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Productivity of coffee and legumes intercropped under different sun exposure face

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Abstract

In mountainous regions, the amount of time that the land is exposed to the sun is one of the factors that influence the productive potential of legumes. The aim of our study was to evaluate, for two different terrain aspects under sun exposure faces, the production of green and dry matter, as well as the nutrient accumulation in the aerial part of legumes and the coffee productivity. The northwest-facing terrain is at 950 m altitude, the average annual temperature is 18.0 °C, the average rainfall is 1320 mm and the average daily solar exposure is 9.1 h. The south-facing terrain is at 690 m altitude, the average annual temperature is 14.0 °C, the average rainfall is 1277 mm and the average daily solar exposure is 6.8 h.The main soil of both terrains are a clayey dystrophic Red-Yellow Oxisol. The experimental design was inrandomized blocks with a 2 x 8 factorial scheme (two different terrain aspects and 8 types of green manure), and four replications were performed.On the northwest-facing terrain, *D. lablab*, *C. spectabilis*, and *S. deeringianum* had the highest amount of dry matter (3.31, 2.98, and 2.85 Mg ha^{-1}, respectively) and nitrogen accumulation (111.54, 91.83, and 91.51 kg ha^{-1}, respectively).The most promising legumes on the south-facing terrain (lower altitude, lower temperature, and lower incidence of light) for dry matter productions were *C. spectabilis* (3.45 Mg ha^{-1}) and *S. deeringianum* (3.30 Mg ha^{-1}). *C. spectabilis* obtained 106.03, 10.36, and 50.42 kg ha^{-1} of N, P, and K, respectively; while *S. deeringianum* accumulated 89.98, 8.10, and 52.54 kg ha^{-1} of N, P, and K, respectively. The use of *C. cajan*, *C. spectabilis*, and *S.deeringianum* resulted in greater coffee productivity on the south-facing terrain than on the northwest-facing terrain.

Keywords: coffee cultivation, family farming, green manure, mulching.
Abbreviations: Ca_calcium;Mg_magnesium; N_nitrogen;P_phosphorous;K_potassium.FAPEMIG- Fundação de Amparo à Pesquisa do Estado de Minas Gerais; CAPES- Coordenação de Aperfeiçoamento de Pessoal de Nível Superior; CNPQ- Conselho Nacional de Desenvolvimento Científico e Tecnológico, FAPES- Fundação de Amparo a Pesquisa e Inovação do Estado do Espírito Santo.

