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Effect of nutrient cycle influenced by inter-row cover crops on the nutritional status of rustic grapevine

Efecto del ciclo de nutrientes influenciado por los cultivos de cobertura en el estado nutricional de la vid rústica

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Luiz Fernandes Cardoso Campos[1]*, Camila Meira de Abreu Campos[2], Leonardo Santos Collier[1] and Alexsander Seleguini[3]

ABSTRACT

The use of plants for permanent or partial coverage of soil in the vineyard inter-rows is a cultural practice used in various wine-growing regions since it is believed that the decomposition of cover crops' straw on the soil surface can increase the availability of nutrients. Therefore, this study aimed to evaluate the nutrient cycling of soil with cover rops in consortium with grapevine (*Vitis labrusca* L. cv. Isabel) cultivated in tropical regions, its nutritional status, and the soil fertility. The experiment was carried out in a vineyard of Isabel cultivar, and three species of ground cover crops were evaluated (*Canavalia ensiformis* L. DC, *Dolichos lablab* L., and weeds). *Canavalia ensiformis* L. DC was more efficient in nutrient accumulation in the canopy than the others. However, the release of nutrients was not statistically different among the cover plants used, being more influenced by the time of grapevine pruning. These coverages did not change the soil chemical properties in the three crop cycles of the two grapevines evaluated and did not affect their nutritional status at the blooming stage of the two harvest seasons evaluated.

Keywords:
Canavalia ensiformis L. DC
Dolichos lablab L
Nutrient release
Vitis labrusca L
Weeds

RESUMEN

El uso de plantas de cobertura parcial o permanente del suelo en las viñas es una práctica cultural utilizada en varias regiones vinícolas, ya que se cree que la descomposición de residuos de plantas de cobertura sobre la superficie del suelo puede aumentar la disponibilidad de nutrientes. Por lo tanto, este trabajo tuvo como objetivo evaluar el ciclo de nutrientes del suelo con cobertura vegetal en consorcio con el cultivo de vid (*Vitis labrusca* L. var. Isabel) cultivada en las regiones tropicales, su estado nutricional y la fertilidad del suelo. El experimento fue realizado en un viñedo de variedad Isabel, y se evaluaron tres especies de cobertura vegetal (*Canavalia ensiformis* L. DC, *Dolichos lablab* L. y malezas). *Canavalia ensiformis* L. DC fue más eficiente en la acumulación de nutrientes en el dosel. Sin embargo, la liberación de nutrientes no fue estadísticamente diferente entre las coberturas vegetales usadas, siendo más influenciada por la época de poda de la vid. Estas no modificaron las propiedades químicas del suelo durante tres ciclos de cultivo de los dos cultivos de vid y tampoco afectaron su estado nutricional en la etapa de floración, en las dos épocas de cosecha evaluadas

Palabras clave:
Canavalia ensiformis L. DC
Dolichos lablab L
Liberación de nutrientes
Vitis labrusca L
Malezas

[1] Universidade Federal de Goiás.Avenida Esperança s/n, Câmpus Samambaia - Prédio da Reitoria. CEP 74690-900 Goiânia - Goiás - Brasil.
[2] Universidade Estadual de Goiás. Br 153 Quadra Área Km 99 - Zona Rural, Anápolis - GO, 75132-903, Brasil.
[3] Universidade Federal do Triâgulo Mineiro. R. Frei Paulino, 30 - Nossa Sra. da Abadia, Uberaba - MG, 38025-180, Brasil.
* Corresponding author: <luizfernandescampos@hotmail.com>

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The use of plants for permanent or partial coverage of soil in the vineyards is a cultural practice used in various wine-growing regions. This technique consists in use plants in consortium with grapevine soil, let them complete their cycle and then convert them in in straw deposited on the soil surface, slightly crushing or incorporating them, with the aid of a roller-crimper (Nachtigal and Schneider, 2007). The cover crop protects the soil from climatic agents and can also maintain or increase the level of soil organic matter, mobilize and cycle nutrients as well as favor the soil biological activity (Guerra and Teixeira, 1997; Fourie, 2012). Furthermore, according to Suzuki and Alves (2006) and Ferreira *et al*. (2012), cover crops significantly contribute to improving the physical properties of soil, increasing the water storage capacity and allowing a nutritional balance for the succeeding of crops.

The use of cover crops on soil can reduce the application of conventional fertilizers and herbicide in vineyards (Souza *et al*., 2012). When soils are tilled and exposed to the intense use of herbicides for weed control, they are prone to nutrient leaching. This practice leads to successive re-applications of chemical fertilizers; consequently, this management also increases production costs and environmental contamination risks (Teixeira *et al*., 2011).

The decomposition of cover crops' straw on the soil surface can increase the availability of nutrients, favoring their absorption by the grapevine. Especially, nitrates (N-NO_3), which is the N form absorbed in higher quantities by the fine roots of the grapevine that presents rapid growth when it blooms (Eissenstat, 2007). Zalamena *et al*. (2013) found higher nitrogen (N) content in the leave collected in full bloom when worked with vineyards intercropped with buckwheat, white oat, and ryegrass. However, the cover crop management via mowing and transferring the crop straw from the inter-row to the grapevine row decreased N content in the leave collected in full bloom. In studies with Fabaceae jack bean (*C. ensiformes* L. DC) and crotalaria (*Crotalaria juncea* L.), Faria *et al*. (2004) found improvements in soil chemical properties, increasing the levels of soil organic matter, exchangeable calcium (Ca), and the Cation Exchange Capacity (CEC) value. The beneficial effect of the lablab on the soil chemical characteristics was restricted to the upper soil layer (0-10 cm deep).

According to Crusciol *et al*. (2008) and Giongo *et al*. (2011), the nutrient release from mixed cover crops depends on several factors: interaction between the species used, biomass management, plant sowing and cutting time, chemical composition of plant residues and its C/N relation, and soil and weather conditions. Thus, the factors that regulate the decomposition can play an important role in crop management, enabling the development of farming techniques that improve the utilization of nutrients in plant residues (Gama-Rodrigues *et al*., 2007).

