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Nitrogen fertilization of vegetables cultivated under no-tillage after cover crops

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ABSTRACT

The production of horticultural crops in no-tillage and in rotation with cover crops reduces the dependency in nitrogen fertilizer, due to increased soil organic matter and by biological fixation performed by legumes. Thus, the aim of this work was to study rates of nitrogen fertilization and cover crops in the agronomic performance of tomato and broccoli grown under no-tillage. The experiment was conducted in a split plot design with four replications. Treatments consisted of cover crops, sunn hemp and millet, and four rates of nitrogen fertilization (0, 50, 100 and 200 kg/ha of nitrogen), for both the tomato and broccoli crops. All soil management was performed in no-tillage. For tomato crops we evaluated the plant growth, the nitrate concentration of sprouts and fruits and yield of commercial and non commercial fruits. For broccoli we evaluated plant growth and yield. There was an interaction effect between cover crop and nitrogen rates to tomato growth measured at 100 days after transplanting, for plant height, number of fruit bunches, dry mass of leaves and diameter of the stalk. The tomato commercial fruit number and yield showed maximum values with 137 and 134 kg/ha of N respectively, on the sunn hemp straw. The nitrate concentration of the tomato sprouts was linearly increasing with the increase of nitrogen rates, when grown on the millet straw. For broccoli production, the maximum fresh mass of commercial inflorescence was with 96 kg/ha of N, when grown on the millet straw.

Keywords: *Solanum lycopersicon*, *Brassica oleraceae* var. itálica, *Crotalaria junceae*, *Pennisetum americanum*, soil management.

RESUMO

Fertilização nitrogenada de hortaliças cultivada em plantio direto em sucessão a plantas de cobertura

A produção de culturas hortícolas em plantio direto e em rotação com plantas de cobertura reduz a dependência do fertilizante nitrogenado devido ao aumento de matéria orgânica do solo e pela fixação biológica pelas leguminosas. Dessa forma, objetivou-se estudar níveis de fertilização nitrogenada e plantas de cobertura na produção de tomate e brócolis cultivados em plantio direto. O experimento foi conduzido em delineamento de parcelas subdivididas com quatro repetições. Os tratamentos constituíram-se de plantas de cobertura, crotalária e milheto e quatro níveis de fertilização nitrogenada de cobertura (0, 50, 100 e 200 kg/ha de N) tanto para o cultivo do tomateiro quanto para o brócolis. Realizou-se todo manejo do solo em plantio direto. Para o tomateiro, foram avaliados o crescimento das plantas, o teor de nitrato dos brotos e frutos e produtividade comercial e não comercial. Para o brócolis, foram avaliados o crescimento das plantas e a produtividade. Houve efeito de interação entre plantas de cobertura e doses de nitrogênio no crescimento do tomateiro medido aos 100 dias após o transplante, para a altura da haste principal, quantidade de pencas de frutos, massa seca de folhas e diâmetro do caule. A máxima produção de frutos foi conseguida com 137 kg/ha de N e a máxima produtividade comercial com 134 kg/ha de N quando o tomateiro foi cultivado sobre a palha de crotalária. A concentração de nitrato nos brotos do tomateiro, quando cultivado sobre a palha de milheto, aumentou linearmente com as doses de nitrogênio. No cultivo do brócolis, a maior produção de massa fresca da inflorescência foi com 96 kg/ha de N quando cultivado na palha de milheto.

Palavras chave: *Solanum lycopersicon*, *Brassica oleraceae* var. itálica, *Crotalaria junceae*, *Pennisetum americanum*, manejo do solo.

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Brazilian vegetable production relies mainly on conventional tillage, with frequent plowing of the top 20 cm of the surface for crop placement. This operation further exposes the soil to erosion through the action of rain, wind and solar radiation (Argenton *et al.*, 2005; Zuazo & Pleguezuelo, 2008). Alongside conventional agriculture, conservationist agriculture is based on fundamentals that focus on the preservation of natural resources and its principles are non-revolving or minimum soil revolving, ongoing maintenance of plants on the soil surface and crop rotation. When this technology is adopted in commercial agriculture, the reduction of agricultural supplies such as fertilizers and agrochemicals becomes a real possibility. However, proper nitrogen fertilization of vegetables is key to productive success, because these species are highly responsive to nitrogen, both when in deficit or in excess of the nutrient (Stivers & Shennan, 1991; Shennan, 1992).