Introduction

The Zona da Mata region located in the Atlantic Forest biome is one of the centers of Arabica coffee production in Minas Gerais state, Brazil (Fig 1). The region is characterized by hilly landscapes ranging from undulating to mountainous, as well as highly weathered and acidic soils (Coelho et al., 2013; Matos et al., 2011; Nunes et al., 2010). In these landscape conditions, many coffee fields have advanced hydric erosion that results in losses of soil, water, organic matter, and nutrients, which in turn leads to low coffee productivity (Franco et al., 2002). Research done in relation to coffee in the Zona da Mata region shows that conventional management, without conservation practices, induces losses in the chemical, physical, and biological soil quality (Nunes et al., 2010; Nunes et al., 2009; Perez et al., 2004; Franco et al., 2002; Mendonça et al., 2001). Due to the high level of soil degradation, practices such as green manuring have started to be used by family farmers in order to overcome soil erosion and improve soil fertility in the region (Coelho et al., 2013). The increase in biodiversity of plants with legumes helps to control erosion, increases nutrient cycling, maintains or increases the quantity and quality of soil organic matter (Vaidya and Bhattarai, 2014; Aguiar et al., 2010) and provides a source of nitrogen (N) for coffee, thus reducing the amount of mineral N that needs to be added to the soil (Coelho et al., 2013;Egodawatta et al., 2012;Matos et al., 2008). Factors such as the choice of green manure species, management of biomass, planting and cutting time, dwelling time of the residues in the soil, and local conditions and their interactions will have an influence on the production of above-ground biomass, the level of nutrient accumulation in the system, and the nutrition of commercial crops (Souza and Guimarães, 2013; Matos et al., 2008; Fontanétti et al., 2006). Another factor that should be observed when choosing the green manure in locations with hilly landscapes is the sun exposure face. This is an important characteristic in determining the above-ground production of biomass and nutritional inputs, and also in the study of the dynamics of organic residues decomposition (Matos et al, 2011; Matos et al., 2008). In the southern hemisphere, the sun's trajectory experiences declination to the north, which results in lower irradiation on south-facing terrain and a consequent decrease in temperature and increase in soil moisture (Coelho et al., 2013; Ferreira et al., 2005). Contrasting results regarding biomass production, decomposition rate, and the release of nutrients into the soil by leguminous species in areas with different soil and weather conditionswere reported by Matos et al. (2008). The results were attributed mainly to the differences in each area's temperature, altitude, and sun exposure.Soil chemistry characteristics and humus chemistry can also be affect by land face exposure (Egli et al., 2009 and Zanelli et al., 2006). The effect of green manure incorporating legumes, as well as its contribution to the productivity of short-cycle commercial crops, has been described in Souza et al. (2015), Silva et al. (2013), Solino et al. (2010), Silva and Menezes (2007), Fontanétti et al. (2006), and Oliveira et al. (2003), however, the average time that the crops were exposed to the sun was not mentioned. This is also the case for studies related to coffee. The research onthe use of green manure with this crop does not mention the aspect of the terrain on which the coffee has been planted and, consequently, there is no information about the average amount of time the plants are exposed to the sun. In long-term cropping systems such as coffee, obtaining information about the amount of sun exposure is important for determining the green manure yield and its contribution to the coffee productivity. The aim of this study was to evaluate, under two environmental conditions with different terrain aspects, the impact of legumes intercropped with coffee on the accumulation of nutrientsin the above-ground legumes and coffee productivity of family farmers from the Zona da Mata region, Minas Gerais state, Brazil.

Results

Green and dry matter of green manures

The statistical analysis showed interaction ($p < 0.05$) between the terrain aspect and green manure used, for all the variables analyzed (Table 1).On the northwest-facing terrain, the legumes *D. lablab*, *C. spectabilis*, and *S. deeringianum* had the highest average values for green matter, with14.39, 12.42, and 12.40 Mg ha^{-1}, respectively. On the south-facing terrain, the species with the highest production of green matter were *C. spectabilis* (14.39 Mg ha^{-1}), *S. deeringianum* (12.15 Mg ha^{-1}), and *S. guianensis* (11.84 Mg ha^{-1}). The green matter production of *A. pintoi*, *C. cajan*, *S. deeringianum*, and the spontaneous plants did not differ for the two different terrain aspects. *C. mucunoides* and *D. lablab* had higher green matter production on the northwest-facing terrain, while *S. guianensis* was superior on the south-facing terrain. For the dry matter, the legumes *D. lablab*, *C. spectabilis*, and *S. deeringianum* had the highest average values, with 3.31, 2.98, and 2.85 Mg ha^{-1}, respectively, on the northwest-facing terrain (Fig 2). For the south-facing terrain, *C. spectabilis* (3.45 Mg ha^{-1}) and *S. deeringianum* (2.79 Mg ha^{-1}) had the highest production of dry matter. On the northwest-facing terrain, *C. mucunoides* and *D. lablab*had an average increase in dry matter of 38 and 55%, respectively, compared to that obtained on the south-facing terrain. On the other hand, *S. guianensis* obtained 31 % higher average production of dry matter on the south-facing terrain when compared to the northwest-facing terrain.

Accumulation of nutrients in green manures

Due to the larger amount of dry matter and N content in the *D. lablab* (33.7 g kg^{-1}of N), *S. deeringianum* (32.2 g kg^{-1}of N), and *C. spectabilis* (30.7 g kg^{-1}of N) grown on the northwest-facing terrain, these legumes accumulated 111.54, 91.83, and 91.51 kg ha^{-1}of N, respectively (Fig 3). These legumes also accumulated the most P content when compared to the other green manures. The D. lablab had the highest K concentration (21.6 g kg^{-1}) among the legumes used in this experiment and, consequently, it accumulated the greatest amount of this nutrient (71.49 kg ha^{-1} K) overall. The largest accumulation of Ca occurred with *D. lablab*, while the largest accumulation of Mg was with *C. spectabilis*, *D. lablab*, *S. deeringianum*, and the spontaneous green manures. For the south-facing terrain, the most promising legume for N and P accumulation into the system was *C. spectabilis* (Fig 3). In terms of highest accumulation of nutrients, *C. spectabilis* and *S. deeringianum* presented the highest contribution of K; *C. spectabilis*, *S. deeringianum*, and *S. guianensis* presented the highest contribution of Ca; and *C. spectabilis* was the best for Mg.

