the beginning of maturation (131 days after pruning), characterized as the moment when the grapes reach maturity color, and when their soluble solid contents were higher than 14 °Brix (Neis et al., 2010, adapted), the number of bunches was counted, a digital caliper was used to measure the length and width of each bunch in a random sample of 18 bunches per experimental unit along the harvesting period. It is worth pointing out that the harvest was performed weekly, as the bunches reached the maturity stage.

After these evaluations, the bunches were collected, the berries of each bunch were counted and their lengths were measured with a digital caliper, considering 18 berries/experimental unit, six from three different parts of the bunch: lower, intermediate and upper. Each bunch was weighed on a precision scale and the value was divided by the number of bunches to obtain the average bunch weight. The production data of each experimental unit were used to calculate the yield (t ha⁻¹). To check whether the intercropping affected grape quality (and/or sugar content), the parameter Brix was measured. For this, 18 berries were collected in each experimental unit, from the lower, intermediate and upper parts of six bunches in three usable plants of each experimental unit at 131, 166 and 173 days after pruning, which corresponded to the beginning, middle and end of harvest. The samples were identified, and,

in the laboratory, they were manually crushed and their °Brix contents were measured using a Brix Refractometer.

Besides the agronomic variables evaluated in common bean and grape crops during the intercropping, the following agroeconomic indicators were evaluated: and use efficiency index (LUE), gross income (GI), net income (NI), monetary advantage (MA), corrected monetary advantage (MAc), rate of return (RR) and profitability index (P). These agroeconomic indicators used to calculate the efficiency of intercropped systems were determined according to Beltrão et al. (1984). Land use efficiency index was calculated using the expression $LUE = (Y_{ab}/Y_{aa}) + (Y_{ba}/Y_{bb})$, where Y_{ab} is the yield of crop "a" intercropped with crop "b"; Y_{ba} is the yield of crop "b" intercropped with crop "a"; Y_{aa} is the yield of crop "a" in sole-cropping and Y_{bb} is the yield of crop "b" in sole-cropping. To compare the intercropping and sole-cropping systems, an experimental area outside the vineyard was cultivated with common beans, using the same spacing and crop management adopted in the intercropping.

Gross income (GI) was calculated considering the average actual price practiced at CEASA-ES, based on the average prices of common beans in November of the years 2016-2018 and of grapes in the months of December to March 2016-2019. Net income (NI) was obtained by the difference between gross income (GI) and total production cost (TPC). Monetary advantage (MA) and corrected monetary advantage (MAc) were calculated by the expressions: $MA = GI \times (LUE - 1) / LUE$ and $MAc = NI \times (LUE - 1) / LUE$. The rate of return (RR) was calculated using the ratio between GI and TPC, expressing the amount earned per dollar (US\$) invested. The profitability index (P) was obtained from the ratio between NI and GI, expressed as percentage. The economic indicators were calculated based on TPC, which considers the effective operating cost (EOC) and the total operating cost (TOC), taking as reference the description of Matsunaga et al. (1976). In order to obtain the TPC, the values of EOC and TOC were also summed with the remuneration of the fixed capital (investment) that was estimated at 6% per year, based on the average savings of the last 4 years (2016 to 2019), while the remuneration of the land was based on the regional lease price, which was US\$ 343.94/ha/year. Costs were calculated based on the average prices for the period from July/2018 to June/2019 collected in the region.

The evaluated variables were subjected to the tests of normality (Lilliefors and Shapiro-Wilk) and homoscedasticity (Bartlett and Levene), requirements

for validating the analysis of variance. After meeting the assumptions, the data were subjected to analysis of variance, considering the main effects and their interaction in the plot and subplot, respectively. The variables were significantly affected by the single factors and no variable was significantly affected by the interaction. Therefore, for the comparison between weed managements (mowing and chemical), the analysis of variance (F test) was already conclusive because they are only two levels. For the subplot factor (number of common bean plants/linear meter), in case of significant effect, its degrees of freedom were decomposed in orthogonal polynomial regression for the variables evaluated in the grape crop and the agroeconomic indicators. For the variables evaluated in common bean crop, as there were only three levels (4, 8 and 12 common bean plants/linear meter), the means were compared by

the Bonferroni t-test (protected LSD). All analyses were performed with R software, version 3.6.2, adopting an "a" of up to 0.05 (R Core Team, 2019).

