Revista
Brasileira de
Ciência do Solo

Division - Soil Use and Management | Commission - Soil Fertility and Plant Nutrition

Nutrient uptake and removal by sweet potato fertilized with green manure and nitrogen on sandy soil

Adalton Mazetti Fernandes[(1)*], **Natália Silva Assunção**[(2)], **Nathalia Pereira Ribeiro**[(2)], **Bruno Gazola**[(2)] **and Rudieli Machado da Silva**[(2)]

[(1)] Universidade Estadual Paulista "Júlio de Mesquita Filho", Centro de Raízes e Amidos Tropicais, Botucatu, São Paulo, Brasil.
[(2)] Universidade Estadual Paulista "Júlio de Mesquita Filho", Faculdade de Ciências Agronômicas, Botucatu, São Paulo, Brasil.

ABSTRACT: Sweet potato crops take up large amounts of nutrients, especially nitrogen. In low-fertility soils, the addition of nitrogen (N) increases the sweet potato yield. Green manure may be an alternative method for improving soil quality and supplying nutrients to this crop. This study aimed to evaluate the plant's nutritional status and the amount of nutrients taken up and removed by sweet potato plants subjected to green manure and mineral N fertilization. The experiment was carried out in the field for two growing seasons using a randomized block design in a split-plot scheme with four replications. The plots consisted of a control treatment (spontaneous weeds) and the previous cultivation of *Crotalaria spectabilis* and *Mucuna aterrima*. The subplots consisted of four N rates (0, 50, 100, and 200 kg ha^{-1}) that were applied to the sweet potato. The species *M. aterrima* is more suitable for use as green manure in the sweet potato than *C. spectabilis*. Nitrogen application rates promoted a greater increase in the biomass of the storage root, nutrient uptake, and removal in the sweet potatoes unfertilized with green manure. In the sweet potato fertilized with *M. aterrima*, mineral N supply in excess (above 50 kg ha^{-1}) increases the nutrient uptake and removal without a significant increase in the biomass of the storage root. In the sweet potatoes unfertilized with green manure, high rates of N (greater than 120 kg ha^{-1}) must be applied to obtain the utmost biomass of the storage root, nutrient uptake and removal.

Keywords: *Ipomoea batatas* L., nutritional demand, nutrient availability, root biomass, organic fertilization.

*** Corresponding author:**
E-mail: adalton.fernandes@unesp.br

Received: September 25, 2019

Approved: January 23, 2020

How to cite: Fernandes AM, Assunção NS, Ribeiro NP, Gazola B, Silva RM. Nutrient uptake and removal by sweet potato fertilized with green manure and nitrogen on sandy soil. Rev Bras Cienc Solo. 2020;44:e0190127.
https://doi.org/10.36783/18069657rbcs20190127

INTRODUCTION

The sweet potato (*Ipomoea batatas* L.) produces high root yields per unit of area and time even on marginal lands (Uwah et al., 2013; Duan et al., 2018). Nevertheless, sweet potato crops take up large amounts of nutrients from the soil (Echer et al., 2009). A study performed in a Brazilian tropical sandy soil has shown that nitrogen (N) and potassium (K) are the nutrients taken up by the sweet potato in the largest amounts, with values of 350 and 226 kg ha^{-1} of N and K, respectively (Echer et al., 2009). Other nutrients are taken up by the plant in lower amounts; however, sweet potato has high nutrient demands from the beginning of the storage root bulking phase to the end of the sweet potato growth cycle (Echer et al., 2009; Rós et al., 2015). Considering that the uptake and removal of nutrients by the sweet potato are relatively high (Echer et al., 2009), supplying nutrients in an appropriate and balanced way becomes necessary so that the sweet potato can express its full production potential.

Using legumes as green manure is a strategy used to provide nutrients for sweet potato grown in succession and it is able to correct the nutritional deficiencies in the root crop when the cultivation of legumes is included in a program of crop rotation (Lebot, 2009). Green manuring with legumes has the advantage of performing biological N fixation to provide N (Weber, 1996) and other nutrients (Uzo, 1983) for plants that are grown in succession, in addition to improve the physical condition and biological activity of the soil (Espíndola et al., 1997; Carsky et al., 2001), increasing nutrient cycling and providing a better use of the fertilizers applied (Espíndola et al., 1997). Furthermore, the addition of plant residues improves the soil structure and aeration, which promotes the lateral growth of the storage roots and decreases the formation of crooked roots (Santos et al., 2006; Pimentel et al., 2009).

However, studies have shown that the species of green manure used can influence the yield of successively cultivated sweet potato (Okpara et al., 2004). Okpara et al. (2004), in a study on infertile soil in Nigeria, found that green manure with mucuna (*Mucuna pruriens*) provided a root yield similar to the yield obtained mineral NPK fertilizer and a higher yield than those under other green manure species. The positive effects of green manure have also been observed in other crops. In wheat, for instance, green manuring with legumes such as forage pea (*Pisum sativum L. subspecies arvense*), forage turnip (*Raphanus sativus* L.), and common vetch (*Vicia sativa* L.) provided yields equivalent to those obtained with the application of 80 kg mineral N ha^{-1}. Growing green manure may favor many crops cultivated in rotation or succession (Scivittaro et al., 2000; Araújo et al., 2005) in the same area by reducing weed infestations (Rosa, 2015) or suppressing nematode damage in horticultural crops (Djian-Caporalino et al., 2019). Vargas et al. (2017) verified that green manure with *C. juncea* had a sufficient N residual effect, which allows the cultivation of at least two short-cycle crops (broccoli followed by zucchini). Makarewicz et al. (2018) verified that potato tubers fertilized with green manure of Persian clover incorporated in the autumn had the highest amounts of phosphorus (P), K, calcium (Ca), and magnesium (Mg). Wilson et al. (2019) found that vetches and field peas managed as green manure were successful in meeting potato's N demand and resulted in potatoes with tuber yield and quality similar those of potatoes grown with conventional fertilizers.

Nutrients released by green manure and not taken up by crops can be lost (Lara-Cabezas et al., 2000) or incorporated into soil organic matter. Therefore, for green manure to provide an efficient supply of nutrients synchrony between the nutrients released from green manure residues and the period of the highest demand from the subsequent plant must be established (Stute and Posner, 1995; Viola et al., 2013). Thus, the green manure may not be sufficient to supply the nutritional demands of sweet potato grown in succession, which may require supplementation with mineral fertilizer.

Nitrogen is one of the nutrients most commonly taken up by sweet potato (Echer et al., 2009) and its supply, by either green manure or mineral fertilizer, is essential to promote plant growth and development. The N also has an important role in dry matter accumulation and the uptake of P and K, as well as in the formation and enlargement of the sweet potato storage roots (Villordon and Clark, 2014; Duan et al., 2018). Furthermore, N is one of the most important factors affecting shoot morphogenesis and the root yield of sweet potato (Ning et al., 2015; Duan et al., 2018) and since it influences the accumulation and distribution of dry matter in the plant (Lebot, 2009), N application increases plant growth and, consequently, the plant's demand for other nutrients (Fageria, 2001).

A positive interaction between N and P leads to an increase in P uptake and a higher yield (Fageria, 2001). Nitrogen can increase the growth of the absorbent roots and consequently increase the capacity of the roots to acquire P; on the other hand, N may reduce the soil pH as a result of NH_4^+ uptake and therefore increase the solubility of phosphate fertilizers (Wilkinson et al., 1999). The N supply, depending on its form (NH_4^+ or NO_3^-), may also increase or decrease micronutrient uptake due to changes in the soil pH (Fageria, 2001). The N-NO_3^- supply may increase calcium concentrations (Ca) in plants more than the N-NH_4^+ supply (Kawasaki, 1995); however, it is known that the response to N application in sweet potato can be reduced if the K availability is low (Lebot, 2009) since K is needed for rapid cambial activity in the storage roots where starch is stored (Rodriguez-Delfin et al., 2015). Nevertheless, the nutritional demands of sweet potato grown in succession with green manure and subjected to different N supply conditions have not been investigated. Therefore, a better understanding of the amount of nutrients that green manure can supply to sweet potato grown in succession, as well as the adequate level of N that should be provided to sweet potato in this management system is necessary to effectively enhance nutrient uptake and plant growth in sweet potato.

Thus, in the present study, we used a control treatment and two species of legumes for green manure, and we cultivated sweet potato in succession with different N fertilization rates to evaluate the nutritional status of the sweet potato and the amount of nutrients taken up and removed by sweet potato in this cropping system.