Coffee productivity

For the productivity of the coffee plants, there were significant differences between the green manurespecies for each terrain aspect (Table 2). Coffee had lower productivity when manuring with the spontaneous plants as opposed to the legumes. For the northwest-facing terrain, when compared to the spontaneous plants, coffee had higher yields with the legumes *D. lablab* (2460 kg ha^{-1}), *S. deeringianum* (2340 kg ha^{-1}), and *A. pintoi* (2280 kg ha^{-1}) - 78, 70, and 65 % higher, respectively. For the south-facing terrain, the highest coffee productivities were obtained with *S. deeringianum* (2700 kg ha^{-1}) and *C. cajan* (2880 kg ha^{-1}) - 87 and 100 % higher, respectively, in comparison with the spontaneous plants. Differences for each legume in accordance with the different terrain aspects ($p < 0.05$) were also observed (Table 2). The coffee productivities in the treatments with *C. cajan*, *S.deeringianum* and *C. spectabilis* were higher on the south-facing terrain than the northwest-facing terrain, while the opposite occurred when using *A. pintoi*.

Discussion

The difference between the green and dry matter of the legumes is due to the specific nature of each species, as well as the soil and climatic conditions of the sites studied. The short-cycle legumes *C. spectabilis*, *S. deeringianum*, and *D. lablab* were on average faster growing, thus reducing the period of competition for light, which favored greater production of green and dry matter compared to the perennial legumes *A. pintoi* and *C. mucunoides*. The productive potential of these legumes in a short time period shows that they are adapted to the environmental conditions of the locations and thus could be considered to have potential for cultivation in the mountainous region of Atlantic Forest biome (Perin et al., 2004). As in this present study, Matos et al. (2008) identified lower production of dry matter for *A. pintoi* among the legumes they studied. *A. pintoi* requires a long time for initial growth. However, it is perennial and stoloniferous, providing high rate of soil cover, which is important for controlling soil erosion (Formentini, 2008). Similarly, for *S.guianensis*, Matos et al. (2008) found 87% more dry matter on south-facing terrain than on west-facing terrain, indicating that *S. guianensis* is better adapted to conditions of higher soil moisture and lower temperature. In evaluating legume behavior in a red-yellow Oxisol at an altitude of 855 m, with annual rainfall of 1418 mm, and minimum and maximum temperature of 21.7and33.2°C, respectively, Teodoro et al. (2011) reported dry matter of 5.65, 5.45, and 2.62 Mg ha^{-1}for*D. lablab*, *C. spectabilis*, and

Table 1. Average yield (n = 4) of green matter from the legumes and spontaneous plants intercropped with coffee in two farms with different terrain aspects, in the Zona da Mata region, Minas Gerais state, Brazil.

Farms / Green Manures	Araponga(northwest-facing terrain)	Pedra Dourada (south-facingterrain)	Means
	.... Mg ha^{-1}		
A. pintoi	5.96 (± 0.38) D a	4.95 (± 0.30) C a	5.45 (± 0.71) D
C. mucunoides	9.92 (± 1.44) B a	7.18 (± 0.75) B b	8.55 (± 1.94) C
C. spectabilis	12.42 (± 0.59) AB b	14.39 (± 3.18) A a	13.40 (± 1.39) A
C. cajan	9.85 (± 0.89) B a	10.74 (± 3.29) AB a	10.30 (± 0.63) B
D. lablab	14.39 (± 0.46) A a	9.31 (± 1.68) AB b	11.85 (± 3.59) AB
S. guyanensis	9.07 (± 0.79) B b	11.84 (± 0.90) AB a	10.45 (± 1.96) B
S. deeringianum	12.40 (± 0.98) AB a	12.15 (± 1.12) AB a	12.28 (± 0.18) AB
Spontaneous	6.42 (± 0.83) CD a	4.74 (± 2.32) C a	5.58 (± 1.19) D
Means	10.05 (2.95) a	9.41 (3,52) a	

Means followed by the same upper case letter in the same column do not differ at the 5% level of probability by Tukey test. Means followed by the same lower case letter in the same line do not differ at the 5% level of probability by Tukey test. Values in parentheses represent the standard deviation of the mean. (n = 4) number of years.