Results and Discussion

The grape-common bean intercropping and weed management did not significantly influence grape performance, as can be observed in most of the variables (Table 1). The number of bunches, bunch length, bunch width, Brix, number of berries per bunch, berry length and yield of 'Niagara Rosada' grape were not significantly affected by the single factors in the plot (weed management) and in the subplot (number of common bean plants/linear meter), and there was no significant effect of the interaction, evidenced by the p-values above 0.05 (Table 1).

Table 1. Mean values of the number of bunches, bunch length, bunch width, Brix, number of berries per bunch, berry length and yield of 'Niagara Rosada' grape as a function of weed management and different densities of the common bean grown in intercropping.

Variables	Mowing				Chemical				CV (%)	CV (%)	p-value ¹	p-value ²	p-value ³
	Densities				Densities								
	0	4	8	12	0	4	8	12					
N° of bunches plant ⁻¹	33.76	33.48	33.25	32.94	33.43	33.43	33.60	33.86	3.12	3.93	0.5944	0.9909	0.7951
Bunch length (cm)	11.92	11.69	11.80	11.48	11.09	11.99	11.04	11.72	6.42	5.7	0.3909	0.6323	0.1971
Bunch width (cm)	5.78	5.68	5.34	5.55	5.62	5.70	5.40	5.66	4.02	6.31	0.9193	0.2452	0.8792
°Brix	14.32	14.33	14.29	14.45	14.13	14.54	14.22	14.23	1.06	1.6	0.3026	0.2755	0.2652
N° of berries bunch ⁻¹	48.73	49.96	49.37	52.91	49.98	48.37	48.22	49.15	4.28	4.37	0.1791	0.2080	0.1840
Berry length (cm)	2.15	2.14	2.15	2.11	2.16	2.15	2.19	2.14	3.49	1.89	0.4585	0.1524	0.8121
Berry weight (g)	5.68	5.61	5.67	5.69	5.66	5.63	5.68	5.68	1.92	1.47	0.9761	0.3969	0.9689
Yield (t ha ⁻¹)	15.18	15.16	15.53	15.42	15.14	15.09	15.39	15.23	2.64	2.69	0.4876	0.3641	0.9852

¹Significance for the comparison of treatments in the plot (chemical and mowing); ²Significance for the comparison of treatments in the subplot (0, 4, 8 and 12 common bean plant/linear meter); ³Significance for the interaction between weed control methods (chemical and mowing) and intercropping (0, 4, 8 and 12 common bean plant/linear meter).

Grape vineyards already established and in production exhibit the characteristics of a rustic plant. Thus, if weed management is correctly performed in the vineyard, it does not affect plant development, whether mowing or chemical. For grape growers, these results provide relevant information regarding weed management, since the producer can perform the management using either the mowing method or the chemical method, or even alternating them, performing a more sustainable weed management in the vineyard.

For apple (*Malus domestica*), weed desiccation or mowing did not affect the yield and growth of plants, changing only the concentrations of nutrients in leaves and soil (Oliveira et al., 2016). In grape cultivation, after evaluating for three years an intercropping with three cover crops: spontaneous vegetation, black oat (*Avena strigosa* Schreb) and intercropping of white clover (*Trifolium repens* L.) + red clover (*Trifolium pratense* L.) + ryegrass (*Lolium multiflorum* L.), Rosa et al. (2013)

observed that the physical properties of the soil in the grape rows were similar to those of the native forest, indicating a good structural quality of the soil. In addition to these results, the post-emergence control of weeds in the management by mowing, chemical herbicides or green manure can be proposed to reduce the impact on the soil and promote the growth of a diversified and balanced flora, which, if managed properly, can provide potential ecological services, without competing with the orchard (Fracchiolla et al., 2016).

It is important to point out that the adoption of chemical control (using herbicide) in intercropping requires careful planning, as this should be recommended for the two crops that are being intercropped, a situation that often becomes a limiting factor for some crops that do not have such a large diversity of registered herbicides. For weed management by mowing, the advantage is that this technique can be adopted in any intercropping. The difficulty for grape growers is related to the availability of

labor, which is often scarce, so chemical management is adopted due to its ease.