MATERIALS AND METHODS

Soil properties and location

The experiment was carried out in the field for two agricultural years (2014-2015 and 2015-2016) in an experimental area at the Center of Tropical Roots and Starches (CERAT) at São Paulo State University (UNESP). In the second agricultural year, the experiment was carried out in an area adjacent to the area of the first year. The experimental areas were located at the Experimental Farm of the College of Agricultural Science at UNESP (22° 77" S, 48° 57" W, and 740 m a.s.l.). Rainfall and temperatures were measured daily during the experimental period (Figure 1).

In both agricultural years (2014-2015 and 2015-2016), neither area was cultivated with crops of commercial interest, and the main spontaneous plants present in the areas were *Digitaria sanguinalis*, *Acanthospermum hispidum*, *Cenchrus echinatus*, *Cyperus rotundus*, *Commelina benghalensis*, *Brachiaria plantaginea*, *Bidens pilosa*, *Emilia sonchifolia*, and *Raphanus raphanistrum*. Before the implementation of the experiment, soil samples (0.00-0.20 m layer) were collected from each area, and the soil chemical and textural properties were determined according to van Raij et al. (2001) and Embrapa (1997) (Table 1). The soil of the experimental areas was classified as a sandy-textured *Latossolo Vermelho distroférrico* (Santos et al., 2018), which corresponds to an Oxisol (Soil Survey Staff, 2014), and had low cation exchange capacity (CEC) and nutrient availability.

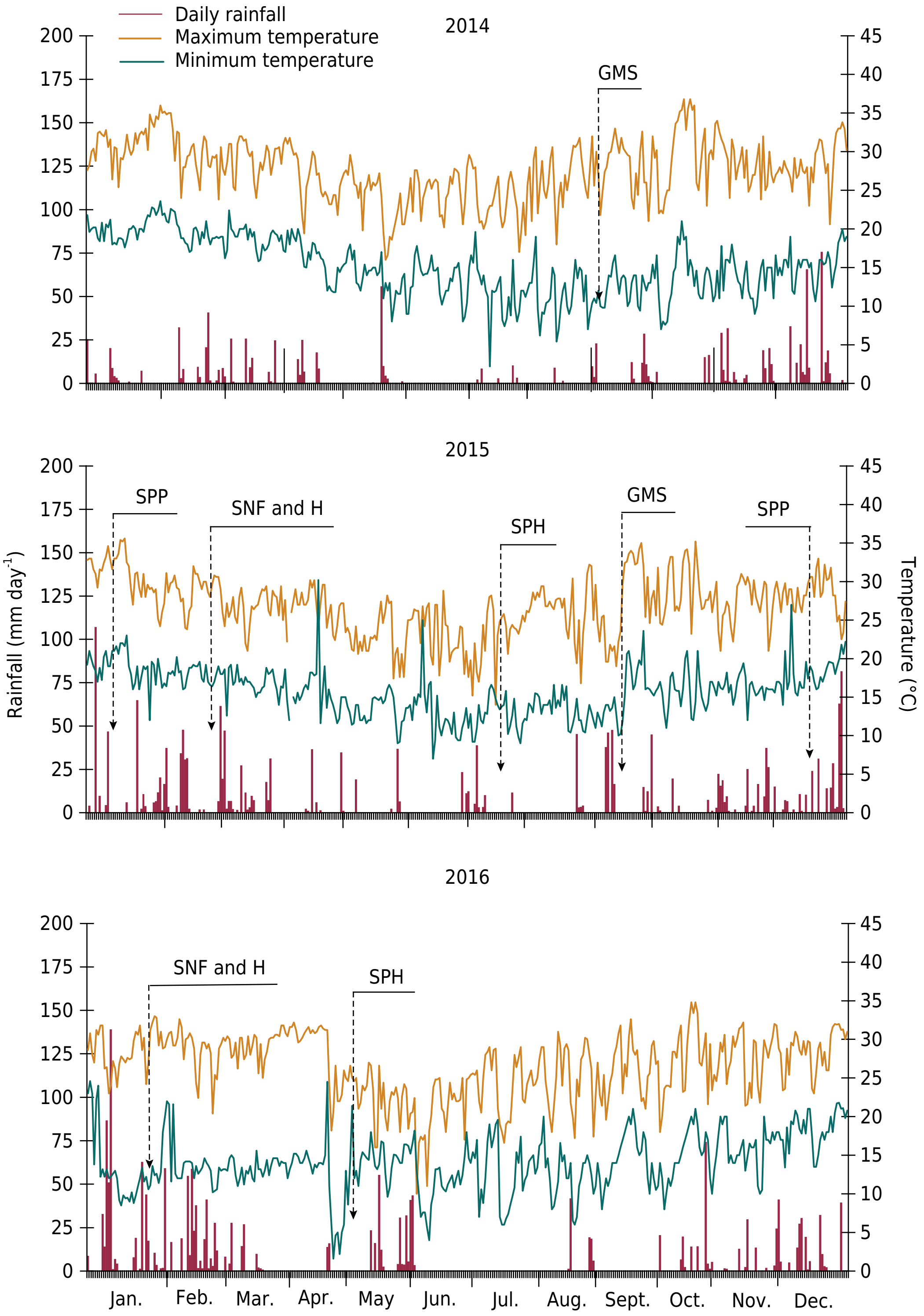

Figure 1. Daily rainfall, maximum, and minimum temperatures recorded in the field experimental area from January 2014 to December 2016 at São Paulo State, Brazil, and times of green manure sowing (GMS), sweet potato planting (SPP), side dressed N fertilization and hilling (SNF and H), and sweet potato harvest (SPH).

Experimental design and treatments

In these two agricultural years, a split-plot experimental design with four replications was used. The main plots were represented by a control treatment, composed of the spontaneous weeds of the seed bank and the previous cultivation of *C. spectabilis* and *M. aterrima*. The subplots consisted of four N rates (0, 50, 100, and 200 kg ha^{-1}) applied to the successively grown sweet potato.

Table 1. Soil chemical and textural properties at the experimental areas before green manure sowing

Soil property[1]	Agricultural year	
	2014-2015	2015-2016
pH($CaCl_2$)	5.6	5.5
Soil organic matter (g dm^{-3})	17	13
$P_{resin\text{-}extractable}$ (mg dm^{-3})	7	10
K^+ ($mmol_c$ dm^{-3})	0.7	3.0
Ca^{2+} ($mmol_c$ dm^{-3})	13	18
Mg^{2+} ($mmol_c$ dm^{-3})	7	5
Total acidity in pH 7.0 (H + Al) ($mmol_c$ dm^{-3})	14	14
CEC ($mmol_c$ dm^{-3})	34	40
Base saturation (%)	60	65
Cu (mg dm^{-3})	0.6	0.8
Fe (mg dm^{-3})	19	17
Mn (mg dm^{-3})	11.5	11.7
Zn (mg dm^{-3})	1.3	1.2
Sand (g kg^{-1})	872	854
Silt (g kg^{-1})	24	58
Clay (g kg^{-1})	104	89

(1) Soil pH was determined in a 0.01 mol L^{-1} $CaCl_2$ suspension at a soil:solution ratio of 1:2.5. Soil organic matter was determined by colorimetric method using a sodium dichromate solution. Soil P and exchangeable Ca, Mg, and K concentrations were determined using an ion exchange resin. Total acidity at pH 7.0 (H+Al) was extracted with calcium acetate at pH 7.0 and determined by titration. The soil CEC is the sum of the concentration of H+Al, K^+, Ca^{2+}, and Mg^{2+} cations. Base saturation was calculated by dividing the sum of the bases (K^+, Ca^{2+}, and Mg^{2+}) by the CEC and multiplying by 100 %. Soil Cu, Fe, Mn, and Zn concentrations were determined using diethylenetriamine pentaacetic acid (DTPA) and atomic absorption spectrophotometry. Soil B concentration was determined using hot water and spectrophotometry. Soil texture was determined by a pipette method.

Each main plot (green manure) was 8 m wide and 20 m long. Each subplot (N rate) was 4 m wide and 4 m long (4 m long × 4 subplots - N rate = 16 m long). Thus, the four subplots were arranged in front of each other and centered within the main plots, occupying an area of 4 × 16 m. Between the outer edge of each set of four subplots and the edge of each main plot, a 2 m border was maintained to ensure that the subplots were not installed at the transition site from one green manure to another. In each subplot, there were five 4-m-long rows of sweet potato spaced 0.80 m apart. For the evaluations, only the three central rows were considered, ignoring 0.5 m at the end of each row of plants.