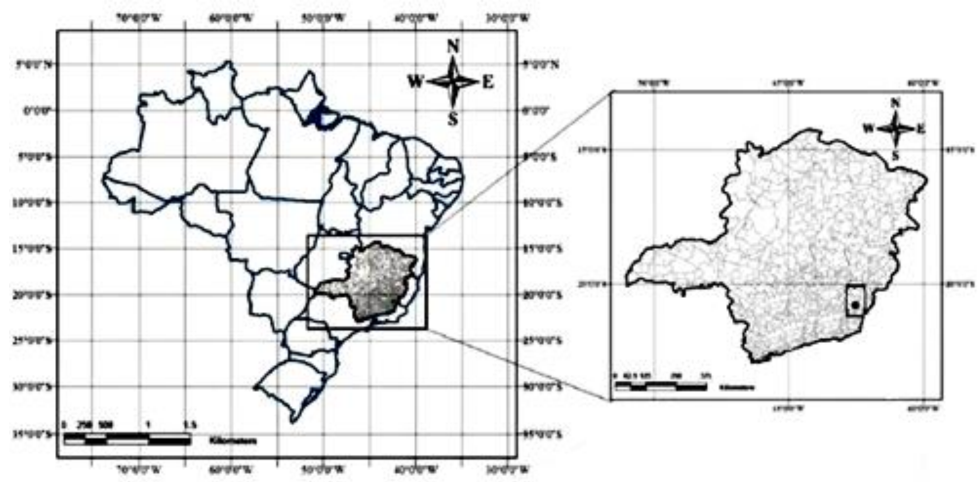

Fig 1. Map of Brazil highlighting the state of Minas Gerais and the location of the Serra do Brigadeiro State Park, Zona da Mata, MG. Source:adaptedfromPaula et al. (2015).

C. cajan, respectively. The dry matter value for the *C. cajan* was similar to the results obtained for the two terrain aspects analyzed in our study, indicating that this legume is highly adaptable to grown in different soil and climatic conditions.

In studying cutting periods (120, 150, 180, and 210 days after sowing) and types of pruning (topping -cutting the plant at a height of1m, and removal of just the lateral branches), for *C. cajan* grown in between the coffee rows in a red-yellow Oxisol at an altitude of 750 m, with average minimum and maximum temperatures of 12.3 and 24.5°C, respectively, Araújo and Balbino (2007) reported the highest amount of green matter (18.93 Mg ha^{-1}) and dry matter (5.44 Mg ha^{-1}) at 150 days after sowing and topping type pruning, in conditions similar to our study. Thus, besides the soil and climate conditions, management of the pruning and the period in which the green manure is cut are fundamental for increasing biomass yield, increasing nutrients in the soil.