A study with management using herbicides with different active ingredients, applying flazasulfuron, glufosinate and glyphosate, reported a 53% decrease in grape mycorrhization (Zaller et al., 2018). According to these authors, this harmful effect was not related to the three different active ingredients investigated, suggesting that non-target effects on grape physiology or adjuvants mixed in herbicide formulations may be responsible for this effect. A better understanding of the side effects of different weed control methods in the grape ecosystem would help develop more ecologically correct management practices in grape cultivation (Likar et al., 2017).

As for the intercropping, it is observed that grape can be intercropped with up to 12 common bean

plants per linear meter with no losses in its production characteristics (Table 1). In small farms, intercropping is more used to reduce production costs (Teixeira et al., 2011). Additionally, it promotes better use of land, water and nutrients by plants and improves profitability. Moreover, common bean straw can return to the vineyard, serving as supply of nutrients and organic matter for grape plants.

According to Table 2, there were changes in soil characteristics six months after the return of common bean straw to the vineyard. However, these same results were also found when grapes were cultivated in sole cropping. It is believed that the increase in nutrient contents was not caused by the straw that was returned to the vineyard, but rather due to the application of organic matter and fertilization along grape cultivation.

Table 2. Soil characteristics, in the 0-20 cm depth layer, sampled before common bean planting (B) and six months after its straw was returned to the soil (A).

Elements	Unit	Mowing				Chemical			
		B0/A0	B4/A4	B8/A8	B12/A12	B0/A0	B4/A4	B8/A8	B12/A12
Phosphorus - Mehlich	mg/dm ³	60/192	127/139	32/113	52/131	46/203	91/146	23/209	73/153
Potassium (K)	mg/dm ³	59/240	130/140	74/140	120/190	63/250	110/110	64/120	73/160
Sulfur (S)	mg/dm	14/12	18/13	18/11	19/11	17/16	16/7	17/19	20/15
Calcium (Ca)	cmol _c /dm ³	2.5/7.3	4/6.5	3.6/4.6	4.6/6.5	5.6/7.3	4.4/7.3	4.3/7.9	4.0/6.1
Magnesium (Mg)	cmol _c /dm ³	0.3/1.1	0.8/0.8	0.6/0.7	0.7/0.7	0.9/1.2	0.8/0.8	0.8/1.1	0.8/1.1
Aluminum (Al)	cmol _c /dm ³	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
H+Al	cmol _c /dm ³	4.2/2.2	2.2/3.4	3.8/3.8	2.5/2.5	2.8/2.6	2.8/2.5	2.8/1.7	2.2/2
pH in H ₂ O	-	5.8/6.9	6.5/6.5	6/6.3	6.5/6.6	6.5/6.8	6.4/6.7	6.5/7.2	6.6/6.8
Organic matter	dag/kg	5.3/3.7	3.3/4.1	5.1/4.7	4.6/3.7	4.7/5.8	4.9/6.4	3.5/5.4	3.5/3.7
Iron (Fe)	mg/dm ³	383/106	228/125	287/162	234/173	299/66	296/90	422/36	302/130
Zinc (Zn)	mg/dm ³	3.8/8.4	12/8	5.5/13	6.5/14	7.8/11	8.3/6.8	4.6/22	7.7/16
Copper (Cu)	mg/dm ³	2.3/2.9	2.9/1.7	2.6/1.8	1.8/2.5	2.0/2.1	2.6/1.5	1.9/1.8	1.4/1.9
Manganese (Mn)	mg/dm ³	95/68	43/41	26/44	32/52	38/66	45/52	46/69	42/55
Boron (B)	mg/dm ³	1/0.9	1.2/0.8	1.1/0.9	0.7/0.9	0.76/1	0.78/0.9	0.95/1	1.01/0.8
Sodium (Na)	mg/dm ³	5/29	17/18	11/16	7/16	7.0/48	11.0/19	5.0/56	14.0/18
CEC at pH 7.0 (T)	cmol _c /dm ³	7.2/11	7.4/11	8.2/9.5	8.1/10	9.5/12	8.3/11	8.1/11	7.2/9.7
Base saturation	%	41/81	70/70	54/60	69/76	70.5/78	66.4/77	65.4/85	69.6/79

B - Analysis carried out on 06/12/2018 - FULIN Laboratório de Análise Agronômica LTDA; A - Analysis carried out on 06/12/2019 - FULIN Laboratório de Análise Agronômica LTDA.