Planting and management of green manures and sweet potato

In the two years, the soil preparation for planting green manures was performed by plowing and harrowing. The sowing of the green manures in both years was carried out by hand and with no mineral fertilizer on September 05th, 2014, and September 17th, 2015. The seeds of the green manure were incorporated into the soil with a closed harrow. In both years, the quantities of seeds used for sowing were 8 and 80 kg ha^{-1} of the species *C. spectabilis* and *M. aterrima*, respectively (Burle et al., 2006). In the control treatment, the soil was prepared, but there was no sowing of any species, i.e., the spontaneous weeds that emerged later were from the soil seed bank.

On January 07th, 2015, and December 10th, 2015, at the beginning of the flowering phase of *C. spectabilis* and *M. aterrima*, the sampling and quantification of dry matter (DM) production of green manures and spontaneous weeds (control) were performed. Subsequently, the areas were managed with a brush cutter, and the residues of the green manures and spontaneous weeds were incorporated into the soil during preparation by harrowing.

For sweet potato planting, 15 cm furrows were opened at a distance of 0.80 m between the rows. The fertilizers were applied in the furrows. Planting fertilization was performed in both years with 100 kg P_2O_5 ha^{-1} using simple superphosphate fertilizer. In the first year, as the soil K concentration was lower (Table 1), 120 kg K_2O ha^{-1} was applied. In the second year, K fertilization was performed using 60 kg K_2O ha^{-1}. Potassium chloride was always the source of the K fertilizer. Phosphorus and K rates were defined based on the soil analysis (Table 1) and the recommendations of Lorenzi et al. (1997). The N rates established in each treatment were applied in parts, with 50 % of each amount at planting and 50 % in the side dressing at 45 days after planting (DAP) (March 04th, 2015 and January 29th, 2016) using urea as the fertilizer.

After the fertilizer application in the planting furrows, 0.30 m hills were built over the fertilized furrows. The sweet potatoes were planted in wet soil on January 15th, 2015, and December 15th, 2015. For the planting, a 0.40 m branch of the cultivar Canadense was used per pit with a 0.30 m distance between plants. The planting was carried out by burying 3 to 4 internodes from the base of the branches to a depth of 10 to 12 cm from the top of the hills.

The sweet potato cropping was carried out with no irrigation. During the crop development period, all cultural practices recommended for sweet potato were performed according to their needs. The experiment was harvested on June 22nd, 2015 and May 07th, 2016 (158 and 144 DAP, respectively).

Plant sampling and analysis

During the flowering phase of *M. aterrima* and *C. spectabilis*, four random samples of all vegetation present on the soil surface of all plots, including the spontaneous weeds in the control plot, were collected in an area of 0.25 m^2. The samples were washed, oven-dried at 65 °C for 96 h, and weighed to obtain the amount of dry matter (DM) accumulated per hectare.

The evaluation of the nutritional status of the sweet potatoes was performed by collecting fully developed fresh leaves from the apex of the branch at 60 DAP, according to the methodology proposed by Lorenzi et al. (1997).

During the sweet potato harvest, which took place on June 22nd, 2015, and May 07th, 2016, four plants were collected in the useful area of each subplot. After being harvested, the plants were washed, separated into shoots and storage roots, and dried in an oven with forced air circulation at 65 °C for 96 h. After being dried, the samples were weighed to obtain the amounts of DM accumulated. The harvest index (HI) was calculated as the proportion of DM accumulated in the storage roots in relation to the DM accumulated in the whole plant (Jenkins and Mahmood, 2003). The total fresh root yield was obtained by weighing the roots that were present in two 1.8 m (± 12 plants) rows from each subplot, and the values were converted to Mg ha^{-1}.

The dry samples of the biomass of the spontaneous weeds and legumes, the leaf evaluation, and the shoots and storage roots of the sweet potato were separately ground to pass through a 40-mesh stainless steel sieve and were subsequently chemically analyzed. The N concentration in the samples was determined by digestion with H_2SO_4 (sulfuric acid) and quantified by the semimicro-Kjeldahl method (Malavolta et al., 1997). Phosphorus, K, Ca, magnesium (Mg), sulfur (S), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) concentrations were determined by atomic absorption spectrophotometry after HNO_3 (nitric acid) and $HClO_4$ (perchloric acid) digestion (Malavolta et al., 1997).

The amounts of nutrients accumulated in the green manure and sweet potato plant parts were calculated by multiplying the nutrient concentration by the amount of DM accumulated in each plant part. The nutrient uptake by the sweet potato was obtained by the sum of the nutrient amount accumulated in the shoots and the storage roots. The nutrient removal was assessed based on the amounts of nutrients accumulated in the storage roots.

Statistical analysis

The data were analyzed using the SISVAR statistical software package (Ferreira, 2011). However, as the primary objectives were to study the nutritional status of the plant and the nutrient uptake and removal by the sweet potato in response to green manure sources and N application rates, we only considered the significant effects of the green manure, N rate, and the green manure × N rate interaction. The data were combined across the two agricultural years. For the main effects of the green manure, the means were compared using the LSD test at the 0.05 probability level, and the N rates were analyzed by regression analysis using SigmaPlot 10.0 software. To analyze the significant green manure × N rate interaction, the green manure means were separated using Fisher's protected LSD test at the 0.05 probability level, and the regression equations were separately adjusted to the values of the green manure treatments.

RESULTS

Biomass yield and nutrient concentration and uptake in green manures

The biomass accumulation in the area with *C. spectabilis* was 41 and 121 % greater than those in the areas with *M. aterrima* and spontaneous weeds (control), respectively (Table 2). *C. spectabilis* accumulated greater amounts of macronutrients, Cu, and Zn than those in the other treatments; however, the Fe accumulated in the biomass of *C. spectabilis* showed no difference between that in the treatment with *M. aterrima*. Only the amounts of Mn accumulated by *M. aterrima* were greater than those in the *C. spectabilis* treatment. The spontaneous weeds (control) always presented lower nutrient accumulation in their biomass than the other green manures.

Plant nutritional status, biomass yield, harvest index, and fresh storage root yield of sweet potato

The concentrations of P, K, Ca, Mg, and S in the sweet potato leaves were influenced only by the green manures (main factor) (Table 3). The cultivation of *C. spectabilis* before the sweet potato provided higher concentrations of P and K in the leaves when compared to the other treatments. In contrast, the concentrations of Mg and S in the plant leaves in the treatment with *C. spectabilis* were only greater than those in the *M. aterrima* treatment. The Ca concentration in the plant leaves in the control treatment was only greater than that of the *M. aterrima* treatment.

The concentrations of N, Cu, Fe, and Mn in the sweet potato leaves were affected by the green manure × N rate interaction (Table 3). Nitrogen fertilization did not change the N concentration in the sweet potato leaves grown after *M. aterrima*; however, in the control treatment and the treatment with *C. spectabilis*, N fertilization increased the leaf N concentration up to between 197 and 200 kg N ha^{-1} (Figure 2a). However, at the lowest N rates, the concentration of N in the sweet potato leaves grown after *M. aterrima* was greater than that in the control treatment.

The Cu concentration in the sweet potato leaves of the control treatment increased linearly with N fertilization, and the Cu concentration in the sweet potato leaves increased up to the N rate of 94 kg N ha^{-1} after *M. aterrima* (Figure 2b). In the treatment with *C. spectabilis,* the Cu concentration in the sweet potato leaves decreased up to the N rate of 133 kg N ha^{-1}. However, at all N rates, the Cu leaf concentrations were highest in the *M. aterrima* treatment.