In relation to the accumulation of nutrients, unlike what was found our study, Favero et al. (2000) reported accumulation of only 35 kg ha^{-1} of K with *D. lablab* grown in clayey dark red Oxisol at an altitude of 732 m. In Teodoro et al. (2011), the accumulation of nutrients was more similar to that observed in this study: *C. spectabilis* accumulated 101, 8.7, and 84.2 kg ha^{-1} of N, P and K, respectively; *D. lablab* accumulated 198.21, 15.35, and 76.95 kg ha^{-1} of N, P and K, respectively, and *C. cajan* accumulated 87.00, 7.12, and 23.70 kg ha^{-1} of N, P, and K, respectively. Due to being a dense coffee system (7140 plants per hectare) and under organic management, productivity of about 2400 kg ha^{-1} is considered to be satisfactory. Paulo et al. (2001) evaluated the productivity of *Apoatã* coffee after three years of green manuring. The authors observed that all the legumes provided increased productivity in comparison with the spontaneous plants. They found that in the first effective harvest (third year), *Crotalaria juncea*, *Cajanus cajan*, and *Glycine max* led to lower productivity than the spontaneous plants, while *Crotalaria spectabilis* had the same productivity as the spontaneous plants. These data indicate that there was competition between the legumes and coffee, given that the coffee productivity had an inverse correlation with the dry weight of the legumes. It is important to note that, unlike this present study, the legumes planted between the coffee rows in the study of Paulo et al. (2001) did not have fertilizer applied. Therefore, the legumes should be fertilized in order to avoid competition with the coffee and consequently increase the coffee's productivity. In another study, involving the legumes *Glycine max*, *Stizolobium deeringianum*, *Crotalaria juncea*, *Crotalaria spectabilis*, and *Cajanus cajan* intercropped with *Mundo Novo* coffee, Paulo et al. (2006) did not identify the influence of the legumes in comparison with the spontaneous plants on the analysis of the coffee productivity. In the present study there was no correlation between the coffee productivity and the dry matter and nutrient accumulation of the green manure (data not shown). On the northwest-facing terrain, *D. lablab*, *S. deeringianum*, and *C. spectabilis* had the highest dry matter and nutrient accumulation - the first two legumes provided the highest coffee productivity, while the latter resulted in inferior

Table 2. Average productivity (n=3) of benefited coffee conducted in an organic system using green manure in two farms with different terrain aspects in the Zona da Mata region, Minas Gerais state, Brazil.

Farms/Green manure	Araponga (northwest-facing terrain)	Pedra Dourada (south-facing terrain)	Means
	...................kg ha^{-1}...............		
A. pintoi	2280 (± 117.6) AB a	2040 (± 323.4) C b	2160 (± 79.8) BC
C. mucunoides	1980 (± 51.6) C a	1980 (± 131,4) C a	1980 (± 82.8) C
C. spectabilis	1800 (± 223.2) C b	2040 (± 75) C a	1920 (± 151.8) C
C. cajan	1800 (± 192.6) C b	2880 (± 65.4) A a	2340 (± 147.6) A
D. lablab	2460 (± 82.8) A a	2340 (± 186.6) B a	2400 (± 49.2) A
S. guyanensis	2160 (± 145.2) B a	2280 (± 130.8) B a	2220 (± 104.4) B
S. deeringianum	2340 (± 83.4) AB b	2700 (± 82.2) A a	2520 (± 73.8) A
Spontaneous	1380 (± 136.8) D a	1440 (± 118.2) D a	1440 (± 88.8) D
Means	2040 a	2220 a	

Means followed by the same upper case letter in the column do not differ at 5% probability by Tukey test. Means followed by lower case letter between each in the line do not differ at 5% probability by Tukey test. Values in brackets represent the standard deviation of the mean (n = 3) number of years.

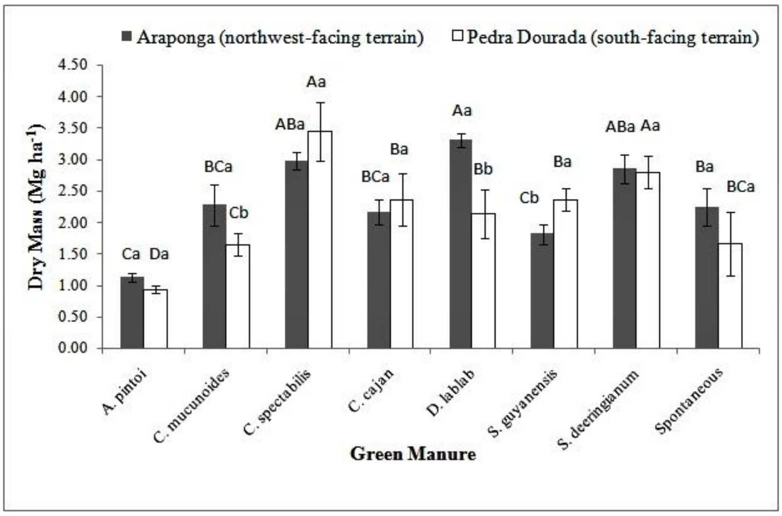

Fig 2. Average yield (n=4) of dry mass of legumes and spontaneous plants intercropped with coffee in two farms with different terrain aspects in the Zona da Mata region, Minas Gerais state, Brazil. Averages followed by the same upper case letter for each farm do not differ at 5% probability by Tukey test. Means followed by lower case letter between each species do not differ at 5% probability by Tukey test. The bars represent the standard deviation of the mean. (n = 4) number of years.