The C/N ratio of common bean straw is 32/1, so a period of at least 90 days is required for most straw to decompose and mineralize (Oliveira et al., 2013). Thus, it is believed that the nutrients will be made available in the next grape cycles and may reduce the costs of fertilization and organic matter application, compared to the sole-cropping. In a study with maize, the highest values of dry mass accumulation in leaves, stem, ears and total, as well as the highest values of leaf area and grain yield, were obtained when maize was cultivated on common bean straw (Oliveira et al., 2013).

Although weed management did not influence most grape variables, it was observed that the management by mowing resulted in heavier bunches (Figure 2).

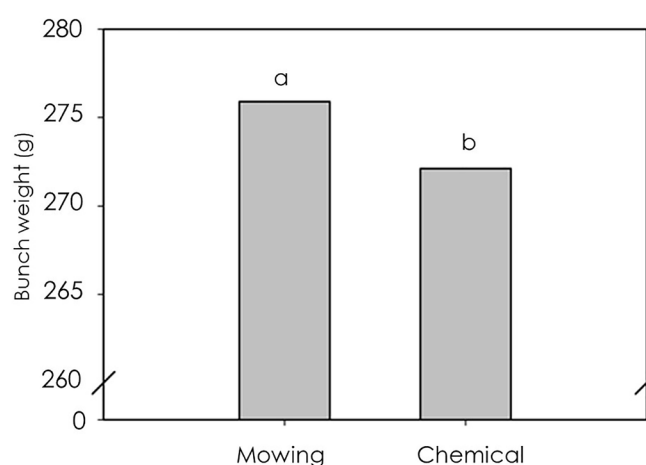


Figure 2. Bunch fresh weight as a function of weed management in the grape-common bean intercropping. Means followed by the same letters do not differ by Fischer's F test at 5% probability level.

In relation to the intercropping, the results show that there was no influence of common bean cultivation on bunch weight and on the other variables evaluated in grape plants. These results have already been found by other authors, who reported that the intercropping of grape with cover crops does not influence its morphological variables, associated with yield and qualitative characteristics (Campos et al., 2017). What is observed is that, in some cases, depending on the type of intercropped plant, there may be a positive relationship for grape yield. The intercropping of grape with cover crops showed not to affect grape yield, but in the following season the intercropping with annual crops increased grape yield by 20 and 35% compared to the sole-cropping (Zalamena et al., 2013). The results showed that weed management by mowing led to higher values of bunch weight compared to the chemical method. These results may be associated with the reduction of mycorrhizae in the vineyard due to herbicide application in the chemical treatment (Zaller et al., 2018). This is because the reduction in mycorrhization promotes decreases the absorption of nutrients and water by grape plants, which may affect their production structures and lead to changes in bunch weight.

Although the effects of fungicides and/or insecticides on soil organisms in vineyards are known (Paoletti et al., 1998), knowledge about the impacts caused by herbicides is still incipient (Stellin et al., 2018). Mowing management promotes some benefits, especially the reduction of erosion through the preservation of organic matter with the gradual release of macro and micronutrients, improves soil physical structure, promotes greater water retention, and increases microbial activity. In the same way, it is observed that the management of weeds with mowing, in substitution to weeding provides less soil losses (Carvalho et al., 2007; Paula et al., 2013).

It is necessary to highlight that, in addition to the different managements (chemical and mowing), the planting of common beans was also introduced, hence returning the straw, which in the medium and long term can contribute to improving the level of soil organic matter, promoting edaphic and/or agronomic gains. Thus, further research is needed to deepen the studies on the impacts of different types of management, whether chemical, mowing or with introduction of legume and/or grass crops, promoting knowledge aimed at a more sustainable management.

As for the variables related to the agronomic characteristics of common bean, there were differences caused by the single factor number of common bean

plants/linear meter in the subplot (Figure 3). For the weed management factor in the plot and for the interaction between weed management and intercropping, no significant effect was observed ($P < 0.05$). For plant height (Figure 3A) and yield (Figure 3F), higher values were found with 8 and 12 common bean plants/linear meter compared to 4 plants/linear meter ($P < 0.05$). Stem diameter (Figure 3B) was not influenced by the density of common bean plants/linear meter ($P < 0.05$). Plant dry mass (Figure 3C) was higher in the intercropping with 4 common bean plants/linear meter compared to 12 plants/linear meter and both treatments were like 8 plants/linear meter ($P < 0.05$). Higher values of number of pods (Figure 3D) were found with 4 common bean plants/linear meter ($P < 0.05$). For 100-seed weight (Figure 3E), higher values were found with 4 and 8 plants/linear meter in comparison to 12 plants/linear meter ($P < 0.05$).