Regarding the use of cover crops, Gama-Rodrigues *et al*. (2007) stated that the use of legumes is a strategy to enhance sustainability, benefiting the soil, the environment of economically important crops. Therefore, this study aimed to evaluate the nutrient cycling of soil with cover crops in consortium with grapevine (Isabel cultivar) cultivated in tropical regions, its nutritional status, and the soil fertility.

MATERIALS AND METHODS

Studied area

The experiment was conducted in the municipality of Itapuranga, Goiás, at the Capoeira Grande Farm (15°34'32"S, 50°00'31"W) with an average altitude of 635 m.a.s.l. The climatic conditions in the region are a rainy season from October to April, with an average rainfall of 1600 mm, and average temperatures of 27 and 34 °C in the dry and wet season, respectively.

The climatic data of that region was considered for the development of this study (Figure 1). The meteorological data, from 2013 to early 2014, were obtained from the automatic station of the City of Goiás, located at 47 km from the experimentation site.

The soil of the experimental area was classified as Red Latosol (Santos, 2013) similar to Oxisol (Soil Survey Staff, 1999). The experimental area was formed by irrigated vineyard (small sprinklers), with cv. Isabel grafted on IAC 572 'Jales' grapevine rootstock, in trellis type conduction system spaced 2.5×2.5 m. At the time of the experiment development, the vineyard was two years old after grafting.

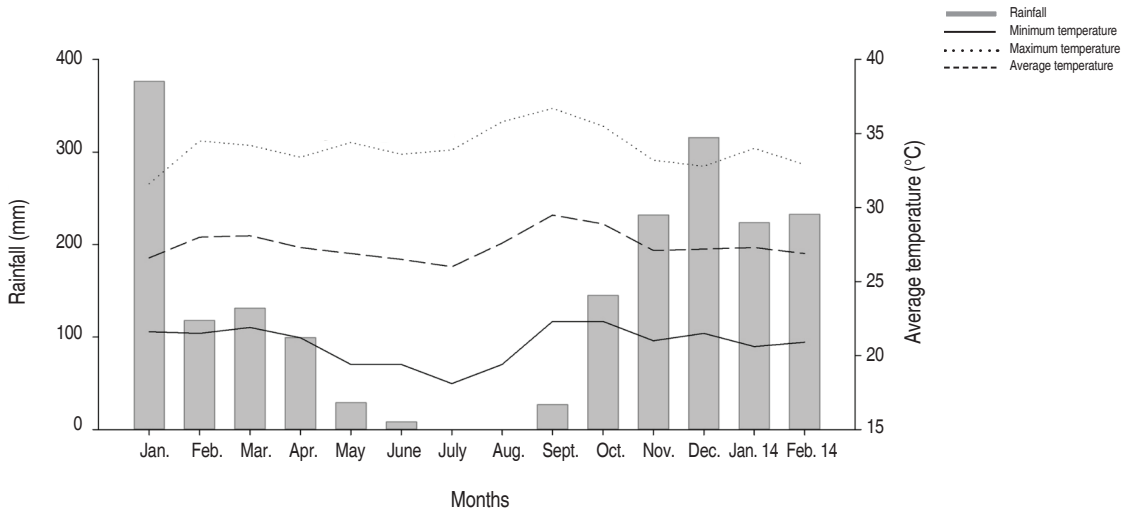

Figure 1. Monthly weather data: Total rainfall and average highest and lowest temperature, obtained from the automatic weather station (INMET, 2014).

Experiment design and treatments

The experiment consisted of a randomized blocks design of six treatments established in a factorial arrange (3×2) with five repetitions. The first factor was cover plants species: *Canavalia ensiformis* L. DC, *Dolichos lablab* L. (lablab) and weeds. The second factor was two different pruning times in the vineyards, performed based on cover crop seeding time. That is, the first grapevine pruning season began 25 days after cover crops sowing (DAS) and the second at 55 DAS. Each plot 9 m² (2.0×4.5 m) was contained two grapevine plants.

Period of conduction

The experiment was conducted in two growing seasons. The period called "winter season" started in February and ended in August 2013, and the period called the "summer season" was from August 2013 to February 2014. In the winter season, the grapevine pruning was performed on March 2nd, 2013 (first pruning, 25 DAS) and April 1st, 2013 (second pruning, 55 DAS) employing a long pruner, keeping five gems per grapevine stick. During the summer season, the grapevine pruning was held on August 31st (first pruning, 25 DAS) and September 30th, 2013 (second pruning, 55 DAS) employing a short pruner, keeping two gems per grapevine stick. After each pruning, bud dormancy breaking was conducted with hydrogenated cyanamide (5%), applied with a foam roller.

Three cycles of cover crops were evaluated: (i) sowing was done on February 5th, 2013, (ii) the plants regrowth was evaluated after their management (mowing April 6th, 2013), and (iii) a new sowing was conducted on August 6th, 2013; monitoring their development within sixty days after sowing. Before each sowing, chemical control was conducted for existing weeds in all plots, using 3 L ha^{-1} glyphosate. Sowing was done in furrows spaced 0.45 m and approximately 1 to 2 cm deep, performed manually, using five seeds of *C. ensiformis* and ten seeds of lablab, without any fertilization or seed inoculation. Weeds emerged from the soil seed bank.

The plots composed of the weed cover showed the following species in the first cycle: *Bidens pilosa* L. > *Digitaria horizontalis* Willd. > *Euphorbia heterophylla* L. > *Commelina benghalensis* L. > *Siegesbeckia orientalis* L. Weeds in the third cycle were: *Bidens pilosa* L.> *Digitaria horizontalis* Willd. > *Amaranthus retroflexus* L. > *Sida rhombifolia* L. > *Euphorbia heterophylla* L. > *Commelina benghalensis* L. The weeds in the second cycle were not determined.