Table 3. Chemical and physical characteristics of the soils at 0–0.2 m depth for two coffee farms located at Araponga and PedraDourada,MinasGerais state, Brazil.

Chemical analysis	Araponga	PedraDourada
Water pH (1:2,5)	5.24	5.04
1Phosphorus (mg dm^{-3})	1.00	2.92
1Potassium (mg dm^{-3})	59.80	53.50
2Aluminum (cmolcdm^{-3})	0.47	0.59
2Calcium (cmolcdm^{-3})	1.74	0.99
2Magnesium (cmolcdm^{-3})	0.74	0.47
3Organic Carbon (g kg^{-3})	29.04	36.80
1Zinc (mg dm^{-3})	1.17	1.56
1Iron (mg dm^{-3})	40.7	14.70
1Manganese (mg dm^{-3})	10.4	20.20
1Copper (mg dm^{-3})	0.50	0.38
Granulometric analysis		
Sand (g kg^{-1})	390	360
Chay (g kg^{-1})	520	450
Textural class	Chayey	Chayey

*In table: pH (hydrogen potential).1-extractorMehlich^{-1}; 2-extractorKCl1mol L^{-1}; 3-methodWalkley Black.

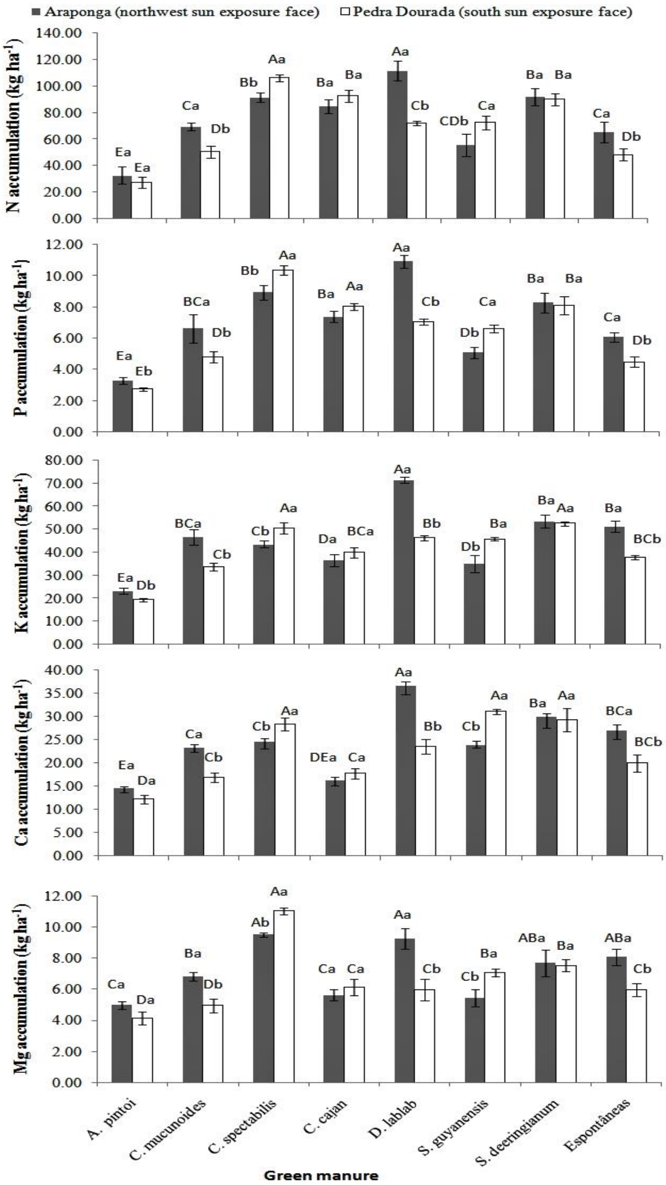

Fig 3. Average accumulation (n = 4) of nutrients in legumes and spontaneous plants intercropped with coffee in two farms with different terrain aspects in the Zona da Mata region, Minas Gerais state, Brazil. Averages followed by the same upper case letter for each farm do not differ at 5% probability by Tukey test. Means followed by lower case letter between each species do not differ at 5% probability by Tukey test. The bars represent the standard deviation of the mean. (n = 4) number of years.