The higher values of plant height (Figure 3A) found in bean plants in the intercropping with 8 and 12 plants/linear meter are possibly associated with the competition for light that occurs as plant density increased. Increments in plant density increases the intraspecific competition for solar radiation, causing etiolation (Leolato et al., 2017). High plant density causes a high self-shading of the leaves, resulting in higher average plant height due to etiolation, which reduces the quality of the marketable product and the average number of leaves per plant (Almeida et al., 2019). What is observed is that, in this case, there may be an allocation of photoassimilates for the growth of the shoots, compared to the roots, favoring the search for light (Taiz et al., 2017)

In sole-cropping, 10-15 common bean plants/linear meter are recommended. The present study proposed an analysis with different densities of common beans plants (4, 8 and 12 plants/linear meter), due to the particular environment conditions within the vineyard, because it was predicted that there would be a gradual reduction of light intensity caused by the growth of the grapevine canopy. In bean plants with erect growth habit under different population densities, the highest grain yield was obtained with spacing between rows of 0.3 m and plant density of 8 plants/linear meter, indicating that the increase in plant population did not result in higher grain yield per area (Shimada et al., 2000).

More spaced bean plants tend to invest more in their development because there is less competition for water, light and nutrients. These results can be observed in Figures 3C and 3D, where in the intercropping of common bean with grape at the density of 4 plants/linear meter the plant invested in greater dry mass accumulation and

number of pods compared to treatments with higher densities. Research with sorghum showed that the leaf dry mass accumulation per plant was higher at the lowest densities (Terra et al., 2010). In common bean, the increase in plant population resulted in a reduction in dry mass, number of pods per plant, number of grains per pod, 100-grain weight, and grain yield (Mondo & Nascente, 2018).

At higher densities, shading reduces the overall efficiency of light interception, which can reduce the accumulation of photoassimilates by plants (Coelho et

al., 2014). Population density and plant arrangement are relevant factors for crop yield (Brito, 2017). In a study conducted with cowpea (*Vigna unguiculata* (L.) Walp.) subjected to different levels of shading, it was observed that the variety 'BRS Acauã' showed an increase in dry mass as shading increased up to 50%, and a reduction when subjected to light restriction of 70% (Coelho et al., 2014). With these results it is possible to infer that there is an optimal point of shading which leads to full development of agricultural crops and promotes higher yield.