Table 2. Soil cover, nutrient concentration, and amount of nutrients in the plant residues of the green manures before soil preparation and sweet potato planting in the experimental area. Data are the means of the two agricultural years

Variables(1)	Green manures			ANOVA (F probability)
	Control(2)	*C. spectabilis*	*M. aterrima*	
Soil cover-biomass (Mg ha^{-1})	3.9c	8.6a	6.1b	<0.001
Concentration (g kg^{-1})				
N	11.4b	24.5a	27.0a	<0.001
P	1.4c	2.1a	1.7b	<0.001
K	15.0b	17.9a	17.7a	<0.001
Ca	3.3b	6.7a	7.4a	<0.001
Mg	2.5b	3.1a	2.4b	0.006
S	0.9b	1.4a	1.1b	<0.001
Concentration (mg kg^{-1})				
Cu	9.6b	14.8a	14.7a	<0.001
Fe	316.4ab	288.2b	354.4a	<0.001
Mn	78.7a	55.9b	84.1a	<0.001
Zn	38.2c	53.5a	44.8b	<0.001
Accumulation (kg ha^{-1})				
N	45c	211a	159b	<0.001
P	5.6c	18.3a	9.8b	<0.001
K	61c	156a	101b	<0.001
Ca	14c	58a	44b	<0.001
Mg	10c	27a	14b	<0.001
S	3.9c	12.4a	6.1b	<0.001
Accumulation (g ha^{-1})				
Cu	41c	129a	80b	<0.001
Fe	1201b	2386a	2320a	<0.001
Mn	301c	474b	537a	<0.001
Zn	159c	466a	265b	<0.001

Values followed by the same letter in the line are not significantly different at $p \leq 0.05$ according to LSD test. (1) Soil cover-biomass was determined by collecting and weighing of the plant residues dry matter (DM) in an area of 0.25 m^2. Nutrient concentration in the plant residues was determined by the method described by Malavolta et al. (1997). The amounts of nutrients accumulated in the soil cover-biomass were calculated by multiplying the nutrient concentration by the amount of DM. (2) Values refer to the spontaneous weeds present in the experimental area.

Table 3. Nutrient concentration in the first fully expanded leaves of sweet potato in response to green manures cultivation. Data are the means of the two agricultural years

Variables(1)	Green manures(2)			ANOVA (F probability)		
	Control	*C. spectabilis*	*M. aterrima*	GM	N	GM×N
N (g kg^{-1})	35.6b	37.5a	37.9a	0.012	<0.001	0.003
P (g kg^{-1})	3.6b	4.0a	3.7b	<0.001	ns	ns
K (g kg^{-1})	35.6b	37.9a	32.9c	<0.001	ns	ns
Ca (g kg^{-1})	9.5a	9.1ab	8.6b	0.034	ns	ns
Mg (g kg^{-1})	3.5a	3.7a	3.1b	0.003	ns	ns
S (g kg^{-1})	4.3ab	4.5a	4.1b	0.039	ns	ns
Cu (mg kg^{-1})	8.4c	9.6b	20.1a	<0.001	<0.001	<0.001
Fe (mg kg^{-1})	358.4a	300.3b	309.5b	<0.001	<0.001	<0.001
Mn (mg kg^{-1})	68.7a	56.9b	52.9c	<0.001	<0.001	0.007
Zn (mg kg^{-1})	31.6a	27.5b	28.9b	<0.001	0.014	ns

Values followed by the same letter in the line are not significantly different at $p \leq 0.05$ according to LSD test. ns: not significant at $p \leq 0.05$. (1) Nutrient concentration was determined by the method described by Malavolta et al. (1997). (2) The green manure values are the means of N rates (0, 50, 100, and 200 kg ha^{-1}) from each green manure treatment.

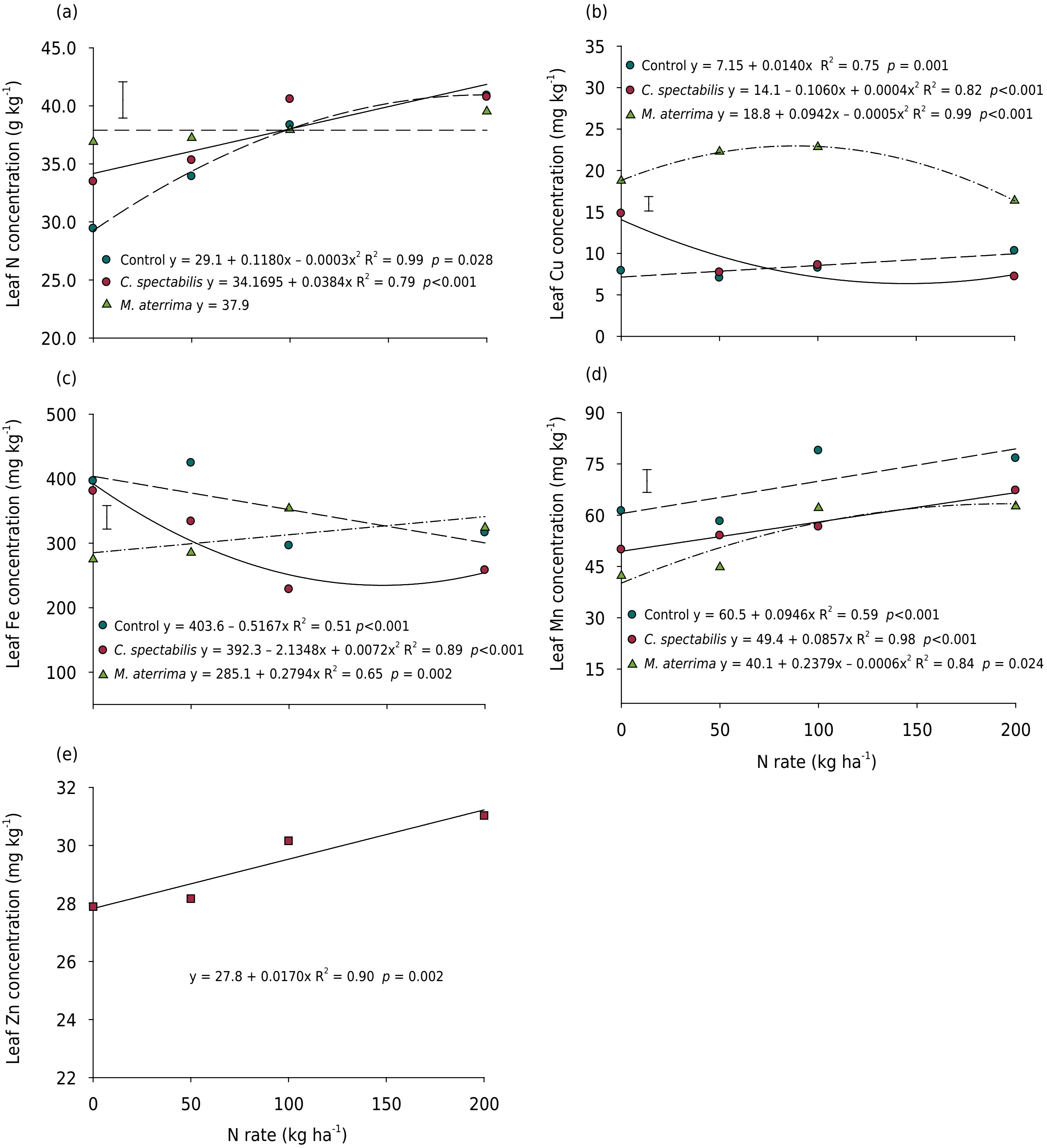

Figure 2. Nitrogen (a), Cu (b), Fe (c), Mn (d), and Zn (e) concentration in the first fully expanded leaves of sweet potato in response to green manure cultivation and N application rate. Square: mean of the three green manure treatments (Control, *C. spectabilis*, and *M. aterrima*). Vertical bars represent the least significant difference at $p \leq 0.05$ according to LSD test. Data are the means of the two agricultural years.

In the control and *C. spectabilis* treatments, N fertilization reduced the Fe concentration in the sweet potato leaves linearly and up to the N rate of 148 kg N ha^{-1}, respectively (Figure 2c). In the *M. aterrima* treatment, the leaf Fe concentration increased linearly with N fertilization. Thus, at the lowest N rates, the leaf Fe concentration was higher in the control and *C. spectabilis* treatments, but at the highest N rate, the leaf Fe concentration in the *M. aterrima* treatment was greater than that in the *C. spectabilis* treatment.

The Mn concentration in the sweet potato leaves increased linearly with N fertilization in the control and *C. spectabilis* treatments, but in the *M. aterrima* treatment, the increase occurred up to the N rate of 198 kg N ha^{-1} (Figure 2d). In the absence of N, the Mn concentrations in the sweet potato leaves were highest in the control treatment. At the highest N rates, the Mn concentrations in the plant leaves of the control treatment surpassed those of other treatments, which did not differ from each other.