productivity (1800 kg ha^{-1}). Thus, the greater supply of nutrients by the green manure does not necessarily indicate higher productivity, since there may be competition for space, light, water, and soil nutrients between the legumes and the coffee (Paulo et al., 2006). It should be emphasized that *A. pintoi* was the legume that obtained the lowest production of dry matter and accumulation of nutrients, however, it provided coffee productivity of 2280 kg ha^{-1}.

On the south-facing terrain, the legumes that obtained the highest amount of dry matter and nutrient accumulation (*C. spectabilis* and *S. deeringianum*) were not those that provided the highest productivities of coffee, which justifies the non-significant correlation between productivity and dry matter and nutrient accumulation. The rate of nutrient release for these legumes in the areas with different terrain aspects must have influenced the coffee's responses to fertilization with legumes. This was verified by Matos et al. (2011) in a west-facing coffee plantation in which times of 269, 233 and 278 days were observed for decomposition of 50 % of the dry matter from the legumes *A. pintoi*, *C. mucunoides*, and *S. guianensis*, respectively. For these same legumes, the time for 50% of the N to be released was 145, 149 and 193 days, respectively. Thus, there was no synchronization for the total nutrients release by the time of the coffee harvest, since the legumes have different decomposition rates. With these results, the correct management of the coffee and green manures (taking into account the conditions of the species, soil, and climate/terrain aspect) can contribute to increase coffee productivity.

Materials and Methods

Characterization of the study area

The experiment was carried out between January 2004 and December 2007 at two experimental units (farms) located in areas belonging to family farmers. For the experimental unit in Araponga county, which is located at 20°41'S and 42°33'W, the altitude is 950 m, the annual average of the monthly maximum temperatures is 34.2°C, the annual average of the monthly minimum temperatures is 12.1º C, the average annual temperature is 18.0 °C, the average rainfall is 1320 mm, the terrain faces northwest, and the average daily solar exposure is 9.1 h (field measurement). For the experimental unit in Pedra Dourada county, which is located at 20°50'S and 42° 08'W, the altitude is 690 m, the annual average of the monthly maximum temperatures is 32.0 °C, the annual average of the monthly minimum temperatures is 10.4 °C, the annual average temperature is14.0 °C, the annual rainfall is 1277 mm, the terrain faces south, and the average daily solar exposure is 6.8 h (field measurement). In other words, the south-facing terrain (Pedra Dourada) has a lower altitude, lower temperature, and lower incidence of light than the terrain facing northwest (Coelho et al., 2013). The landscape of these two experimental units is hilly with slopes of 40 %. The soils are well-drained, and deep. They are also highly-weathered, acidic, and have low natural fertility. The main soils of both properties are clayey dystrophic red-yellow Oxisols, in accordance with EMBRAPA classifications (2006). The chemical and physical characterization of the soils at 0–0.2 m depth at the time of the initial installation of the experiment is shown in Table 3.

Soil and coffee management

The two coffee farms have been using an organic system since the formation of the seedlings. The seedlings were planted in November/December 2002, but before planting, liming was done, and thermophosphate and potassium sulfate were applied in accordance with the soil analysis and recommendations of the Soil Fertility Committee for Minas Gerais state (Alvarez V. et al., 1999). At the Araponga site, 260 kg ha^{-1} of limestone, 64 kg ha^{-1} of plaster, 125 kg ha^{-1} of potassium sulfate, and 800 kg ha^{-1}ofthermophosphate were applied. In Pedra Dourada, 1200 kg $ha^{-1}$of limestone, 300 kg ha^{-1} of plaster, 125 kg ha^{-1} of potassium sulfate, and 800 kg ha^{-1} of thermophosphate were applied.