In no-tillage, permanent maintenance of crop residues on the surface helps protect the soil from erosion and reduction in water evaporation. As the straw decomposes, organic matter is increased, and when the organic matter is mineralized, the availability of nutrients in the soil solution increases, making them available to the plants (Sainju *et al.*, 2002; Whitehead & Singh, 2005; Torres *et al.*, 2008; Pacheco *et al.*, 2011). In this context, legumes have the further advantage of incorporating atmospheric N into the system due to biologic fixation by symbiotic bacteria activity in roots (Rasmussen *et al.*, 2012).

Cover crops are essential to the vitality of the productive agricultural process, as they provide benefits to the environment resulting in higher crop yields and reducing the environmental impact of the whole agricultural process. In this context, an important factor is the possibility of reduction of agricultural inputs, especially nitrogen fertilizer, which is reflected in the reduction of both the production costs and environmental impact by contamination with nitrates from fertilizers (Torres *et al.*, 2005, 2008). The adoption of no-tillage and cover crops, especially to legumes, are fundamental to the increase in the amount of nitrogen in the system and the reduction of nitrogen fertilizers over time (Doane *et al.*, 2009). Thus, no-tillage and rotation with cover crops over space and time provide increased soil fertility (Hobbs, 2007). The use of sunn hemp as green manure improved the foliar nitrogen content and agronomic performance of broccoli that recovered 9.2% of nitrogen from symbiotic fixation (Perin *et al.*, 2004). In tomato crop, the requirement of nitrogen fertilizer decreased when cultivated on legume mulching (Thönnissen *et al.*, 2000; Sainju *et al.*, 2002).

However, the objective of this work was to study nitrogen fertilization rates for production of tomato and broccoli in no-tillage and rotation with cover crops, millet and sunn hemp.

MATERIAL AND METHODS

This study was conducted at the Experimental Farm of APTA, Ribeirão Preto, São Paulo State, Brazil (21°12'S, 47°51'W, altitude 646 m). The soil was classified as Oxisol eutroferric (USDA Soil Taxinomic), clay texture, with following chemical characteristics of samples collect from 0 to 20 cm depth: $pHCaCl_2$= 5.2; OM= 21 g/dm^3; P resin= 42 mg/dm^3; K, Ca, Mg and H+Al with 3.2, 23, 12 and 32 $mmol_c$/dm^3 respectively; cation exchange capacity= 70 mmolc/dm^3 and basis saturation (V%)= 55. The experimental area is characterized by sequencial cultivation of tomato/cover crops in no-till during three years before establishment of the experiment.

The treatments consisted of two cover crops, sunn hemp (*Crotalaria junceae*) and millet (*Pennisetum americanum*), and four nitrogen rates (0, 50, 100 and 200 kg/ha) applied in topdressing fertigation in tomatoes and broccoli crops in no-tillage. The experimental design was a split-plot with four replications, totalling 32 experimental units. Each experimental unit was 35 m^2 in area (7x5 m) and the total area was 1120 m^2.

In order to increase the base saturation to reach 80%, 2.2 t/ha of dolomitic lime was applied (Trani *et al.*, 1996), without performing the incorporation of the corrective to preserve the no-tillage characteristic of the experimental area, leaving it to react on the soil surface. Then, the sowing of the cover crops was carried out, in December 2010, with a grain seed-drill specific for no-tillage, equipped with cutting discs and a 15 cm deep chisel. The sowing rate was 35 and 27 seeds per linear metre for the millet and the sunn hemp respectively, at distances of 45 cm. Seventy days after sowing date, harvesting was carried out, in three points of 1 m^2 per experimental unit, to measure the cover crops' dry mass yield, followed by the cutting down of the plants with the aid of a crimping roller for the formation of straw on the soil surface. Afterwards, glyphosate herbicide was applied to the total area for control of the remaining weeds. During the cover crops growing time, the rainfall was 547 mm, the average maximum temperature 30.9°C and minimum average 19.8°C.

The crop row opening for tomato planting was performed with the seed-drill used for cover crop seeding, in order to preserve the physical integrity of the cultivated soil. In this moment the fertilization was done with 40 kg/ha of N, 500 kg/ha of P_2O_5 and 100 kg/ha of K_2O. The rows were spaced at 1.5 m intervals and the seedlings transplanted with 0.40 m spacing between plants. The hybrid Deborah Victori with indeterminate growth was used and crop inherent practices were performed. The experimental treatments were applied on the topdressing, with 0, 50, 100 and 200 kg/ha of N through fertigation, divided in three applications, at 30, 60 and 90 days after transplanting date, and ammonium nitrate was used as N fertilizer source. At the same time of N topdressing, potassium fertilization was performed, with 200 kf K_2O divided in three applications, using potassium sulphate as the source. The tomato was conducted with a double stalk and 12 fruit clusters per plant.