The Zn concentration in the sweet potato leaves was significantly affected by the green manure and N rate (main factors); however, this variable was not significantly affected by the green manure × N rate interaction (Table 3). The absence of significant green manure × N rates interaction indicates that the green manures studied influenced the Zn concentration in the sweet potato leaves regardless of the amounts of N applied (0, 50, 100, or 200 kg ha^{-1}), and that the response of sweet potato to N fertilization was the same in any of the green manure treatments (Control, *C. spectabilis*, and *M. aterrima*). Thus, in the control treatment, it was observed that the concentration of Zn in the leaf was higher than those in the treatments with legumes (*C. spectabilis* and *M. aterrima*), which did not differ from each other. Moreover, N fertilization linearly increased the mean values of Zn concentration in the sweet potato leaves of all green manure treatments (Control, *C. spectabilis*, and *M. aterrima*) (Figure 2e).

The DM accumulated in the whole plant, the total fresh storage root yield, the DM accumulated in the storage roots, and the harvest index were influenced by the green manure × N rate interaction (Table 4). The total yield of fresh storage roots and the biomass of the whole plant and storage roots were increased by N fertilization in all green manure treatments. However, in the control treatment, the increase in the plant and root biomass and the total yield of fresh storage roots in response to N rates was 65 to 74 %, whereas increases of 26 to 43 % and 20 to 28 % were observed in sweet potato grown after *C. spectabilis* and *M. aterrima*, respectively (Figures 3a and 3b). At N rates lower than 100 kg ha^{-1}, the total yield of fresh storage roots as well as the plant and root biomass did not differ between the two legume treatments but were higher than those in the control treatment. Under high N rates, the green manure did not affect either the sweet potato biomass or the total yield of fresh storage roots. The harvest index (HI) decreased as the N rate increased in the *C. spectabilis* treatment, but it increased up to the rates of 53 and 95 kg N ha^{-1} in the control and *M. aterrima* treatments, respectively (Figure 3d). In the absence of N, the HI did not differ between the control and *C. spectabilis* treatments, and the HI was higher in the control and *C. spectabilis* treatments than in the *M. aterrima* treatment. When N rates were above 100 kg ha^{-1}, the HI in the *C. spectabilis* treatment was lower than those of the other treatments, which did not differ from each other.

Nutrient concentrations in sweet potato plant parts

The analysis of the green manure × N rate interaction is presented for the nutrient concentration in the shoots and storage root of sweet potato (Tables 5 and 6). Nitrogen fertilization did not affect the P, Fe, or Mg concentration in the sweet potato shoot, but the P concentrations in the shoot were lower in the legume treatments (Table 5). The Mg concentrations in the sweet potato shoots of the *C. spectabilis* treatment were higher than those in the control treatment only at zero (0) and 100 kg N ha^{-1}. The Fe concentrations in shoots were nearly unaffected by green manure (Table 5). Nitrogen fertilization linearly increased the N and Cu concentrations in the sweet potato shoots in the *M. aterrima* treatment. In the control and *C. spectabilis* treatments, N fertilization did not influence the N and Cu concentrations in the shoots. Overall, the N concentrations in the sweet potato shoots of the *M. aterrima* treatment were higher than those in the control only at

Table 4. Whole plant dry matter (DM) accumulation at harvest, total yield of fresh storage roots, storage root DM accumulation, DM harvest index nutrient uptake, and removal by sweet potato in response to green manure cultivation. Data are the means of the two agricultural years

Variables(1)	**Green manures**(2)			**ANOVA (F probability)**		
	Control	***C. spectabilis***	***M. aterrima***	**G**	**N**	**G × N**
Whole plant DM (Mg ha^{-1})	9.4c	11.0b	11.9a	<0.001	<0.001	0.025
Total yield of fresh St. roots (Mg ha^{-1})	32.6c	38.0b	40.2a	<0.001	<0.001	0.008
Storage root DM (Mg ha^{-1})	7.4c	8.3b	9.1a	<0.001	<0.001	0.046
DM harvest index	0.78a	0.76b	0.76b	<0.001	<0.001	0.025
N uptake (kg ha^{-1})	79c	119b	128a	<0.001	<0.001	NS
P uptake (kg ha^{-1})	11.5c	13.7b	14.5a	<0.001	<0.001	0.007
K uptake (kg ha^{-1})	131c	155b	171a	<0.001	<0.001	0.004
Ca uptake (kg ha^{-1})	25.3c	32.2b	34.3a	<0.001	<0.001	<0.001
Mg uptake (kg ha^{-1})	13.3b	18.2a	18.1a	<0.001	<0.001	0.003
S uptake (kg ha^{-1})	12.6b	15.8a	16.2a	<0.001	<0.001	NS
Cu uptake (g ha^{-1})	71c	84b	100a	<0.001	<0.001	<0.001
Fe uptake (g ha^{-1})	2875b	3596a	3659a	<0.001	<0.001	0.011
Mn uptake (g ha^{-1})	267b	385a	394a	<0.001	<0.001	<0.001
Zn uptake (g ha^{-1})	111b	148a	154a	<0.001	<0.001	0.050
N removal (kg ha^{-1})	46b	71a	73a	<0.001	<0.001	NS
P removal (kg ha^{-1})	8.0b	10.1a	10.4a	<0.001	<0.001	0.048
K removal (kg ha^{-1})	89c	103b	114a	<0.001	<0.001	0.045
Ca removal (kg ha^{-1})	8.0c	9.3b	11.1a	<0.001	<0.001	0.023
Mg removal (kg ha^{-1})	4.5c	5.3b	5.9a	<0.001	<0.001	NS
S removal (kg ha^{-1})	6.2b	8.6a	8.1a	<0.001	<0.001	NS
Cu removal (g ha^{-1})	50c	60b	74a	<0.001	<0.001	<0.001
Fe removal (g ha^{-1})	935b	1131a	887b	<0.001	0.050	NS
Mn removal (g ha^{-1})	93c	102b	125a	<0.001	<0.001	0.014
Zn removal (g ha^{-1})	72b	86a	92a	<0.001	<0.001	0.050

Values followed by the same letter within a column are not significantly different at $p \leq 0.05$ according to LSD test. NS: not significant at $p \leq 0.05$. (1) Wole plant DM and storage root DM were determined by weighing the dry samples of each plant part. Total yield of fresh storage roots was determined by weighing the samples of fresh storage roots. Nutrient uptake was determined by multiplying plant biomass by nutrient concentrations obtained according to the methods of Malavolta et al. (1997). Nutrient removal was determined by multiplying the storage root biomass by the concentration of nutrients in the storage roots obtained according to the methods of Malavolta et al. (1997). (2) The green manure values are the means of N rates (0, 50, 100, and 200 kg ha^{-1}) from each green manure treatment.

N rates above 50 kg N ha^{-1}, and at the lowest N rate, the Cu concentration in the shoot of the control exceeded those of the legume treatments.

The K, Ca, and S concentrations in the sweet potato shoot increased quadratically up to N rates between 102 and 112 kg N ha^{-1} in the *C. spectabilis* treatment (Table 5). However, the K concentrations in shoots in the *C. spectabilis* treatment were lower at the lowest and highest N rates, whereas the S concentrations in the shoots in the legume treatments were lower than that in shoots in the control. The Ca concentration in the sweet potato shoot was not affected by the green manure, regardless of the N application rate. In the control, N fertilization increased the Mn concentration in the sweet potato shoot until 94 kg N ha^{-1}, whereas the Zn concentration decreased linearly with the N fertilization rate. In the legume treatments, the Mn and Zn concentrations in the sweet potato shoots were similar but were higher than those in the control, especially at higher N rates.

In the storage roots, the K concentration was not altered by the treatments and was 12.3 g kg^{-1} on average (Table 6). The N, Mg, and S concentrations in the plant roots of the control treatment were not affected by N fertilization. In the legume treatments,