At higher density (12 plants/linear meter),

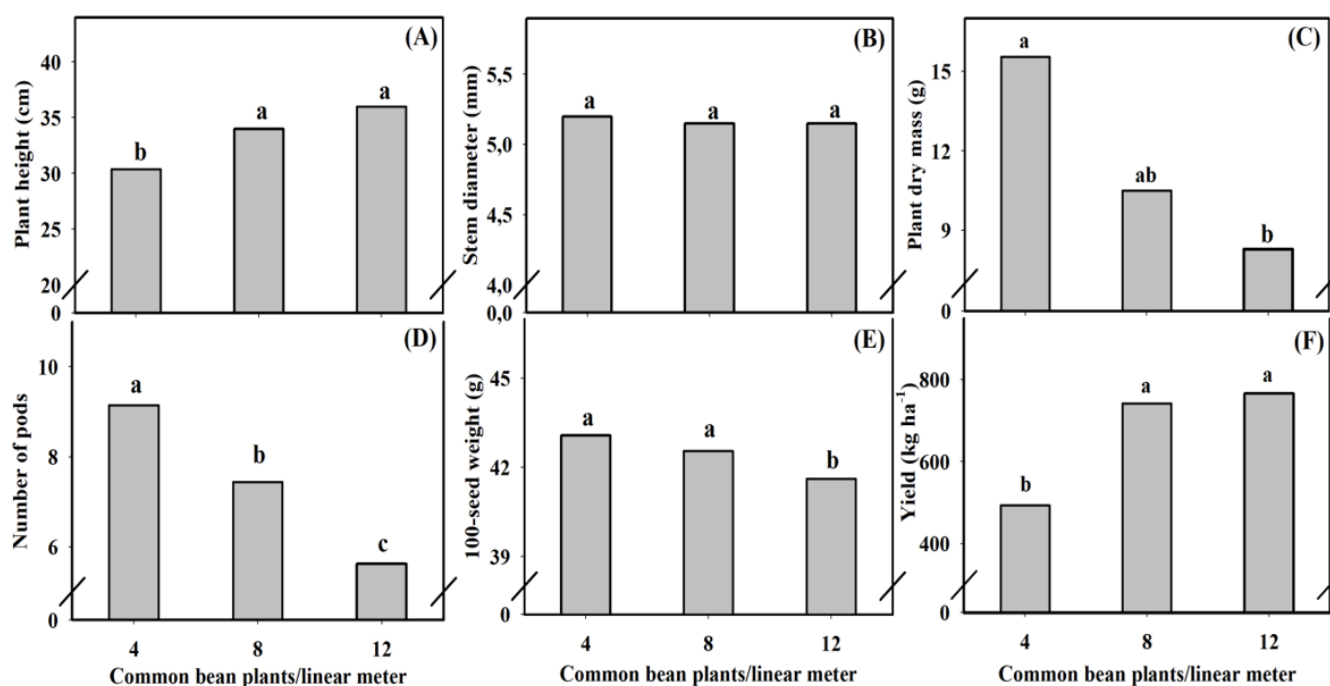


Figure 3. Plant height (A), stem diameter (B), plant dry mass (C), number of pods (D), 100-seed weight (E) and yield (F) of common bean as a function of the number of common bean plants per linear meter in the intercropping with grape. Means followed by the same letters do not differ by the Bonferroni t-test (protected LSD) at 5% probability level.

this competition caused less accumulation of photoassimilates in the grains, resulting in a lower 100-seed weight (Figure 3E). Corroborating these results, Morais et al. (2001) evaluated different spacings in common beans and observed that the decrease in interrow spacing increases grain yield. A study on the shading tolerance of moth bean (*Vigna aconitifolia*) intercropped with two species of tropical legume crops showed that shading reduced almost all growth characteristics, except plant height (Chiangmai et al., 2013). These results corroborate those found in the present study, as shown in Figure 3. In extensive plantations with large plant populations, the shading of lower leaves leads to a reduction in crop yield, due to the lower amount of solar radiation they receive (Rocha, 2008; Taiz & Zeiger, 2013).

There was an increase of yield when the density increased from 4 to 8 plants/linear meter, but there was

no increase from 8 to 12 plants/linear meter, indicating that higher densities can be a limiting factor to achieve high yields, due to competition for production factors: water, nutrients and light.

It should be emphasized that common bean was planted seven days after grape pruning and, during its whole process of growth and development, the grapevine canopy also grew, which in turn decreases light intensity under the common bean canopy, a factor that may have affected the plants grown at higher density/linear meter. This competition seems to have generated lower accumulation of photoassimilates, directly affecting the dry mass of the common bean plant (Figure 3C). This indicates that there must be a balance between vegetative growth and production performance.

These results demonstrate the importance of evaluating plant density in the grape-common bean

intercropping, because lower densities (4 plants/linear meter) promote better vegetative development of common bean and higher densities (8 and 12 plants/linear meter) result in higher yield. If only these results were analyzed, the most interesting density for grape growers would be 8 plants/linear meter as it promotes higher yield than 4 plants/linear meter and uses a smaller number of seeds than 12 plants/linear meter. However, it is necessary to evaluate which density would be more interesting from the agroeconomic point of view and, to solve these doubts, the evaluation of agroeconomic

indicators is essential.

For the agroeconomic indicators evaluated, a significant effect was caused by the number of plants/linear meter in the subplot, with no effect of weed management or interaction ($P < 0.05$). The variables land use efficiency index, monetary advantage and corrected monetary advantage, Figures 4A, 4D and 4E, showed a quadratic behavior in the regression analysis, while gross income and net income, Figures 4B and 4C, showed a linear behavior.