Crop fertilization was scheduled during the winter and summer seasons (Table 1). In order to manage vineyard health in winter, products containing Metiram + Pyraclostrobin and Metalaxyl-M + Mancozeb and in the

summer were sprayed with Metalaxyl-M + Mancozeb, Thiophanate-Methyl and Chlorothalonil + Azoxystrobin + Difenoconazole to prevent and control fungal diseases.

Nutritional status evaluation of cover crops

The aerial part of biomass samples was dried at 65 °C to determine cover crops' nutrients at the time of the cuts. The method for chemical analysis was wet digestion of the dry samples according to the methodology of Bataglia *et al.* (1983). Traces elements (N, P, K, Ca, Mg, Cu, Fe, Mn, and Zn) were determined in the aerial part of cover crops, reporting the total accumulation of traces as kg ha^{-1}.

Table 1. Fertilizer application, in grams per grapevine plant, using nitrogen (N), phosphorus pentaoxide (P_2O_5), potassium oxide (K_2O) and micronutrient during winter and summer seasons.

Application time		Winter season				Summer season			
		10 DBP	15 DAP	45 DAP	80 DAP	10 DBP	15 DAP	45 DAP	80 DAP
Fertilizer (g $plant^{-1}$)	P_2O_5	35	-	-	-	60	-	-	-
	N	-	20	20	-	8	20	20	-
	K_2O	-	-	-	15	20	-	-	15
	FTE BR12	-	25	-	-	-	-	-	-

DBP = Days before pruning; DAP = Days after pruning; FTE = Fritted Trace Elements.

Evaluation of nutrient release by cover crops

'Litter bags' were used to evaluate the plant decomposition (Thomas and Asakawa, 1993). Four litter bags were placed randomly on the soil surface of each plot during the three cycles of cover crops. Sampling was performed at 20, 40, 60 and 80 d, and in each sampling, the litter bags were oven-dried at 65 °C until reaching a constant weight.

The parameters associated with the nutrient release dynamics were calculated based on the weight of dry residue remaining after 80 d of decay and the nutrient concentration in them. To describe the nutrient release from the plant straw, the exponential mathematical model $X=X_0^{(-kt)}$ were adopted, where X is the amount of remaining nutrient that was presented after a time t (d), X_0 is the initial amount of nutrient, and k is a release constant (Thomas and Asakawa, 1993). By reorganizing the equation terms, it is possible to calculate the release constant of nutrients (k) by the material, $k=-\ln (X/X_0)/t$. With the value of k, the half-life ($t_{1/2}$) at which half of the nutrients contained in the residue will be released was calculated ($T_{1/2}$ =0.693/k) (Paul and Clark, 1989).

Soil fertility evaluation

At the end of 2013 (summer season), four soil sub-samples were collected in each plot, with the help of a Dutch auger, to form a composite sample from the 0-0.20 m layer. In the laboratory, the organic matter (OM), pH, Cation Exchange Capacity (CEC), P, K, Ca, Mg, Al and potential acidity (H+Al) were determined, using the methodology of Embrapa (1997).

Grapevine nutritional status evaluation

The leaf nutritional diagnosis was made using grapevine leave at two different pruning times in each evaluated season. The winter sampling was held on March 31st and April 30th of 2013, counting as first pruning and second pruning, respectively. The summer season sampling was held on October 5th and 27th, first and second pruning, respectively. For the analysis, five full leave per plant were collected in each plot, totaling ten leave per sample. The leave were collected in the grapevine's full bloom stage, opposite to the first bunch of the season's branch. The leave were washed and dried in a forced-air oven at 65 °C until reaching constant weight; they were milled and prepared for the analysis of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn), according to the methodology of Bataglia *et al.* (1983).

Table 2. Nutrient levels in gravepine leave collected during blooming.

Nutrient	Deficiency	Slight deficiency	Normal	Slight excess	Excess
			(g kg^{-1})		
N	< 26	26-29	30-35	36-40	>40
P	< 1.3	1.3-2.3	2.4-2.9	3.0-3.9	>3.9
K	< 7	7-14	15-20	21-29	>29
Ca	< 8	8-12	13-18	19-32	>32
Mg	< 3.0	3.0-4.7	4.8-5.3	5.4-10.0	>10.0
S	< 2.0	2.0-3.2	3.3-3.8	3.9-6.0	>6.0
			(mg kg^{-1})		
B	< 20	20-44	45-53	54-100	>100
Cu	< 5	5-17	18-22	23-40	>40
Fe	< 50	50-96	97-105	106-200	>200
Mn	< 20	20-66	67-73	74-300	>300
Zn	< 1.5	15-29	30-35	36-200	>200

Source: Terra and Tecchio (2008).

The concentration levels recommended by Campinas Agronomic Institute were used for the vineyard leaf nutritional diagnosis (Table 2) (Terra and Tecchio, 2008).

The collected data were submitted to ANOVA, and the means were compared using Tukey test at a 5% level.

RESULTS AND DISCUSSION

Nutritional status of cover crops

The *C. ensiformis* biomass showed a higher accumulation of N in the first cycle, and P and K in the second cycle (Table 3). Padovan *et al*. (2011) found that *C. ensiformis* was efficient in cycling nutrients, especially immobilized N, K and Ca. It was also determined that *C. ensiformis* can accumulate N, K and Ca in concentrations of 415, 256 and 327 kg ha^{-1}, respectively, when evaluating extract nutrient capability from the soil through organic system production in the summer conditions (Saminêz *et al*., 2006). These results reinforce its great potential as a cover crop and provide basic information for planning the management of plant biomass. Bertin *et al*. (2005) found higher total nitrogen content in Crotalaria, *C. ensiformis*, and lablab, statistically differing from fallow and millet. This result confirms the relationship established by De-Polli and Chada (1989) in which the N content is superior in more tender species.