At 100 days after transplanting, two plants per experimental unit were collected to measure the plant growth. We measured the height of the primary and secondary stalks (using a measuring tape), and diameters of the stalk, base and apex of both main and secondary stalks (using a digital calliper). Also, the number of cluster was counted, fruit number and fresh weight of marketable and non-marketable fruits of both stalks, and finally, dry weight of leaves per plant, measured after drying at 65°C in a kiln with forced air circulation for 72 hours. At the same time, the nitrate content of removed sprouts above the third bunch of fruits was measured, with the aid of a portable Horiba compact NO_3^- meter.

Fruits of 8 plants per experimental unit were harvested to measure the tomato yield. They were divided into marketable and non-marketable fruits, counted and measured for fresh weight. The total number of harvests was seven and in the third, the nitrate content in the fruit juice was measured with the help of the same equipment used to measure the nitrate content of the sprouts. The tomato crop cycle was from March to August, 2011, with 600 mm total rainfall, 28.1°C maximum average temperature, and average minimum of 13.3°C.

After the tomato harvesting, the area remained fallow until December, when the sunn hemp and the millet were sown again in their respective experimental units from the previous year, following the same methodology of 2010, but without liming.

The cover crops were grown for seventy days. Then, they were measured for yield of dry mass, after were mowed and kept on the soil surface for the broccoli cultivation. During the cover crops growing time, the rainfall was 505 mm, the average maximum temperature 30.4°C and minimum average 18.6°C.

The preparation of the area for broccoli cultivation was carried out in the same way as was done for the tomato, opening up the crop rows, at intervals of 1.5 m, using the same seeder previously used for sowing cover crops. During crop fertilization, 400 kg/ha of P_2O_5 and 120 kg/ha of K_2O were applied, totaly excluding nitrogen from the fertilization. The broccoli seedlings were transplanted allowing 0.4 m of space between the plants. The hybrid Marathon was used. The experimental treatments were applied through fertigation, with 0, 50, 100 and 200 kg/ha of nitrogen, divided in two applications, at 30 and 50 days after transplanting, and ammonium nitrate was used as the source of nitrogen. The cultivation practices inherent to the crop were performed to control and avoid pests and phytopathogens. At the end of the broccoli cultivation cycle the fresh mass and the diameter of the commercial

Table 1. Dry mass production (DM) and nitrogen, phosphorus, potassium, calcium and magnesium accumulated in the aerial part of sunn hemp and millet grown in 2011 and 2012. Ribeirão Preto, APTA, 2012.

Cover crops	DM (t/ha)		N (kg/ha)		P (kg/ha)	
	2011	2012	2011	2012	2011	2012
Sunn hemp	3.5	2.5	48.5	34.6	5.4	3.9
Millet	4.4	3.2	49.0	35.7	8.8	6.4
	K (kg/ha)		Ca (kg/ha)		Mg (kg/ha)	
Sunn hemp	52.5	37.5	17.2	12.3	8.0	7.3
Millet	84.7	61.6	14.2	10.3	12.4	9.0

Table 2. Number of commercial and non commercial fruit (NCF and NNCF), commercial and non commercial fruit yield (CY and NCY) and nitrate concentration in sprout and fruits (NtS and NtF) of tomato in response to experimental treatments of cover crops and nitrogen rates. Ribeirão Preto, APTA, 2012.

Characteristics	NCF (1000 fruits/ha)		NNCF (1000 fruits/ha)		CY (t/ha)	
	Sunn hemp	Millet	Sunn hemp	Millet	Sunn hemp	Millet
Rates of nitrogen (kg/ha)						
0	471	553	190	186	58.0	72.0
50	543	630	150	143	68.6	79.3
100	601	538	166	144	74.6	68.0
200	581	564	200	166	72.6	70.6
Effect of regression	Q*	ns	ns	ns	Q*	ns
Cover crops (CC)	ns		ns		ns	
Rates of nitrogen (NN)	**		ns		*	
CC x LN	**		ns		**	
	NCY (t/ha)		**NtS (mg/kg)**		**NtF (mg/kg)**	
	Sunn hemp	Millet	Sunn hemp	Millet	Sunn hemp	Millet
Rates of nitrogen (kg/ha)						
0	11.8	13.0	2300	2325	228	222
50	10.0	8.4	2475	2600	232	210
100	11.0	10.4	2962	3287	232	236
200	13,5	10.7	2850	3137	248	222
Effect of regression	ns	ns	ns	L**	ns	ns
Cover crops (CC)	ns		ns		ns	
Rates of nitrogen (NN)	ns		**		ns	
CC x LN	ns		ns		ns	

ns= non significant; **and*= significant at 1 and 5% probability; Q= quadratic regression; L= linear regression.

inflorescence were measured. The foliar area was measured using a CI-202 portable laser leaf area meter (CID-Bio Science), and the dry mass of leaves, stalk and commercial inflorescence were measured after drying at 65°C for 72 hours in a kiln with forced air circulation. The measurements were taken from eight plants per experimental unit. The broccoli was grown from April to July of 2012, with total rainfall of 203 mm, average maximum temperature of 26.9°C and minimum average of 15.1°C.