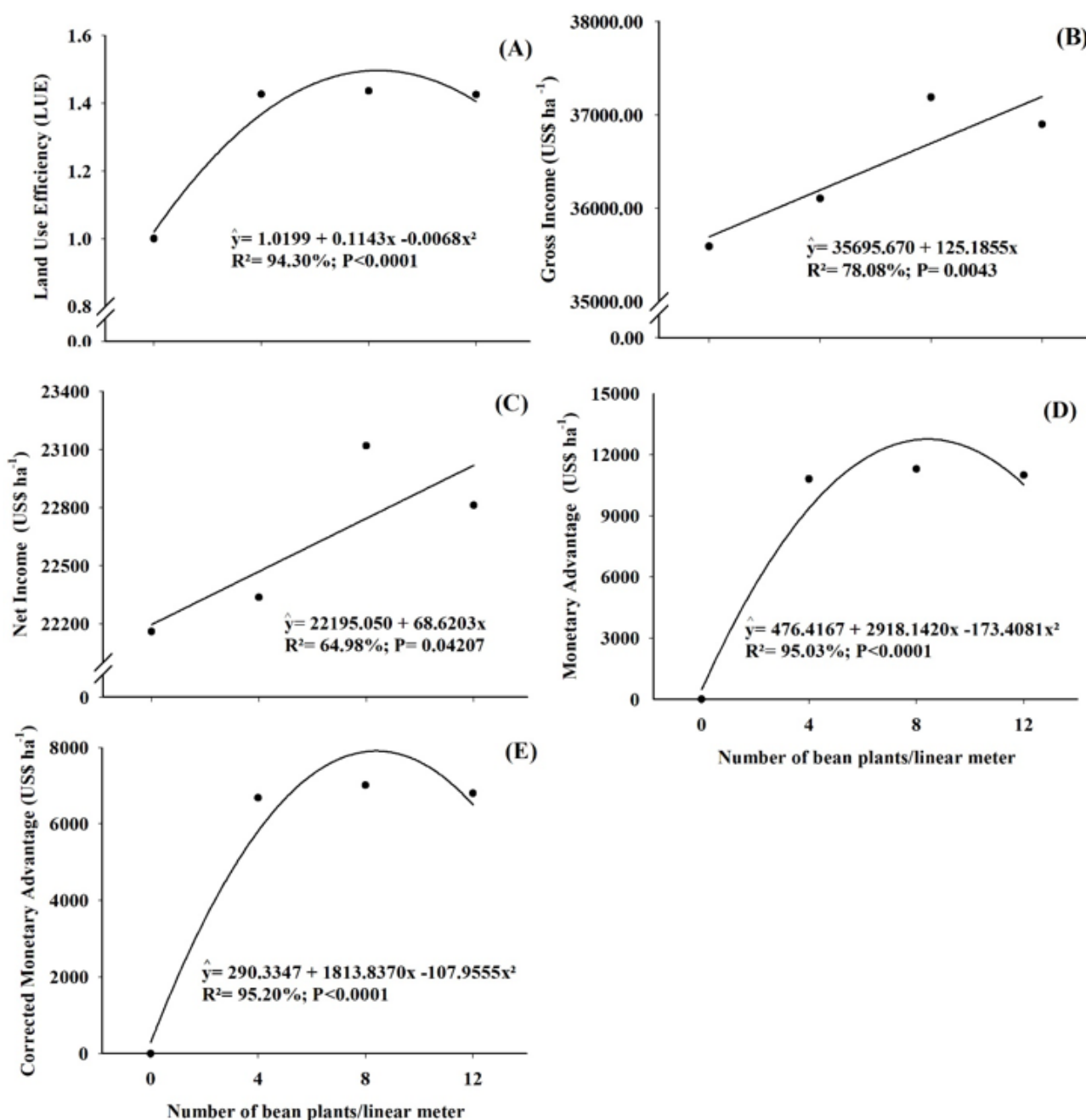


Figure 4. Agroeconomic indicators: Land Use Efficiency (A), Gross Income (B), Net Income (C), Monetary Advantage (D) and Corrected Monetary Advantage (E) as a function of the number of common bean plants per linear meter in grape-common bean intercropping.

For land use efficiency index, the highest result (1.5) was found in the intercropping with 8.4 common bean plants/linear meter (Figure 4A). Knowing the value of LUE is important because it determines the relative area of land, under sole-cropping conditions, that is required to promote the yields achieved in the intercropping (Colombo et al., 2018). Therefore, calculating this index becomes crucial because, if the value is below 1.0 it becomes unfeasible to invest in the intercropping. It is important to emphasize that the farmer should not rely only on the evaluation of LUE for decision-making regarding the choice of species in the intercropping system, because this is an index that evaluates only the yield of the systems (intercropping and sole-cropping), not taking into account the production costs that in turn are directly linked to the economic indicators which also serve to determine the viability of the systems.