Lablab did not present statistical difference regarding N accumulation in the first cycle and P and K in the second cycle. Given these results, it is possible to infer that the weeds have benefited from good soil fertility, justifying by the efficient accumulation of nutrients in their biomass (Table 3). In a study of cover crops developed in Cerrado region (State of Maranhão), it was found that lower release of N by the spontaneous vegetation was probably due to the low amount of N in the residue, associated with the low dry plant matter decomposition rate, they also found lower accumulation of P in the biomass (Leite *et al*., 2010).

Silva *et al*. (2002) found, in orange orchard, that *C. ensiformis* and the lablab were the species that showed higher amount of macronutrient levels in the canopy, followed by velvet bean that stood out in N and P levels, *Crotalaria spectabilis* for K and Ca, and dwarf velvet bean for N and S. According to Souza *et al*. (2012), the content and amount of nutrient uptake by the cover crops species can influence the

decomposition of plant material and the performance of the subsequent cultivation. In several studies involving cover crops, the amount of accumulated nutrients depends on the species, the phenological management stage, and the climatic conditions. Regarding the micronutrient accumulation, a significant effect was observed for the canopy corresponding to Cu and Zn levels, the weeds accumulated the lowest amount of these micronutrients, and *C. ensiformis* presented the highest levels, not significantly differing from lablab (Table 3).

Table 3. Nutrient accumulation in the canopy of cover crops, lablab (LB), *C. ensiformis* (CE) and weeds (W) in three consortium cycles and two grapevine pruning times.

Nutrients	Cycle	Grapevine pruning time		F	Treatments			SMD	CV (%)
		1st	2nd		LB	CE	W		
		(kg ha^{-1})			(kg ha^{-1})				
N	1°	188.42	163.93	1.58^{ns}	158.06 b	253.51 a	116.95 b	59.54	30.28
	2°	154.64	181.19	1.69^{ns}	167.54	193.38	142.82	62.41	33.30
	3°	234.73	256.37	0.29^{ns}	253.38	252.59	230.68	121.36	44.27
P	1°	28.74	22.77	4.30*	22.55 a	27.77 a	26.94	8.79	30.57
	2°	26.24	23.69	0.89^{ns}	21.55 b	33.43 a	19.92 b	8.27	29.70
	3°	28.92	26.69	0.30^{ns}	27.45	31.12	24.85	12.34	39.77
K	1°	64.66	46.58	7.55*	52.80	56.83	57.24	20.10	32.38
	2°	52.07	57.26	0.81^{ns}	53.60 ab	65.23 a	45.17 b	17.59	28.84
	3°	58.40	53.93	0.21^{ns}	55.23	56.70	56. 55	30.00	47.85
Ca	1°	72.53	60.63	0.85^{ns}	60.17	62.31	77.27	39.49	53.14
	2°	122.27	139.45	0.69^{ns}	151.56	138.08	102.94	63.06	43.17
	3°	87.29	78.00	0.49^{ns}	83.48	87.16	77.31	40.54	43.95
Mg	1°	16.36	11.65	6.03*	12.92	14.18	14.92	5.86	37.48
	2°	16.44	17.56	0.34^{ns}	16.70	19.59	14.71	5.83	30.75
	3°	8.83	11.09	0.69^{ns}	8.83	11.80	9.24	8.32	28.96
Cu	1°	0.56	0.53	0.07^{ns}	0.52	0.55	0.57	0.32	52.05
	2°	0.86	0.83	0.13^{ns}	0.79 ab	1.02 a	0.73 b	0.27	28.85
	3°	0.29	0.36	1.40^{ns}	0.26	0.34	0.37	0.18	48.94
Fe	1°	15.20	11.44	4.65*	13.45	13.90	12.60	5.33	35.86
	2°	20.81	22.33	0.19^{ns}	25.55	23.98	15.18	10.54	43.78
	3°	6.62	6.52	0.01^{ns}	6.36	7.50	5.85	2.76	37.67
Mn	1°	3.85	5.20	1.67^{ns}	4.10	4.33	5.15	3.18	62.87
	2°	5.62	5.57	0.003^{ns}	5.14	6.74	4.91	2.93	46.95
	3°	4.28	5.03	0.26^{ns}	4.08	5.35	4.53	4.51	37.53
Zn	1°	0.78	0.96	1.29^{ns}	0.80	0.97	0.83	0.46	47.40
	2°	1.64	1.40	1.71^{ns}	1.39 ab	1.91 a	1.26 b	0.56	32.96
	3°	0.72	0.70	0.05^{ns}	0.70	0.72	0.72	0.33	42.15

Means followed by different letters in the same line differ according to the Tukey test to 5% level. ^{ns}not significant (P>0.05), *significant (P<0.05), **significant (P<0.01). SMD=Significant Mean difference; CV=Coefficient of variation.

Copper is an essential element for plants, but in high concentrations can cause toxicity, which may extend to man and animals that consume copper contaminated food. Cover crops can be an alternative for the mitigation of copper excess in the soil, which by decomposing provide an increase of the straw amount, among which there is the organic material capable of promoting the immobilization of the available copper and decrease its presence in soil (Albarello *et al*., 2013).

Cavalcante *et al*. (2012) found that the plants evaluated for cover crops had, among the micronutrients, high accumulation of Fe and Mn. Duarte and Coelho (2008) observed that the legumes *Crotalaria* sp, *C. ensiformis* and velvet bean (*Mucuna* sp) extracted higher amounts of P, Ca, Mg, S, Zn, and Fe than weeds. In this study, the levels of P, K, Ca, and Fe were higher in the plants grown in the first pruning time and the first cover crop cycle than the other two cycles.

Release of nutrients by cover crops

The nutrient release parameters are not shown for Mn in the first cycle, and Fe in the three cycles because their contents were higher than the initial after 80 d of decomposition, indicating that sample contamination might have occurred by soil residues. The N, P, K, and Mg release parameters were significantly higher in the first pruning time, showing a higher amount of nutrients released, constant decomposition and shorter half-life (Table 4).

Table 4. Quantity released (kg ha^{-1}), release constant k (d^{-1}) and half-life ($t_{1/2}$) for nutrients of cover crops, lablab (LB), *C. ensiformis* (CE) and weeds (W), after 80 d in decomposition in the first consortium cycle and two grapevine pruning times.