Statistical analysis was performed using the SAS program, consisting of analysis of variance (F≤0.05) in function of the experimental design, and regression analysis for quantitative data and nitrogen rates of the experimental treatments (Little *et al*., 2006).

RESULTS AND DISCUSSION

Conservationist agriculture favours the increase of organic matter in the soil, and consequently nutrient availability to the crops (Torres *et al.*, 2008). The use of leguminous plants in crop rotation and straw accumulation on soil surface enables the input of atmospheric nitrogen via biologic fixation performed by symbiotic bacteria on the plant (Rasmussen *et al.*, 2012). However the accumulation of nitrogen on the aerial part of grasses, such as millet, also contributes biologically to increasing the nitrogen in the system as the mineralization of the organic matter occurs (Torres *et al.*, 2005; Pacheco *et al.*, 2011). The dry mass yield of cover crop aerial parts is highly variable as a function of edaphoclimatic attributes, such as mineral accumulation. Dry mass accumulation was larger in millet than in sunn hemp, with 3.8 t/ha against 3.0 t/ha, on average of both years (Table 1). Both cover crops had the same accumulation for nitrogen. However, sunn hemp accumulated more calcium, but millet was more efficient to accumulate phosphorus, potassium and magnesium. Cultivated in different regions of Goiás, millet had variable yield between 3.6 to 8.5 t/ha (Pacheco *et al.*, 2011). Regarding tomato growth measurements at 100 days after transplanting, the cover crop treatments and nitrogen rates interacted on the characteristic height of the tomato's plant, with linear regression adjustment on the millet and quadratic regression adjustment of the nitrogen rates on the sunn hemp, achieving greater height of main stalk with 100 kg/ha of N rate (Figure 1a and 1b). There was no diference in the height of the secondary stalk as a function of the treatments.

The quantity of flower bunch on the main stalk had a significant response to nitrogen rates applied in the experiment, with quadratic adjustment when cultivated in rotation with the sunn hemp, and linear adjustment in millet (Figure 1c and 1d). On the sunn hemp straw, the rate of 120 kg/ha of N provided the greatest quantity of

Table 3. Dry mass of leaf, stalk and inflorescence (DML, DMS and DMI), diameter and fresh mass of inflorescence (DI and FMI), and foliar area (FA) of broccoli in response to experimental treatments of cover crops and nitrogen rates. Ribeirão Preto, APTA, 2012.

Characteristics	DML (g/plant)		DMS (g/plant)		DMI (g/plant)	
	Sunn hemp	Millet	Sunn hemp	Millet	Sunn hemp	Millet
Rates of nitrogen (kg/ha)						
0	68	49	90	91	73	69
50	84	53	103	75	99	76
100	71	65	115	84	91	78
200	71	58	113	84	83	69
Effect of regression	ns	ns	ns	ns	ns	ns
Cover crops (CC)	ns		ns		ns	
Rates of nitrogen (NN)	ns		ns		ns	
CC x LN	ns		ns		ns	
	DI (cm)		**FMI (g/plant)**		**FA (cm^2/plant)**	
	Sunn hemp	**Millet**	**Sunn hemp**	**Millet**	**Sunn hemp**	**Millet**
Rates of nitrogen (kg/ha)						
0	26	25	852	759	14.190	14.756
50	27	25	859	806	14.661	19.159
100	26	28	903	871	16.334	14.572
200	25	25	791	701	15.241	15.882
Effect of regression	ns	ns	ns	Q**	ns	ns
Cover crops (CC)	ns		ns		ns	
Rates of nitrogen (NN)	ns		**		ns	
CC x LN	ns		ns		ns	

ns= non significant; **and*= significant at 1 and 5% probability; Q= quadratic regression.

flower bunches in tomato (Figure 1c). On the secondary stalk, the quantity of flower bunches was similar between treatments, with average of 5 flower bunches. Leaf dry mass of tomato had maximum values with the 104 kg/ha of N when it was grown after the sunn hemp (Figure 1e). However, the treatments had no effect on the fresh mass of fruit, that had average value of 2,3 kg/plant, as well as on the number of marketable and non-marketable fruits, that had average values of 20 and 22 fruits/plant respectively, when measured at 100 days after transplanting of tomato.