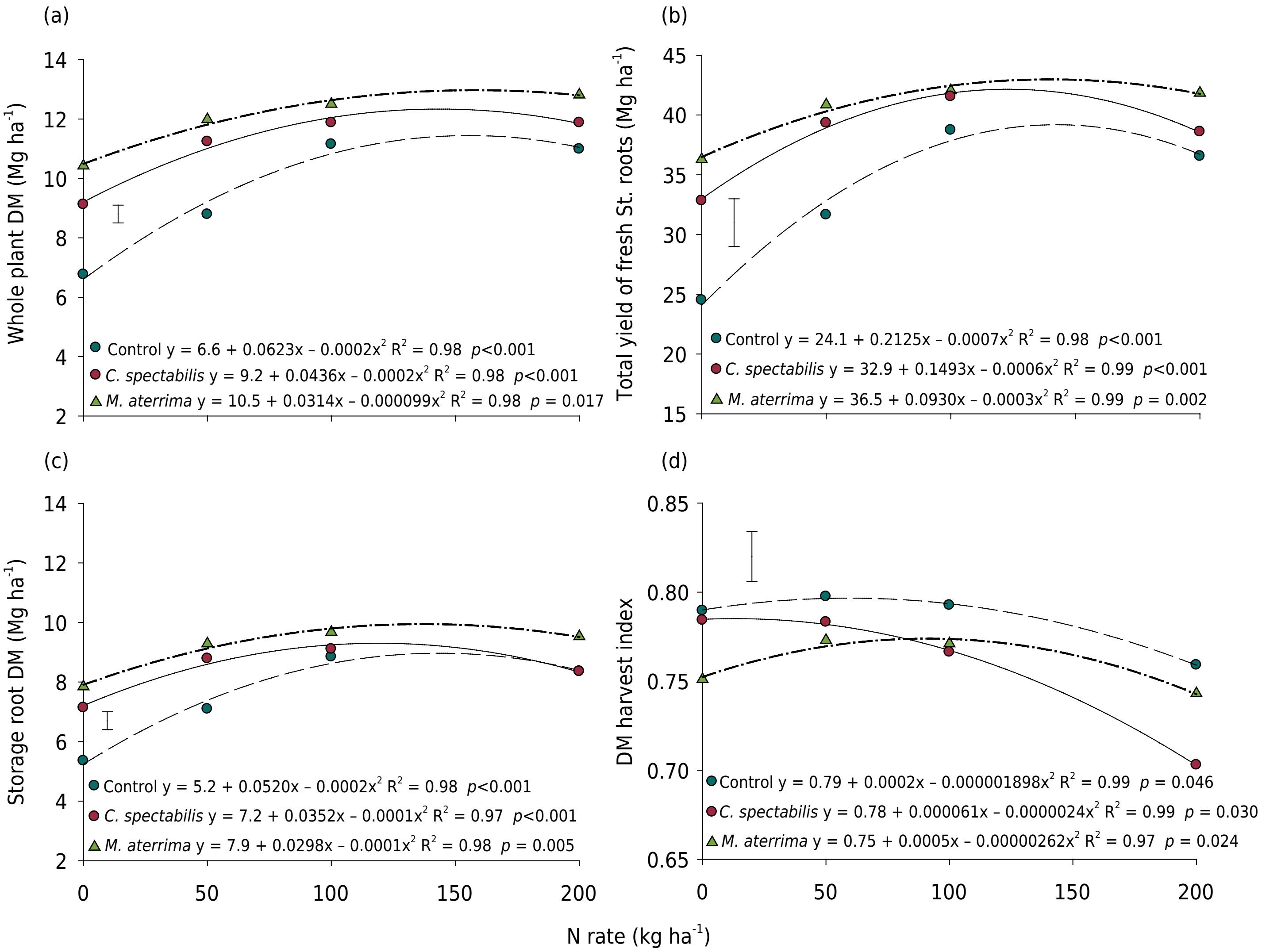

Figure 3. Whole plant dry matter (DM) accumulation at the harvest (a), total yield of fresh storage roots (b), storage root DM yield at the harvest (c), and DM harvest index (d) of sweet potato in response to green manures cultivation and N application rate. Vertical bars represent the least significant difference at $p \leq 0.05$ according to LSD test. Data are the means of the two agricultural years.

the N concentration in the plant roots increased linearly with N fertilization. The Mg concentration in plant roots increased linearly with N fertilization in the *C. spectabilis* treatment and up to the N rate of 110 kg N ha^{-1} in the *M. aterrima* treatment, while the S concentration in the *C. spectabilis* and *M. aterrima* treatments increased up to N rates of 102 and 124 kg N ha $^{-1}$, respectively. The green manures did not change the Mg concentration in sweet potato roots, while the S concentration in the roots of *C. spectabilis* treatment was higher, especially at zero (0) and 100 kg N ha^{-1}. The N concentration in the sweet potato roots of the legume treatments was higher than that in the control, especially at higher N rates.

In the control and *C. spectabilis* treatments, the P concentration in the sweet potato roots decreased linearly with the N fertilization rate, while the Fe concentration decreased up to N rates of 115 and 132 kg N ha^{-1}, respectively (Table 6). The green manures did not alter the P concentration in the sweet potato roots, but the Fe concentrations in the roots of the *C. spectabilis* treatment were higher than those in the *M. aterrima* treatment at all N rates. In the control, N fertilization increased the Cu concentration in the roots up to the rate of 126 kg N ha^{-1}, while in the legume treatments, there was a reduction in the concentration of Cu up to N rates between 98 and 115 kg N ha^{-1}. Especially at the lowest and highest N rates, the Cu concentrations in the roots of the legume treatments were higher than that in the control treatment.

Table 5. Green manure × N rate interaction for nutrient concentration in the shoot of sweet potato. Data are the means of the two agricultural years

Green manure	**N rate (kg ha^{-1})**				**Regression**	***R*^{2}**
	0	**50**	**100**	**200**		
		N concentration (g kg^{-1})				
Control	16.4a	15.9a	15.7b	17.5b	y=16.4	ns
C. spectabilis	15.9a	18.2a	18.7ab	18.7ab	y=17.9	ns
M. aterrima	17.4a	18.7a	21.3a	21.2a	y=17.975+0.0185x	0.72*
		P concentration (g kg^{-1})				
Control	1.7a	2.0a	1.7a	1.6a	y=1.8	ns
C. spectabilis	1.3b	1.3b	1.2b	1.4b	y=1.3	ns
M. aterrima	1.5ab	1.5b	1.4b	1.3b	y=1.4	ns
		K concentration (g kg^{-1})				
Control	20.4a	23.7a	20.6a	22.2a	y=21.7	ns
C. spectabilis	17.1b	20.7ab	20.2a	18.8b	y=17.35+0.064042x-0.000285x^2	0.79*
M.aterrima	19.9a	19.5b	20.0a	21.2ab	y=20.1	ns
		Ca concentration (g kg^{-1})				
Control	7.7a	8.3a	8.6a	8.7a	y=8.3	ns
C. spectabilis	7.9a	8.7a	9.2a	8.1a	y=7.88+0.025412x-0.000124x^2	0.99*
M. aterrima	8.2a	8.5a	8.4a	7.8a	y=8.2	ns
		Mg concentration (g kg^{-1})				
Control	4.0b	4.2a	4.6b	4.5a	y=4.3	ns
C. spectabilis	4.6a	4.7a	5.4a	4.7a	y=4.9	ns
M. aterrima	4.3ab	4.3a	4.2b	4.5a	y=4.3	ns
		S concentration (g kg^{-1})				
Control	3.1a	3.4a	3.4a	3.3a	y=3.3	ns
C. spectabilis	2.7b	2.9b	3.0a	2.6b	y=2.62+0.007318x-0.000036x^2	0.99*
M. aterrima	2.6b	3.0b	3.1a	2.8b	y=2.9	ns
		Cu concentration (mg kg^{-1})				
Control	10.7a	10.0a	10.3a	9.8a	y=10.2	ns
C. spectabilis	8.1b	8.5b	9.0a	8.9a	y=8.6	ns
M. aterrima	8.3b	9.8a	9.1a	10.2a	y=8.725+0.007786x	0.53*
		Fe concentration (mg kg^{-1})				
Control	1038a	987ab	875a	956a	y=964	ns
C. spectabilis	928a	881b	1002a	818a	y=907	ns
M. aterrima	935a	1068a	970a	933a	y=977	ns
		Mn concentration (mg kg^{-1})				
Control	98.1a	79.8b	82.1b	101.1a	y=96.9-0.371523x+0.001970x^2	0.94**
C. spectabilis	104.6a	104.6a	108.8a	109.6a	y=106.9	ns
M. aterrima	98.0a	94.3a	99.6a	101.7a	y=98.4	ns
		Zn concentration (mg kg^{-1})				
Control	22.5a	18.0b	19.1b	16.9b	y=21.20-0.024429x	0.68*
C. spectabilis	21.6a	22.5a	23.8a	22.5a	y=22.6	ns
M. aterrima	20.5a	22.1a	22.2ab	21.3a	y=21.5	ns

Values followed by the same letter within a column are not significantly different at $p \leq 0.05$ according to LSD test. ns: not significant at $p \leq 0.05$; * $p \leq 0.05$; and ** $p \leq 0.01$.