Nutrient	Parameter	Pruning time		F	Treatments			SMD	CV (%)
		1st	2nd		LB	CE	W		
					1st cycle				
N	(kg ha^{-1})	189.33	119.99	7.44*	144.25	140.92	178.81	78.80	45.01
	k (d^{-1})	0.030	0.022	20.44**	0.025	0.027	0.026	0.006	19.84
	$t_{1/2}$ (d)	23.67	33.16	16.31**	28.65	26.58	30.02	7.28	22.63
P	(kg ha^{-1})	24.98	17.13	5.85*	18.28	23.71	21.17	10.06	42.22
	k (d^{-1})	0.026	0.018	6.08*	0.022	0.025	0.020	0.009	36.27
	$t_{1/2}$ (d)	28.25	46.94	5.21*	37.37	31.48	43.93	25.35	59.57
K	(kg ha^{-1})	62.05	43.13	8.77**	50.29	54.12	53.36	19.79	33.25
	k (d^{-1})	0.040	0.033	13.60**	0.038	0.038	0.034	0.006	15.80
	$t_{1/2}$ (d)	17.54	21.72	12.61**	18.74	18.99	21.17	3.64	16.40
Ca	(kg ha^{-1})	47.97	34.08	1.55ns	36.41	41.05	45.62	34.54	42.23
	k (d^{-1})	0.014	0.010	4.07ns	0.011	0.013	0.012	0.007	30.62
	$t_{1/2}$ (d)	51.84	56.88	0.91ns	58.41	53.21	51.46	16.36	26.59
Mg	(kg ha^{-1})	14.67	9.53	7.94*	11.28	12.62	12.40	5.65	41.28
	k (d^{-1})	0.029	0.022	11.12**	0.026	0.028	0.022	0.006	22.33
	$t_{1/2}$ (d)	25.20	34.09	14.32**	28.17	27.07	33.70	7.28	21.71
Cu	(kg ha^{-1})	0.49	0.47	0.06ns	0.46	0.49	0.48	0.33	29.76
	k (d^{-1})	0.028	0.026	0.36ns	0.028	0.029	0.023	0.010	33.39
	$t_{1/2}$ (d)	26.98	29.92	0.69ns	25.95	26.20	33.19	11.00	34.16
Zn	(kg ha^{-1})	0.59	0.70	0.43ns	0.61	0.78	0.49	0.49	31.38
	k (d^{-1})	0.018	0.016	0.71ns	0.0168 ab	0.0203 a	0.0129 b	0.007	34.88
	$t_{1/2}$ (d)	44.37	51.28	0.93ns	45.94 ab	35.11 b	62.42 a	22.15	40.92

Means followed by different letters in the same line differ according to the Tukey test to a 5% level. nsnot significant (P>0.05), *significant (P<0.05), **significant (P<0.01). SMD=Significant Mean difference; CV=Coefficient of variation.

In the first cover crop cycle, there was a significant difference in the release constant (k) and half-life of Zn, especially in the *C. ensiformis,* that presented the highest release constant (0.0203 d^{-1}) of this nutrient and shorter half-life (35.11 d), but not differing from the lablab, which in turn does not differ from weeds (Table 4).

In the second cycle, there was a significant difference for the amount released and release constant for N, P, K, Ca, Cu, and Zn; the half-life was significant for N, P, K, and Ca (Table 5). Generally, lablab performed better in the release of nutrients for Ca and Zn. The release of P was higher for *C. ensiformis* (24.99 kg ha^{-1}), with a half-life of 43.46 d, revealing its efficiency in recycling this nutrient because it also showed higher dry P in the biomass (Table 5). Gamma-Rodrigues *et al*. (2007) found that N, P, Ca, and Mg release rates were higher in the *C. ensiformis* compared to *Arachis* sp, siratro, tropical kudzu, and weeds. Calonego *et al*. (2012) also found that the lablab straw was efficient in N, P, and K release.

Table 5. Quantity released (kg ha^{-1}), release constant k (d^{-1}) and half-life ($t_{1/2}$) for nutrients of cover crops, lablab (LB), *C. ensiformis* (CE) and weeds (W), after 80 d in decomposition in the second consortium cycle and two grapevine pruning times.

Nutrient	Parameter	Pruning time		F	Treatments			SMD	CV (%)
		1st	2nd		LB	CE	W		
					2ndcycle				
N	(kg ha^{-1})	115.51	130.63	0.47^{ns}	122.87	156.51	89.83	67.93	48.76
	k (d^{-1})	0.017	0.017	0.0001^{ns}	0.0163 ab	0.0211 a	0.0124 b	0.006	33.49
	$t_{1/2}$ (d)	45.86	52.19	1.05^{ns}	49.88 ab	34.78 b	62.41 a	19.13	34.48
P	(kg ha^{-1})	16.89	15.37	0.31^{ns}	12.84 b	24.99 a	10.56 b	8.40	46.01
	k (d^{-1})	0.012	0.014	0.63^{ns}	0.0115 b	0.0177 a	0.0100 b	0.005	31.06
	$t_{1/2}$ (d)	59.13	63.18	0.48^{ns}	66.55 a	43.46 b	73.44 a	18.15	26.23
K	(kg ha^{-1})	39.88	42.06	0.11^{ns}	39.99 ab	53.42 a	29.51 b	20.62	44.47
	k (d^{-1})	0.018	0.017	0.18^{ns}	0.0170 ab	0.0219 a	0.0133 b	0.006	29.85
	$t_{1/2}$ (d)	41.20	49.33	2.88^{ns}	45.98 ab	34.91 b	54.91 a	14.82	28.92
Ca	(kg ha^{-1})	70.37	94.17	2.02^{ns}	97.08	97.18	52.53	51.85	24.05
	k (d^{-1})	0.011	0.014	0.36^{ns}	0.0128 ab	0.0153 a	0.0090 b	0.005	38.30
	$t_{1/2}$ (d)	68.92	64.44	0.47^{ns}	62.64 ab	54.71 b	82.69 a	20.34	26.95
Mg	(kg ha^{-1})	10.71	13.58	2.09^{ns}	11.87	14.81	9.76	6.15	44.73
	k (d^{-1})	0.013	0.004	8.16**	0.016	0.019	0.014	0.006	33.72
	$t_{1/2}$ (d)	57.31	43.57	6.26*	47.94	47.31	56.08	17.01	29.79
Cu	(kg ha^{-1})	0.47	0.54	0.68^{ns}	0.456 ab	0.684 a	0.381 b	0.26	45.94
	k (d^{-1})	0.010	0.014	6.01*	0.0107 ab	0.0148 a	0.0093 b	0.005	38.40
	$t_{1/2}$ (d)	77.11	61.02	4.72*	70.18	61.00	76.02	22.97	29.38
Zn	(kg ha^{-1})	0.83	0.97	0.57^{ns}	0.706 a	1.302 a	0.690 b	0.58	27.22
	k (d^{-1})	0.009	0.015	8.53**	0.0092 b	0.0162 a	0.0106 ab	0.007	49.25
	$t_{1/2}$ (d)	94.97	66.14	4.50*	101.63	60.55	79.49	54.20	27.51
Mn	(kg ha^{-1})	2.87	2.53	0.23^{ns}	2.45	3.87	1.78	2.20	31.42
	k (d^{-1})	0.008	0.008	0.11^{ns}	0.008	0.011	0.006	0.006	28.28
	$t_{1/2}$ (d)	97.71	123.44	1.66^{ns}	108.54	87.07	136.11	61.84	49.40