When tomato was cultivated on the sunn hemp straw, the diameter of the base of main stalk, the diameter of the base and top of secondary stalk showed maximum values with 200 mm, In rotation with the millet, the maximum values of secondary stalk base diameter were obtained with 78 kg/ha of N (Figure 2b). Although the vegetable recovery rate from nitrogen originating from biologic fixation is relatively low, around 12 to 35% (Lenzi *et al*., 2009), it is still enough to raise the plant nutritional state and

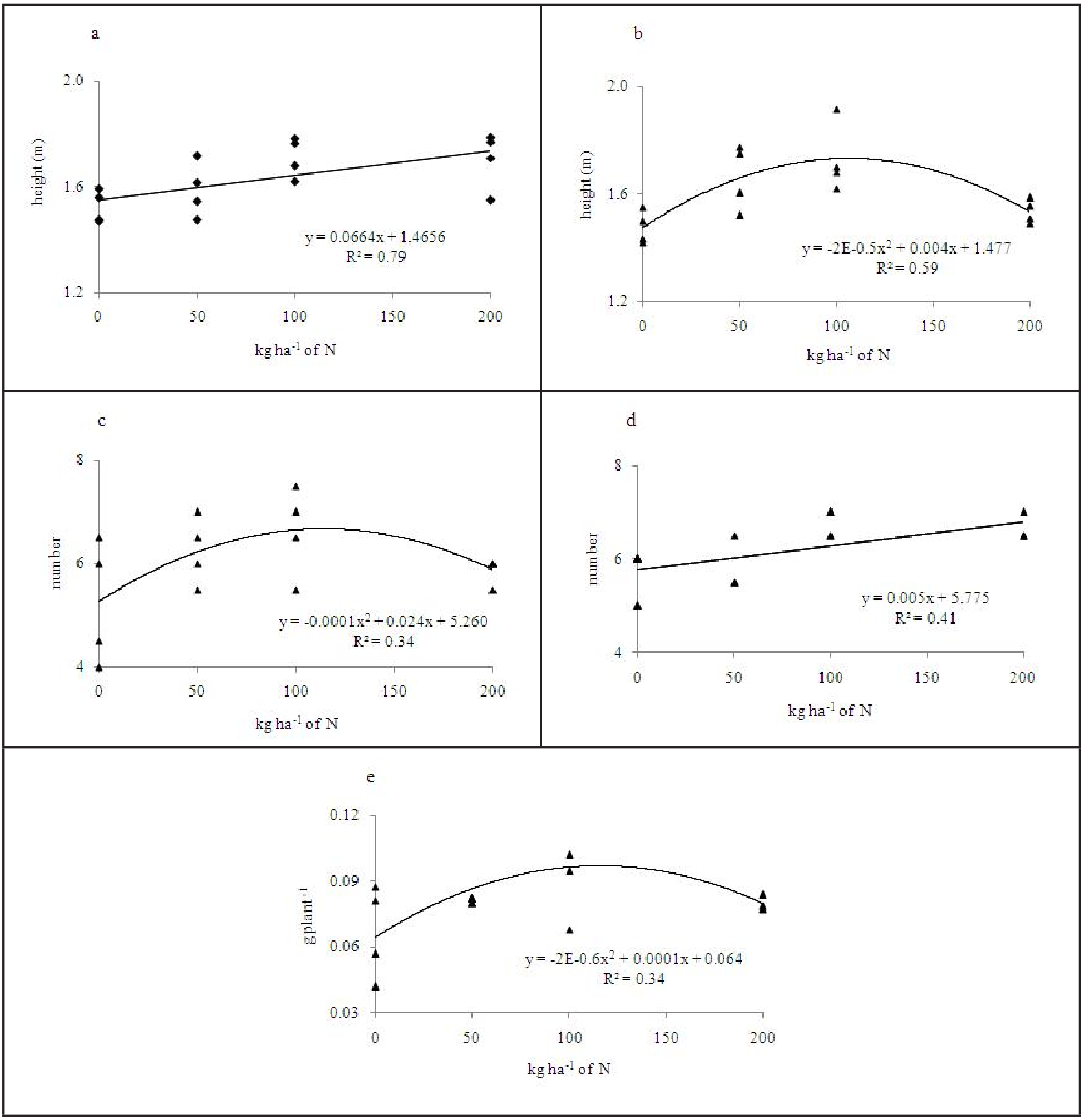

Figure 1. Response to rates of nitrogen: height of main stalk of tomato grown on millet (a) and on sunn hemp straw (b); quantity of flower bunches of tomato grown on sunn hemp (c) and on millet straw (d); leaf dry mass of tomato grown on sunn hemp straw (e). Ribeirão Preto, APTA, 2012.