According to Figures 4B and 4C, the intercropping with 12 plants per linear meter promoted the highest values of gross income (US\$ 37197.90/ha) and net income (US\$ 23018.50/ha). Comparatively, net income is shown to be a more relevant index than gross income (Beltrão et al., 1984). However, considering the net income value

as a determinant factor for choosing the best density of common bean plants in intercropping with grape can be a very superficial analysis, because there are other economic indicators such as MA and MAC, which consider not only the values of net income, but also the production efficiency through LUE.

The indicators monetary advantage and corrected monetary advantage are extremely important because they analyze if there is agronomic superiority in the intercropping systems (Colombo et al. 2018). The best results for monetary advantage (Figure 4D) and corrected monetary advantage (Figure 4E) were found in the intercropping with 8.4 common bean plants/linear meter, which resulted in values of US\$ 12753.13 and US\$ 7909.23, respectively. On the other hand, the lowest values were found in the sole-cropping of grape, probably because it did not benefit from the agroeconomic advantages promoted by the intercropping.

When intercropped with grape, the cultivation of common beans using 8 to 12 plants per linear meter leads to the highest values of agroeconomic indicators, demonstrating that this is an interesting density to be used in this type of intercropping.

Table 3. Mean values of agroeconomic indicators: rate of return (RR) and profitability index (P) as a function of the number of common bean plants per linear meter in the intercropping with grape.

Evaluated variables	Mowing				Chemical				CV (%)	CV (%)	p-value ¹	p-value ²	p-value ³
	0	4	8	12	0	4	8	12					
RR (US\$/US\$)	2.64	2.62	2.64	2.62	2.65	2.63	2.64	2.62	1.41	1.41	0.6977	0.2953	0.9926
P (%)	62.17	61.75	62.16	61.81	62.32	61.91	62.17	61.84	0.86	0.87	0.6656	0.2960	0.9892

¹Significance for the comparison of treatments in the plot (chemical and mowing); ²Significance for the comparison of treatments in the subplot (0, 4, 8 and 12 common bean plant/linear meter); ³Significance for the interaction between weed control methods (chemical and mowing) and intercropping (0, 4, 8 and 12 common bean plant/linear meter).

For the economic indicators rate of return and profitability index, there was no significant effect of the single factors in the plot and in the subplot or of the interaction ($P < 0.05$). Therefore, the means of each treatment were presented in Table 3.

Grape yield did not differ significantly between treatments (Table 1), but was much higher compared to that of the common bean crop, and these factors directly reflect the monetary values that serve as the basis for the calculation of RR and P. Thus, as the monetary values of GI and NI obtained by the common bean crop at different densities are very low in the formation of indices when intercropped, they are not relevant to promote significant difference between treatments for RR and P.

As can be observed, there were no significant differences for economic indicators related to management factors (chemical and mowing), only for treatments related to the densities of 4, 8 and 12 plants/

linear meter. This result is explained because, as the common bean density increased, the yield and costs also increased, and these factors are directly linked to the agroeconomic indicators, leading to differences between treatments (Figure 4). In the case of the intercropping of grapes with common beans, the time of grape pruning and the sowing time and density of common bean are decisive to obtain satisfactory results, especially of the secondary crop (common beans).

In the intercropping, common bean plants do not affect the development of the grape crop. Under the conditions in which the experiment was carried out, with common bean sown seven days after grape pruning, it was observed that the grape crop also did not compromise the development of common bean, which obtained satisfactory yield, as can be observed by the LUE values.

The highest crop yields were obtained in the intercropping as the LUE values were higher than 1,

demonstrating that in the intercropping at all densities there was better use of the available environmental factors compared to the sole-cropping system, leading to the highest values of gross income, net income and monetary advantage.

Conclusions

Mowing and chemical weed managements can be recommended for the grape-common bean intercropping because they are efficient and do not affect the performance of intercropped crops.

The intercropping of grape cv. 'Niagara Rosada' with common bean is feasible because the gross and net income increase up to the density of 12 common bean plants per linear meter and the intercropping with 8 plants per linear meter results in higher values of land use efficiency and monetary advantage.

ACKNOWLEDGMENTS

To the State University of Norte Fluminense Darcy Ribeiro - UENF, for the great opportunity for research and knowledge acquired; to the Federal Institute of Espírito Santo - IFES, for providing the necessary conditions to carry out this research; to the producer Teodoro Henrique Barth, for having given up his vineyard area to carry out the experimente. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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