Means followed by different letters in the same line differ according to the Tukey test to 5% level. ^{ns}not significant (P>0.05), *significant (P<0.05), **significant (P<0.01). SMD=Significant Mean difference; CV=Coefficient of variation.

In the second cover crop cycle there were significant differences between pruning times for the decomposition constant (k) of Mg, Cu, and Zn, and for the half-life of Mg and Cu. In the third cycle was found a significant difference only for the half-life of Cu. The lablab showed higher resistance to the release of this nutrient, with a half-life of 46.37 d. The half-life for Cu was also influenced by the grapevine pruning times, as the first time presented a long duration, 42.48 d. For K, the grapevine pruning time influenced the amount released with higher amounts in the first season (Table 6).

Table 6. Quantity released (kg ha^{-1}), release constant k (d^{-1}) and half-life ($t_{1/2}$) for nutrients of cover crops, lablab (LB), *C. ensiformis* (CE) and weeds (W), after 80 d in decomposition in the third consortium cycle and two grapevine pruning times.

Nutrient	Parameter	Pruning time		F	Treatments			SMD	CV (%)
		1st	2nd		LB	CE	W		
		3ndcycle							
N	(kg ha^{-1})	229.55	250.78	0.31^{ns}	248.08	248.00	224.41	117.20	43.11
	k (d^{-1})	0.049	0.049	0.005^{ns}	0.049	0.051	0.047	0.010	18.03
	$t_{1/2}$ (d)	14.49	14.68	0.04^{ns}	14.32	14.10	15.34	2.78	16.85
P	(kg ha^{-1})	27.80	25.51	0.32^{ns}	26.28	30.15	23.53	12.54	41.57
	k (d^{-1})	0.042	0.040	0.29^{ns}	0.040	0.044	0.039	0.011	23.30
	$t_{1/2}$ (d)	17.51	18.03	0.23^{ns}	18.20	16.44	18.68	4.69	23.31
K	(kg ha^{-1})	52.34	40.67	7.83*	46.94	45.37	47.20	12.93	24.57
	k (d^{-1})	0.043	0.038	2.27^{ns}	0.039	0.042	0.040	0.010	21.01
	$t_{1/2}$ (d)	16.80	18.85	3.25^{ns}	18.28	17.06	18.14	3.52	17.45
Ca	(kg ha^{-1})	83.24	74.32	0.45^{ns}	79.51	83.94	72.89	41.19	46.18
	k (d^{-1})	0.039	0.039	0.004^{ns}	0.038	0.041	0.037	0.012	26.94
	$t_{1/2}$ (d)	19.30	18.85	0.05^{ns}	19.74	17.36	20.12	6.15	28.49
Mg	(kg ha^{-1})	8.46	7.34	1.35^{ns}	8.45	8.02	7.23	2.96	33.09
	k (d^{-1})	0.042	0.041	0.03^{ns}	0.041	0.044	0.040	0.012	25.34
	$t_{1/2}$ (d)	17.56	17.61	0.001^{ns}	17.84	16.80	18.10	4.60	23.13
Cu	(kg ha^{-1})	0.22	0.30	2.11^{ns}	0.18	0.29	0.32	0.17	30.31
	k (d^{-1})	0.020	0.025	1.82^{ns}	0.016	0.026	0.026	0.010	38.70
	$t_{1/2}$ (d)	42.48	26.94	15.42**	46.37 a	28.33 b	29.44 b	12.26	31.19
Zn	(kg ha^{-1})	0.72	0.69	0.05^{ns}	0.69	0.72	0.71	0.34	42.03
	k (d^{-1})	0.061	0.061	0.08^{ns}	0.059	0.063	0.061	0.010	14.19
	$t_{1/2}$ (d)	11.46	11.49	0.002^{ns}	11.80	11.10	11.53	1.78	13.71
Mn	(kg ha^{-1})	4.20	3.11	3.02^{ns}	4.02	3.72	3.22	1.92	46.57
	k (d^{-1})	0.055	0.051	0.89^{ns}	0.055	0.051	0.053	0.014	23.28
	$t_{1/2}$ (d)	13.33	14.33	0.52^{ns}	13.30	14.46	13.74	4.29	27.44

Means followed by different letters in the same line differ according to the Tukey test to a 5% level. ^{ns}not significant (P>0.05), *significant (P<0.05), **significant (P<0.01). SMD=Significant Mean difference; CV=Coefficient of variation.