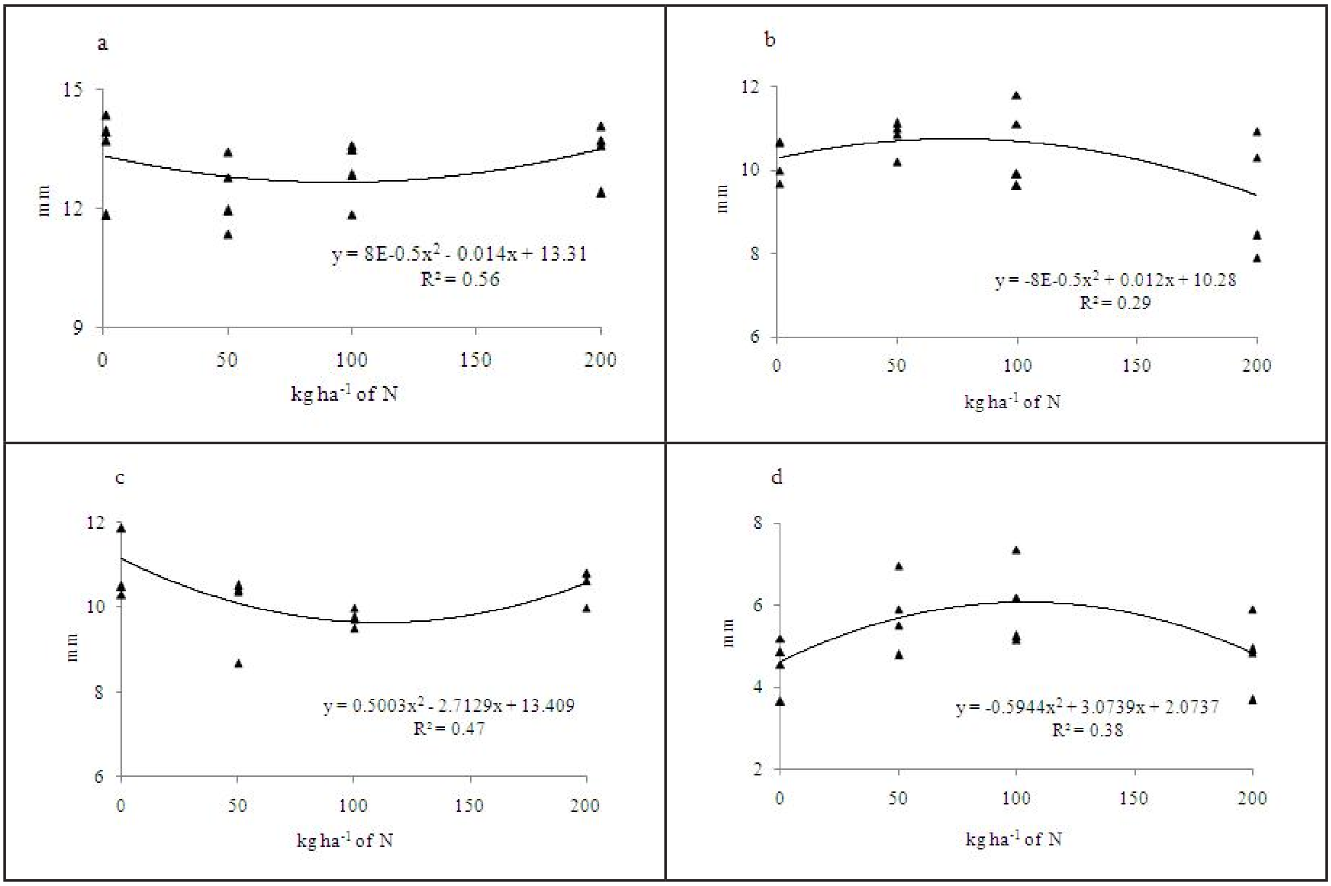

Figure 2. Characteristics evaluated in response to rates of nitrogen: Basal diameter of main stalk of tomato grown on sunn hemp straw (a); basal diameter of secondary stalk of tomato grown on millet (b) and sunn hemp straw (c); top diameter of secondary stalk of tomato grown on sunn hemp straw (d) . Ribeirão Preto, APTA, 2012.