In the *C. spectabilis* treatment, N fertilization linearly increased the Zn concentration in the sweet potato roots and quadratically reduced the Mn concentration in roots up to the rate of 39 kg N ha^{-1} (Table 6). The Ca concentration in the sweet potato roots in

Table 6. Green manure × N rate interaction for nutrient concentration in the storage roots of sweet potato. Data are the means of the two agricultural years

Green manure	**N rate (kg ha^{-1})**				**Regression**	R^2
	0	**50**	**100**	**200**		
		N concentration (g kg^{-1})				
Control	5.9b	6.2b	5.9b	7.1b	$y=6.3$	ns
C. spectabilis	8.2a	8.1a	8.1a	9.7a	$y=7.95+0.007871x$	0.76*
M. aterrima	7.0ab	8.1a	7.8a	8.8a	$y=7.20+0.008786x$	0.81*
		P concentration (g kg^{-1})				
Control	1.2a	1.1a	1.1a	1.0a	$y=1.1675-0.001021x$	0.99*
C. spectabilis	1.3a	1.2a	1.2a	1.1a	$y=1.298-0.000936x$	0.95*
M. aterrima	1.2a	1.1a	1.1a	1.1a	$y=1.1$	ns
		K concentration (g kg^{-1})				
Control	11.9a	12.7a	11.8a	11.6a	$y=12.0$	ns
C. spectabilis	12.0a	12.4a	13.3a	11.6a	$y=12.3$	ns
M. aterrima	12.7a	13.0a	12.5a	12.6a	$y=12.7$	ns
		Ca concentration (g kg^{-1})				
Control	1.0a	1.1b	1.2ab	1.0a	$y=1.1$	ns
C. spectabilis	1.1a	1.1b	1.1b	1.2a	$y=1.1$	ns
M. aterrima	1.1a	1.3a	1.3a	1.1a	$y=1.13+0.003919x-0.00002x^2$	0.89*
		Mg concentration (g kg^{-1})				
Control	0.6a	0.6a	0.6a	0.6a	$y=0.6$	ns
C. spectabilis	0.6a	0.6a	0.7a	0.7a	$y=0.58+0.000693x$	0.83**
M. aterrima	0.6a	0.7a	0.7a	0.6a	$y=0.61+0.001767x-0.000008x^2$	0.99*
		S concentration (g kg^{-1})				
Control	0.9ab	0.9a	0.9b	0.9a	$y=0.9$	ns
C. spectabilis	1.0a	1.1a	1.2a	1.0a	$y=1.0+0.002847x-0.000014x^2$	0.74*
M. aterrima	0.8b	1.0a	1.0b	0.9a	$y=0.80+0.002972x-0.000012x^2$	0.85*
		Cu concentration (mg kg^{-1})				
Control	5.5c	6.7c	6.6a	6.5b	$y=5.50+0.022739x-0.00009x^2$	0.84*
C. spectabilis	7.5b	7.2b	6.4a	7.8a	$y=7.75-0.022795x+0.000116x^2$	0.84*
M. aterrima	9.0a	7.9a	7.1a	8.2a	$y=9.07-0.031932x+0.000139x^2$	0.97**
		Fe concentration (mg kg^{-1})				
Control	134a	105ab	99b	116ab	$y=133.5-0.656182x+0.002864x^2$	0.98**
C. spectabilis	153a	123a	128a	126a	$y=149.8-0.458818x+0.001736x^2$	0.79**
M. aterrima	95b	94b	83b	103b	$y=93.7$	ns
		Mn concentration (mg kg^{-1})				
Control	13.0a	13.8a	13.0b	13.4b	$y=13.3$	ns
C. spectabilis	11.3b	9.8b	12.0b	16.2a	$y=10.9-0.018634x+0.000236x^2$	0.94**
M. aterrima	13.1a	13.6a	15.1a	13.4b	$y=13.8$	ns
		Zn concentration (mg kg^{-1})				
Control	8.3b	9.2a	9.6b	9.2b	$y=9.1$	ns
C. spectabilis	8.4ab	9.7a	11.1a	11.5a	$y=8.99+0.014114x$	0.79**
M. aterrima	10.0a	9.7a	10.3ab	9.9ab	$y=9.9$	ns

Values followed by the same letter within a column are not significantly different at $p \le 0.05$ according to LSD test. ns: not significant at $p \le 0.05$; *: $p \le 0.05$; and **: $p \le 0.01$.

the *M. aterrima* treatment increased up to the rate of 98 kg N ha^{-1}, but this pattern did not occur in the other treatments. The sweet potato roots in the *M. aterrima* treatment presented higher Ca concentrations at intermediate N rates and higher Mn concentrations when compared to those of the *C. spectabilis* treatment, especially at N rates below 100 kg N ha^{-1}. The Zn concentrations in the plant roots of the *C. spectabilis* treatment were higher than that in the roots of the control treatment only at higher N rates.

Nutrient uptake and removal by sweet potato

The amounts of N and S taken up by the sweet potatoes were affected only by green manure and N rates (Table 4). The highest N uptake occurred in the sweet potato grown after *M. aterrima*, followed by those in the *C. spectabilis* treatment and the control. The S uptake in the treatments with legumes did not differ, and it was higher than that in the control. Regardless of the type of green manure, N fertilization increased the N uptake by the sweet potato by 57 % up to the highest N rate, whereas an increase in the S uptake of 64 % occurred up to 152 kg N ha^{-1} (Figures 4a and 4f).

The uptake of P, K, Ca, and Mg was affected by the green manure × N rate interaction (Table 4). In the control treatment, the uptake of P and Mg was lower than that in the treatments with legumes only at the lowest and the highest N rates (Figures 4b and 4e). The P uptake in the sweet potatoes grown after both legumes was similar; however, after *M. aterrima*, the Mg uptake was higher than that in the C. *spectabilis* treatment only in the absence of N fertilization. At rates lower than 100 kg N ha^{-1}, the uptake of K and Ca by sweet potato in the control treatment was lower than those in the other treatments (Figures 4c and 4d). In the absence of N fertilization, the uptake of K and Ca by the sweet potato was higher in the *M. aterrima* treatment than in the C. *spectabilis* treatment and, at the highest N rate, the uptake of K was also higher in the plants treated with *M. aterrima* than in the other treatments.

The P uptake in the legume treatments and the Ca uptake in the *M. aterrima* treatment increased up to the rate of 50 kg N ha^{-1} (Figures 4b and 4e). In the control, the P uptake increased up to 126 kg N ha^{-1}, and the Ca uptake in the control and *C. spectabilis* treatments increased up to rates of 200 and 195 kg N ha^{-1}, respectively. The K and Mg uptake increased linearly with N fertilization in the *M. aterrima* treatment; however, in the control and *C. spectabilis* treatments, the uptake of both nutrients increased up to rates among 129 and 182 kg N ha^{-1} (Figures 4c and 4e). In the control treatment, N fertilization increased the uptake of P, K, Ca, and Mg by the sweet potato by 55, 71, 105, and 104 %, respectively (Figures 4b, 4c, 4d, and 4e). However, in the cultivation after *C. spectabilis*, N fertilization increased the uptake of P, K, Ca, and Mg by 16, 50, 63, and 78 %; in the cultivation after *M. aterrima*, the increases in uptake were 7, 22, 21, and 32 %, respectively. Regardless of the type of green manure, the maximum uptake of macronutrients by the sweet potato in response to N fertilization was 127, 13-15, 158-190, 34-39, 17-23, and 18 kg ha^{-1} of N, P, K, Ca, Mg, and S, respectively.

The uptake of micronutrients in sweet potato was affected by the green manure × N rate interaction (Table 4). The sweet potato grown after both legumes showed the same Fe uptake regardless of the N fertilization rate; however, the uptake of Cu, Mn, and Zn was similar between the legume treatments only at the highest N rate. At the lowest N rate, the uptake of Cu, Mn, and Zn was highest in the *M. aterrima* treatment (Figures 4g, 4i, and 4j). At all N rates, the uptake of Fe, Mn, and Zn by the sweet potato in the control treatment was lower than those in the legume treatments (Figures 4h, 4i, and 4j). At all N rates, the Cu uptake by the sweet potato in the control treatment was lower than those in the other treatments, except at the rate of 100 kg N ha^{-1}.