In the first and third cycles, there is a similar behavior in the nutrient release parameters where the plants do not differ significantly for most nutrients. These results can be explained by the fact that the plants of the second cycle grew longer until management (105 d), while in the first and third cycles the plants grew no more than 60 d. Therefore, the age of the plant can be associated with its nutrient composition (Souza *et al*., 2012). While the young plants are more tender and have a higher decomposition rate, older plants have most of their parts lignified and,

therefore, are more resistant to decomposition and present a consequent lower release of nutrients. Besides, the first and third cycles coincided with periods of the year with higher temperatures and higher rainfall, favoring the decomposition of the straw. For the second cycle, although there was irrigation, and the thermal amplitude was lower, which may decrease the decomposition activity of the straw.

Soil fertility

There was no significant difference among the cover crops for soil chemical attributes after three cultivation cycles of two grapevine crops (Table 7).

Comparing the values before and after the cover crop, the increase of P, K, Ca, and H+Al level is clear. According to Collier *et al*. (2011), this is due to possibly intake of these nutrients after decomposition of the previous straw. Silva *et al*. (2002) also observed Ca increase after the implementation of intercropped leguminous family species in an orange-pear orchard, compared to the ground situation before the experiment. Faria *et al*. (2004), using leguminous cover crops with vineyards under Ultisol in Petrolina (state of Pernambuco) after eight years, noted several improvements in the chemical characteristics of the soil, including an increase the exchangeable Ca in the 0-10 cm depth compared to the control without cover crops. Rosa *et al*. (2009) found that acidity and nutrient availability in the soil were influenced by cover crops associated with the grapevine, in the mountainous region of the state of Rio Grande do Sul.

Table 7. Chemical attributes of Red Latosol (Oxisol) before experiment installation (collection conducted March 8th, 2013) and after three cycles (collection on December 16th, 2013) with the cultivation of grapevine intercropped with cover crops.

Parameters	Initial level	Cover crop treatment			SMD	CV(%)
		Lablab	*C. ensiformis*	Weeds		
pH ($CaCl_2$)	6.20	6.11	6.03	6.12	0.18	2.68
P (Mehl) (mg dm^{-3})	3.80	8.83	9.33	5.03	7.23	40.33
K (mg dm^{-3})	105.00	124.70	129.40	111.00	34.26	24.87
Ca ($cmol_c\ dm^{-3}$)	5.60	6.27	6.57	6.55	0.98	13.41
Mg ($cmol_c\ dm^{-3}$)	2.60	1.79	1.73	1.69	0.54	27.54
H+Al ($cmol_c\ dm^{-3}$)	1.70	2.42	2.65	2.46	0.33	11.63
SB ($cmol_c\ dm^{-3}$)	8.47	8.35	8.31	8.90	1.32	13.72
CEC ($cmol_c\ dm^{-3}$)	10.17	10.93	10.75	11.41	1.43	11.51
O.M. (g dm^{-3})	38.00	17.50	18.30	13.00	7.27	39.50
V (%)	81.50	76.34	77.28	77.69	4.02	4.61

Means of treatments followed by different letters in the same line were different according to the Tukey test with a 5% of significance. H+Al= potencial activity; SB = sum of basic cations; CEC = cation exchange capacity; OM = organic matter; V = base saturation. SMD= significant mean difference, CV= coefficient of variation.

Nascimento *et al*. (2003) studied the effect of several tropical herbaceous legumes, cultivated as cover crops, on the chemical characteristics of a degraded Luvisol. According to their findings, it was observed significant effects of the legumes on soil fertility with significant increases in pH and exchangeable bases, positively reflecting on the CEC and base cation saturation index. Despite the cover crops promoting discrete soil acidification by raising H+Al levels and reducing organic matter levels, there was no increase in exchangeable Al that remained null in all soil samples.

The K content in soil increased 19.7 mg dm^{-3} in the plots cultivated with lablab, 24.4 mg dm^{-3} with *C. ensiformis* and 6 mg dm^{-3} with weeds. The P content in the soil also increased reporting values of 5.03 mg dm^{-3}, 5.53 mg dm^{-3}, and 1.23 mg dm^{-3} in the plots cultivated with lablab, *C. ensiformis*, and weeds, respectively. On the other hand,

Cardoso *et al*. (2013) found that the P content in the soil increased by 0.6 mg dm^{-3} when cultivated with *C. ensiformis* and millet. According to the authors, this P increase may be related to the ability of these plants to absorb the P subsurface soil layers and make it available on the surface, after the decomposition of straw. Such association can also be attributed to an element of easily leaching such as K, and plants with deeper roots can cycle this nutrient.

Negative effects were observed for Mg, soil organic matter, and basic cation saturation; showing decreasing levels in the soil at the end of the experiment. The organic matter content was reduced in the plots with weeds from 38 g dm^{-3} to 13 g dm^{-3}. For lablab, the reduction was lower, reflecting the effect of higher biomass production by these plants, thereby maintaining a good level of organic matter in the soil. Collier *et al*. (2011) found, in treatment with *C. ensiformis*, decrease of organic matter in soil because of a positive priming effect, to stimulate the soil biota in the decomposition of the existing organic matter. The activating effect (priming) is defined as the rapid change of the organic carbon and nitrogen content of the soil. It can be positive (mineralization of C and N) by adding low C/N ratio materials or nitrogen mineral fertilizers. Otherwise, this effect can be negative (net immobilization) by the addition of high C/N material (Buso and Kliemann, 2003).

Nutritional status of grapevine

Cover crops did not affect the nutritional status of the grapevines at blooming in both crop seasons (Table 8). A different outcome was noticed by Zalamena *et al*. (2013), who verified lower content of P and K in the leave of grapevines planted with species of cover crops compared to the control treatment (weeds). This reduction can be attributed to the higher absorption and accumulation of both elements in the tissue of cover crops, reducing the availability in the soil for grapevine plants (Celette *et al*., 2009; Brunetto *et al*., 2011).