favour vegetable growth and yield. When tomato is cultivated following legumes and grasses, in no-tillage or conventional tillage, Delate *et al.* (2011) did not find any difference between cover crops species and tillage methods for the height of the tomato plant or the number of fruits or the crop yield. After vetch (*Pigeon pea*), a leguminous plant, the tomato displayed better vegetative and productive performance than when cultivated after species of grasses and *brassicaceaes*, which reflects in a significant reduction in the use of nitrogen fertilizers (Lenzi *et al.*, 2009). Our results showed quadratic regression of the nitrogen doses for leaf dry weight production and for tomato fruit yield after the sunn hemp, but insignificance with millet, with no difference between those cover crops, which differs from results indicating that leguminous species are more efficient at reducing nitrogen used on crops.

There were interaction effects of the treatments to the number and yield of marketable fruits (Table 2) The maximum number of fruits and the yield of marketable fruits were obtained with 148 and 134 kg/ha when the tomato was cultivated in rotation with the sunn hemp (Figure 3a and 3b). When this crop was grown on the millet straw, rates of N applied did not promote any changes.

Regarding the nitrate content of tomato sprouts and fruits, there wasn't interactive effect between the treatments (Table 2). However, there was significant effect of nitrogen rates, with linear regression adjustment, on the nitrate content of sprouts when tomato was cultivated in rotation with the millet. No effect was observed on the nitrate content of tomato fruits.

This result contradicts the expectation that the legume would reduce nitrogen fertilization, as already shown by Sainju *et al*. (2001). These authors reported similar fruit yield and biomass of tomato when 90 and 180 kg/ha of N were used after cover crop and in no tillage conditions. They concluded that it would not be necessary the N fertilization in tomato crops when leguminous cover crops were used but after grasses growing, those values were lower than with the use of nitrogen fertilizer. Although vegetable productivity when cultivated after legumes has been similar with rates varying in the range of 15 to 200 kg/ha of N (Sainju & Sing, 1997). However, the results of this study showed reduction of N fertilizer even when tomato was cultivated after millet.

Tomato yield responses are limited to uses of nitrogen higher than 60 kg/ha when cultivated after cover crops (Thönnissen *et al.*, 2000). These results showed that nitrogen accumulated and recycled by millet in its shoot may have contributed enough to the nitrogen availability for tomato nutrition, and it reduced the quantity of nitrogen fertilizer used in the grown. Considering the high C/N rate and the dry weight