At each location, Catuai Vermelho cultivar of *Coffea arabica* was planted with spacing of 2.8 x 0.5 m. In 2004, over the course of the year, three 150 g m^{-2} applications of castor bean cake, one 60 g m^{-2} application of potassium sulfate, and one 150 g m^{-2} application of limestone were administered within the rows and between the rows of coffee. In 2005, 120 g m^{-2} of limestone, 80 g m^{-2} of thermophosphate, and 20 g m^{-2} of potassium sulfate were applied between the rows; while within the rows, 400 g m^{-2} of castor bean cake was divided into four applications throughout the rainy season, in addition to 200 g m^{-2} of potassium sulfate. In 2006 and 2007, between the rows, 120 g m^{-2} of limestone, 80 g m^{-2} of thermophosphate, and 20 g $m^{-2}$of potassium sulfate were applied; while within the rows, 750 g $m^{-2}$of castor bean cake was divided into three applications, in addition to 200 g m^{-2} of potassium sulfate.

Legumes management

The legumes were sown between the coffee rows at spacing of 0.4 m, which resulted in a total of five lines of legumes for each coffee row. After germination, five plants per linear meter remained, which corresponded to 89286 legume plants per hectare. The legumes were planted for four consecutive years (2004–2007), always at the beginning of the rainy season.

Experimental design

The experimental design was in randomized blocks with a 2 x 8 factorial scheme: two different solar exposure environments (northwest-facing and south-facing terrain) and 8 different green manure that were grown between the coffee rows, which included Pinto peanuts (*Arachis pintoi*), calopo (*Calopogonium mucunoides*), crotalaria (*Crotalaria spectabilis*), stylosanthes (*Stylosanthes guianensis*), pigeon peas (*Cajanus cajan*), lablab beans (*Dolichos lablab*), velvet beans (*Stizolobium deeringianum*), and spontaneous plants.

Variables analyzed

At 150 days after seeding, the aerial part of the plant was cut and weighed in order to obtain the weight for the green matter. The remaining green manure was cut and spread under the canopy of the coffee plants. After obtaining the weight of the green matter, about 100 g of the green material was oven dried at 65°C until reaching a constant weight, there by obtaining the dry matter.

Total N content in the legumes was analyzed by dry combustion, using a Perkin Elmer CHNS/O 2400 analyzer. Total P was determined by the molybdenum blue method (Braga and Defelipo, 1974) after perchloric and nitric acid digestion (Sarruge and Haag, 1974). In the same digestion, total K was determined by flame photometry; while Ca and Mg were determined by atomic absorption spectrophotometry. The nutrient accumulation in the aerial part of the green manure was obtained by multiplying the nutrient percentage by the dry weight.

The evaluation of the coffee productivity was done using the averages from 2005, 2006, and 2007, with the coffee beans being picked from the eight central plants in each experimental unit.

Statistical analysis

The data obtained relating to the green and dry matter, nutrient accumulation from the aerial part of the green manure, and coffee productivity were subjected to variance analysis and mean by Tukey test. Pearson correlation was also performed between the coffee productivity and nutrient accumulation in the green manures. The SAEG 5.0 statistical program (FUNARBE 1993) was used to process the statistical analyses.

Conclusions

The perennial legumes *A. pintoi*, *C. mucunoides*, and *S. guianensis* produced less green and dry matter and had lower nutritional accumulation in comparison with the annual legumes *C. spectabilis*, *D. lablab*, and *S. deeringianum* grown in mountainous regions of the Atlantic Forest biome.
In comparing the two different terrain aspects, there was no difference in the production of green and dry matter for *A. pintoi*, *C. cajan*, *S. deeringianum*, and the spontaneous plants. However, *C. Mucunoides* and *D. lablab* were prominent with higher production of green and dry matter on the northwest-facing terrain, and *S. guianensis* produced more green and dry matter on the south-facing terrain. All the legumes showed potential for the contribution of N, P, K, Ca, and Mg into the soil, which contributes significantly to fertilization of the coffee. On the northwest-facing terrain, the coffee had higher productivity when fertilized with the legumes *D. lablab*, *S. deeringianum*, and *A. pintoi*. On the south-facing terrain, the highest coffee productivity was obtained when using the legumes *S. deeringianum* and *C. cajan*, respectively.

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