According to Celette *et al*. (2009), along with the grapevine cycle, the cover crop plants also absorb the water and nutrients from the soil solution, especially N, which may even reduce the availability of this element to the grapevine. Thus, increase in total N content in the leave of grapevines intercropped with annual cover crops is not normally expected, and may even be the opposite, as Wheeler *et al*. (2005) noted.

N, P and K levels were higher in the summer season compared to winter. This increase can be attributed to the fact that grapevine plants may have benefited from the nutrients released by the decomposition of previous cover crops and soil organic matter at the second harvest since there had already been two cycles of cover crops. It can be inferred that the use of cover crops over time provides better nutrient availability in the soil, with consequent benefits for the main crop. Faria *et al*. (2004) studied changes in soil characteristics after eleven legume cycles with nine grapevine crops seasons and noticed a soil fertility improvement in the sixth and ninth seasons.

For grapevine, and most of the crops, the standard levels of nutrients that are correlated with the higher production are not well established, but it is possible to work with a concentration range for the interpretation of the results. The concentration ranges recommended by the Agronomic Institute of Campinas for grapevine plants are divided into five levels: deficiency, slight deficiency, normal, slight excess and excess (Table 2) (Terra and Tecchio, 2008).

The grapevine plants showed a slight N deficiency in the winter season, however, in the summer season, the N content was in the optimal (normal) range, reinforcing the use of this nutrient arising from the decomposition of cover crops and soil organic matter. The plant P content in the winter and summer season showed a slight excess. According to Mafra *et al*. (2011), the grapevine has a low demand for P, that is attributed to the association of grapevines with mycorrhizal fungi present in the roots of plants in poor soils, which exploit little soluble forms of this element. However, this is not the case of the present work, because the P content in the soil presented as low to medium, according to Sousa *et al*. (2004) (Table 6), so if there was a mycorrhizal association, it might have contributed to increasing the absorption of this nutrient.

The K content in the grapevines, for the two crops, was framed within the slight deficiency range. Grapevine leave showed excess of Ca in the two seasons, except for treatment with the weeds in the winter crop, which was in

slight excess range. The scarcity level was observed for Mg in the two seasons, regardless of cover crops. The dynamics of these three nutrients in vineyards are very important, and the relationship between the nutrients, such as K/Mg and K/(Ca+Mg) should be considered. When there is an inverse relationship between these elements, especially high content of K and low Mg and Ca, an abiotic anomaly known as "desiccation of the rachis" can occur (Fráguas *et al*., 1996; Miele *et al*., 2009). According to Silva *et al*. (2005), high K, high Ca and low Mg levels also contributed to the emergence of desiccation of the rachis.

Table 8. Nutrients in grapevine canopy intercropped with, lablab (LB), *C. ensiformis* (CE) and weeds (W) and grapevine pruning times.

Nutrient	Harvest	Pruning times		F	Treatments			SMD	CV(%)
		1st	2nd		LB	CE	W		
N (g kg^{-1})	Winter	27.61	26.65	1.19 ^{ns}	26.80	26.69	27.91	2.72	8.88
	Summer	35.44	33.00	7.64 *	34.61	34.28	33.77	2.73	7.06
P (g kg^{-1})	Winter	4.44	2.63	99.03 **	3.55	3.54	3.52	0.56	14.10
	Summer	4.43	4.28	1.04 ^{ns}	4.53	4.29	4.24	0.44	9.06
K (g kg^{-1})	Winter	8.13	7.97	0.09 ^{ns}	8.18	7.54	8.44	1.61	17.74
	Summer	11.68	11.70	0.01 ^{ns}	11.62	11.68	11.78	0.70	5.32
Ca (g kg^{-1})	Winter	25.40	44.86	13.92 **	35.80	33.50	21.10	24.48	35.25
	Summer	32.48	31.78	0.07 ^{ns}	32.24	31.94	32.22	8.30	22.82
Mg (g kg^{-1})	Winter	2.00	3.07	17.18 **	2.80	2.30	2.50	0.79	27.82
	Summer	2.63	2.62	0.008 ^{ns}	2.60	2.67	2.61	0.60	20.21
Cu (mg kg^{-1})	Winter	11.26	10.33	0.50 ^{ns}	10.80	10.20	11.40	4.07	33.30
	Summer	11.27	12.00	2.78 ^{ns}	12.20	11.30	11.40	1.36	10.35
Fe (mg kg^{-1})	Winter	366.53	424.07	24.71 **	402.30	384.60	399.00	35.87	8.02
	Summer	179.40	181.13	0.008 ^{ns}	164.30	191.20	185.30	59.41	29.11
Mn (mg kg^{-1})	Winter	170.33	182.66	0.12 ^{ns}	179.60	162.10	187.80	111.29	55.70
	Summer	92.00	113.93	7.06 *	93.60	104.10	111.20	25.58	21.95
Zn (mg kg^{-1})	Winter	26.01	28.28	0.770 ^{ns}	26.61	26.71	28.12	8.02	26.10
	Summer	21.93	21.80	0.003 ^{ns}	21.10	19.60	24.90	7.58	30.65

Means of treatments followed by different letters in the same line were different according to the Tukey test with a 5% of significance. SMD= significant mean difference, CV= coefficient of variation.

For micronutrients in cover crop treatments, the Cu was framed as under slight deficiency in two crops seasons. The Fe content was in the excess range in the winter season and a slight excess in the summer season. The Mn content fell in the slight excess range in two crop seasons. A slight deficiency was observed for Zn content in grapevine leave, in two crops seasons.

The nutrient release parameters did not differ among the evaluated cover crops but depend on the grapevine pruning time. Cover crops did not change the soil chemical attributes of soil fertility in three crop cycles and two grapevine crops. Cover crops did not affect the nutritional status of the grapevines at blooming in the two evaluated times.

CONCLUSIONS

Canavalia ensiformis is more efficient in the accumulation of nutrients in its aerial parts than other cover crops.

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