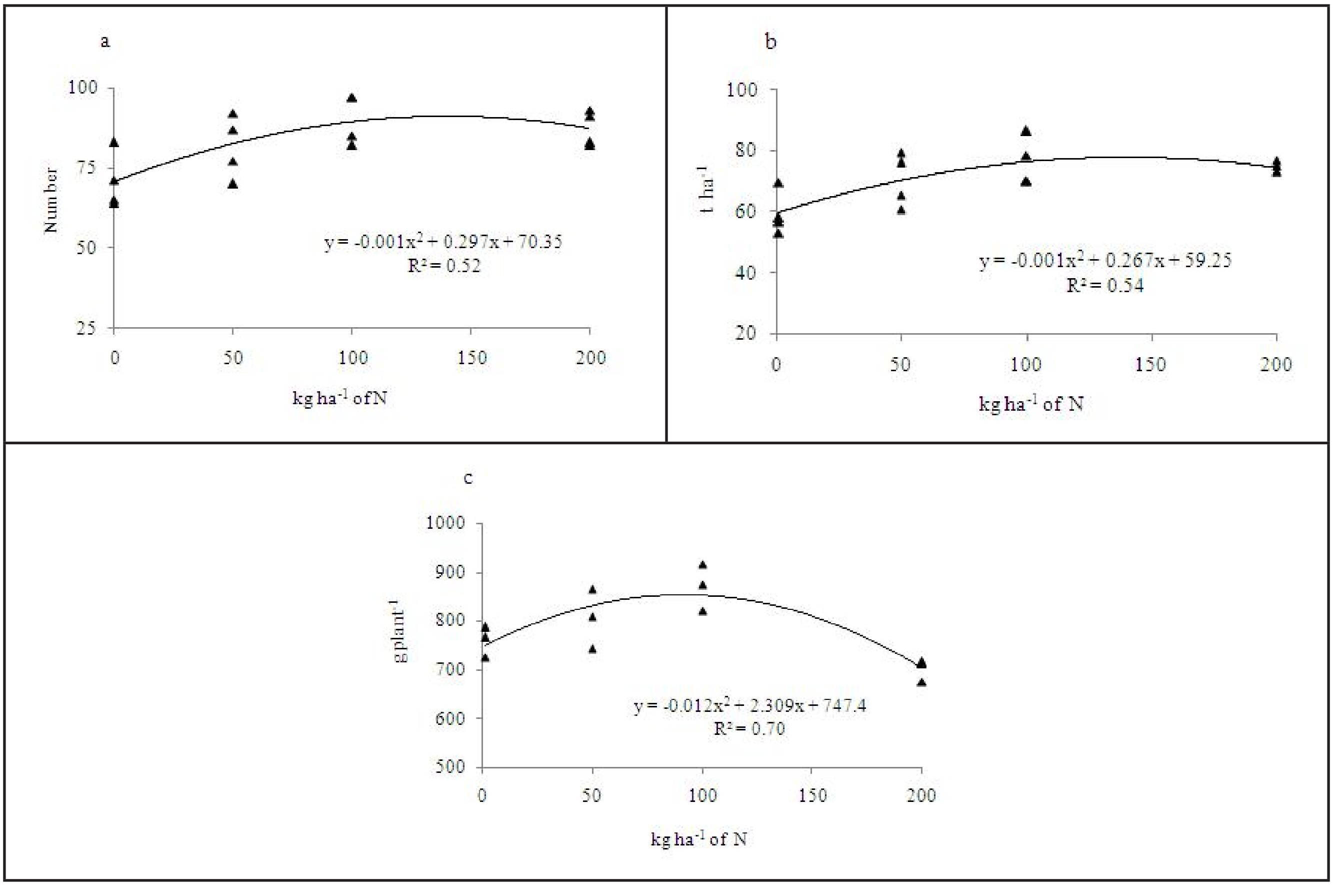

Figure 3. Characteristics evaluated in response to rates of nitrogen: Commercial tomato fruit number (a) and commercial tomato yield grown on sunn hemp straw (b); fresh mass of inflorescence of broccoli grown on millet straw (c). Ribeirão Preto, APTA, 2012.

yield of millet compared to sunn hemp, this crop could provide better protection to the soil surface, and improve the use efficiency of nitrogen through the good synchrony of mineralization and demand for the next crop (Rosolem *et al.*, 2004).

The maintenance of the straw on the soil surface and preserving soil structure in no-tillage benefits the root growth of tomato, which improves nutrient absorption, but elevated soil compaction in no-tillage may reduce productivity given restricted root growth and nutrient absorption (Sainju *et al.*, 2000; Yaffa *et al.*, 2000).

The tomato yield response after cover crops and nitrogen fertilization is greatly variable, mostly due to crop environment (Lenzi *et al.*, 2009). When cultivated after incorporation of maize straw, the tomato did not respond to nitrogen fertilization, a fact related to the increase in soil organic matter, whereas in other cultivation conditions, it had linear or quadratic productivity in response to nitrogen rates used in cultivation, with better doses between 97 and 167 kg/ha (Faria *et al.*, 1996). Kumar *et al.* (2005) report that although cover crops enable better vigor and productivity of tomato, nitrogen fertilization favours the crop yield performance, independently of the species used as cover, either legumes or grasses. Using vetch as a cover crop before tomato, Araki & Ito (2004) reported significant reduction in nitrogen fertilization of tomato crops.

For the broccoli cultivation, no effect of the treatments was observed on the dry mass of leaves, inflorescence stalk, inflorescence diameter, and foliar area of plants (Table 3). However, the rates of N increased the inflorescence fresh mass when broccoli was grown in rotation with millet and the maximum yield was achieved with 96 kg/ha of N, displaying a quadratic regression (Figure 3c). In a situation where the cultivation area is in conservationist practices, with emphasis on the improvement of soil organic matter, broccoli does not have productive response as a function of nitrogen fertilization. Whereas in an environment where the soil has low content of organic matter, the response to nitrogen fertilization was significant, even with utilization of cover crops before cultivation (Muramoto *et al.*, 2011).

In conclusion, the nitrogen rates applied on the vegetables interacted with the cover crops for the agronomic characteristics of tomato plants, given that when in rotation with sunn hemp, the response was significant until a certain nitrogen level for plant height and fruit yield, as well as broccoli inflorescence fresh weight in rotation with millet. So the quantity of N applied to achieve great production of the tomato and broccoli was reduced in relation to current recommendation, regardless of cover crops that were used. The technology of vegetable cultivation in no-tillage and after cover crops (both millet and sunn hemp) reduces the amount of nitrogen and consequently the environmental impact of the production system.

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