In the control treatment, the Cu uptake by the sweet potato increased up to the rate of 147 kg N ha^{-1}; however, the increase in Cu uptake was linear with the increase in N fertilization in the legume treatments (Figure 4g). In the *C. spectabilis* treatment, the Fe uptake increased up to 158 kg N ha^{-1}, but in the other treatments, the Fe uptake increased linearly with N fertilization. Nitrogen fertilization also linearly increased Mn uptake by sweet potato plants in all green manure treatments (Figures 4h and 4i). In the control, *C.*

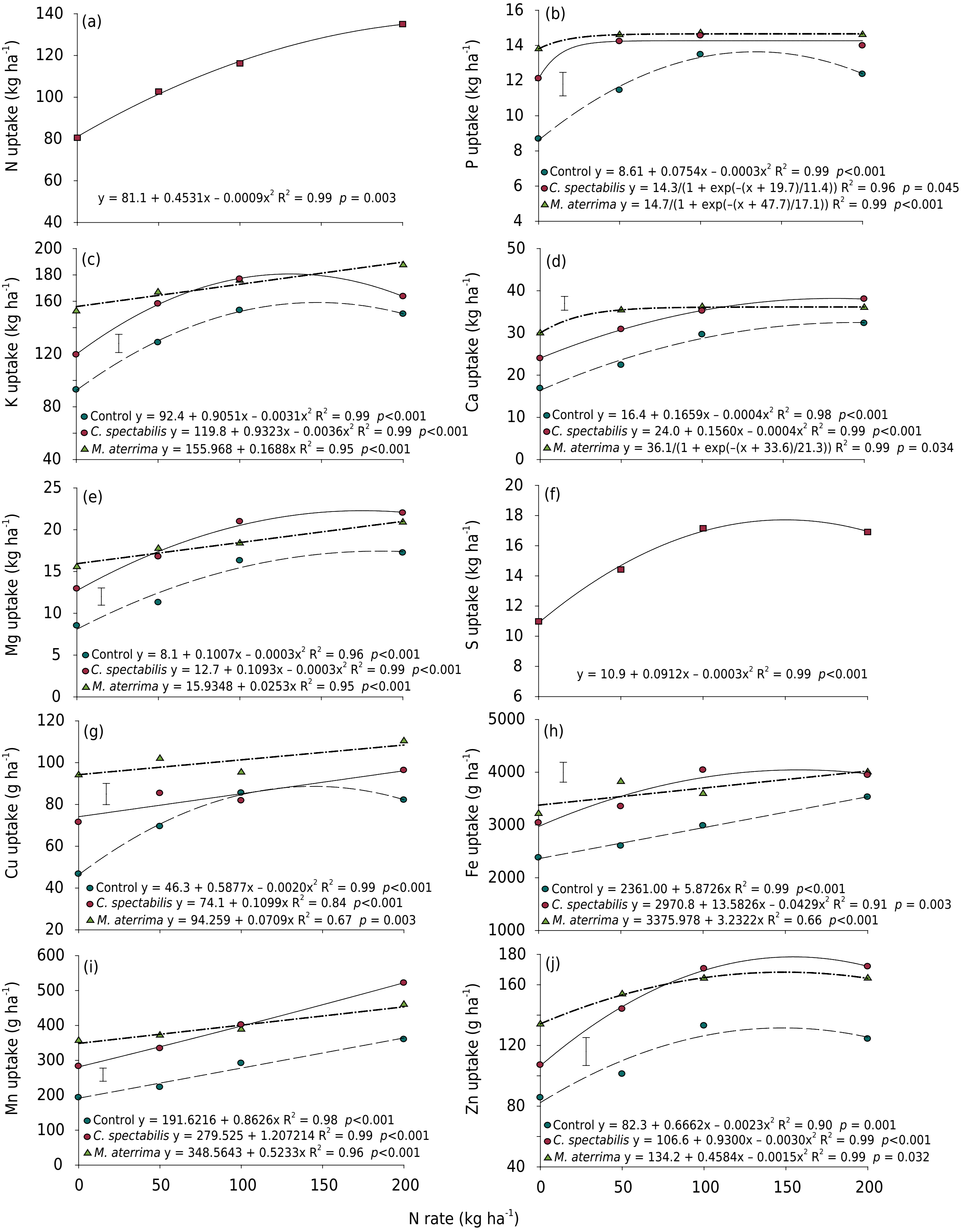

Figure 4. Nutrient uptake by sweet potato in response to green manures cultivation and N application rate. Square: mean of the three green manure treatments (Control, *C. spectabilis*, and *M. aterrima*). Vertical bars represent the least significant difference at $p \leq 0.05$ according to LSD test. Data are the means of the two agricultural years.

spectabilis, and *M. aterrima* treatments, the Zn uptake increased up to N rates of 145, 155, and 153 kg N ha^{-1}, respectively (Figure 4j). In the control treatment, N fertilization increased the uptake of Cu, Fe, Mn, and Zn by 93, 50, 90, and 59 %, respectively. In the *C. spectabilis* treatment, the increases in the uptake of Cu, Fe, Mn, and Zn in response to N fertilization were 30, 36, 86, and 68 %, respectively, whereas in the *M. aterrima* treatment, N fertilization increased the uptake of Cu, Fe, Mn, and Zn by only 15, 19, 30, and 26 %, respectively. The maximum micronutrient uptake in response to N fertilization ranged from 89 to 108, 3536 to 4046, 364 to 521, and 131 to 179 g ha^{-1} for Cu, Fe, Mn, and Zn, respectively.

The removal of N, Mg, and S was influenced only by the main factors (Table 4). The N and S removal in legume treatments did not differ and were higher than those in the control. In the *M. aterrima* treatment, the Mg removal was higher than those in the other treatments. Nitrogen fertilization increased the removal of N, Mg, and S up to rates of 195, 181, and 137 kg N ha^{-1}, respectively (Figures 5a, 5e, and 5f). The removal of N, Mg, and S increased between 54 and 85 % in response to N application and reached values of 76, 7.1, and 9.4 kg ha^{-1}, respectively.

Phosphorus, K, and Ca removal was affected by the green manure × N rate interaction (Table 4). At the lowest N rates, the removal of P, K, and Ca by the plants in the control treatment was lower than those in the legume treatments. At the highest N rates, the plants in the control treatment removed less P than those in the *M. aterrima* treatment (Figures 5b, 5c, and 5d). Phosphorus removal in both legume treatments did not differ, regardless of the N fertilization rate, but the K removal at the highest N rates and the Ca removal at the intermediate N rates were greater in the *M. aterrima* treatment than in the other two treatments. Phosphorus removal was not affected by N fertilization in the *M. aterrima* treatment; however, in the control and *C. spectabilis* treatments, P removal increased up to the N rates of 133 and 94 kg N ha^{-1}, respectively. Potassium removal increased up to the rate of 108 kg N ha^{-1} in the *C. spectabilis* treatment and up to rates of 130 and 138 kg N ha^{-1} in the control and *M. aterrima* treatment, respectively. In the *M. aterrima* treatment, Ca removal increased up to 121 kg N ha^{-1}, but in the other treatments, the increases occurred up to rates between 145 and 147 kg N ha^{-1}. In the control treatment, N fertilization increased the removal of P, K, and Ca by 57, 66, and 77 %, respectively; however, in the *C. spectabilis* treatment, the increases in the removal of these nutrients were 19, 41, and 26 %, respectively. When sweet potato was grown after *M. aterrima*, N fertilization increased the removal of K and Ca by 21 and 49 %, respectively. The maximum removal amounts of P, K, and Ca in response to N fertilization ranged from 9.7 to 11.1, 107 to 122, and 9.9 to 13.4 kg ha^{-1}, respectively.

Iron removal was only affected by the main factors (Table 4). Iron removal was highest in the *C. spectabilis* treatment and, regardless of the green manures, the Fe removal was linearly increased with N fertilization (Figure 5h).

The removal of other micronutrients was affected by the green manure × N rate interaction (Table 4). At the lower N rates, the Cu removal was lower in the control and higher in the *M. aterrima* treatment (Figure 5g). At the highest N rate, the Mn removal by the *M. aterrima* treatment plants was not higher than those in the other treatments (Figure 5i). In the control, the Zn removal was lower than that in the legume treatments (Figure 5j). In the absence of additional N, the Zn removal in the *M. aterrima* treatment was higher than that in the *C. spectabilis* treatment; however, when increasing rates of N were provided these differences disappeared.

In the *M. aterrima* treatment, N fertilization did not affect Cu removal; however, in the control and *C. spectabilis* treatments, the Cu removal increased up to N rates of 136 and 50 kg N ha^{-1}, respectively (Figure 5g). The Mn removal increased linearly with N fertilization in the *C. spectabilis* treatment, whereas in the control and *M. aterrima* treatments, the increases occurred up to 160 and 124 kg N ha^{-1}, respectively (Figure 5i). The Zn removal

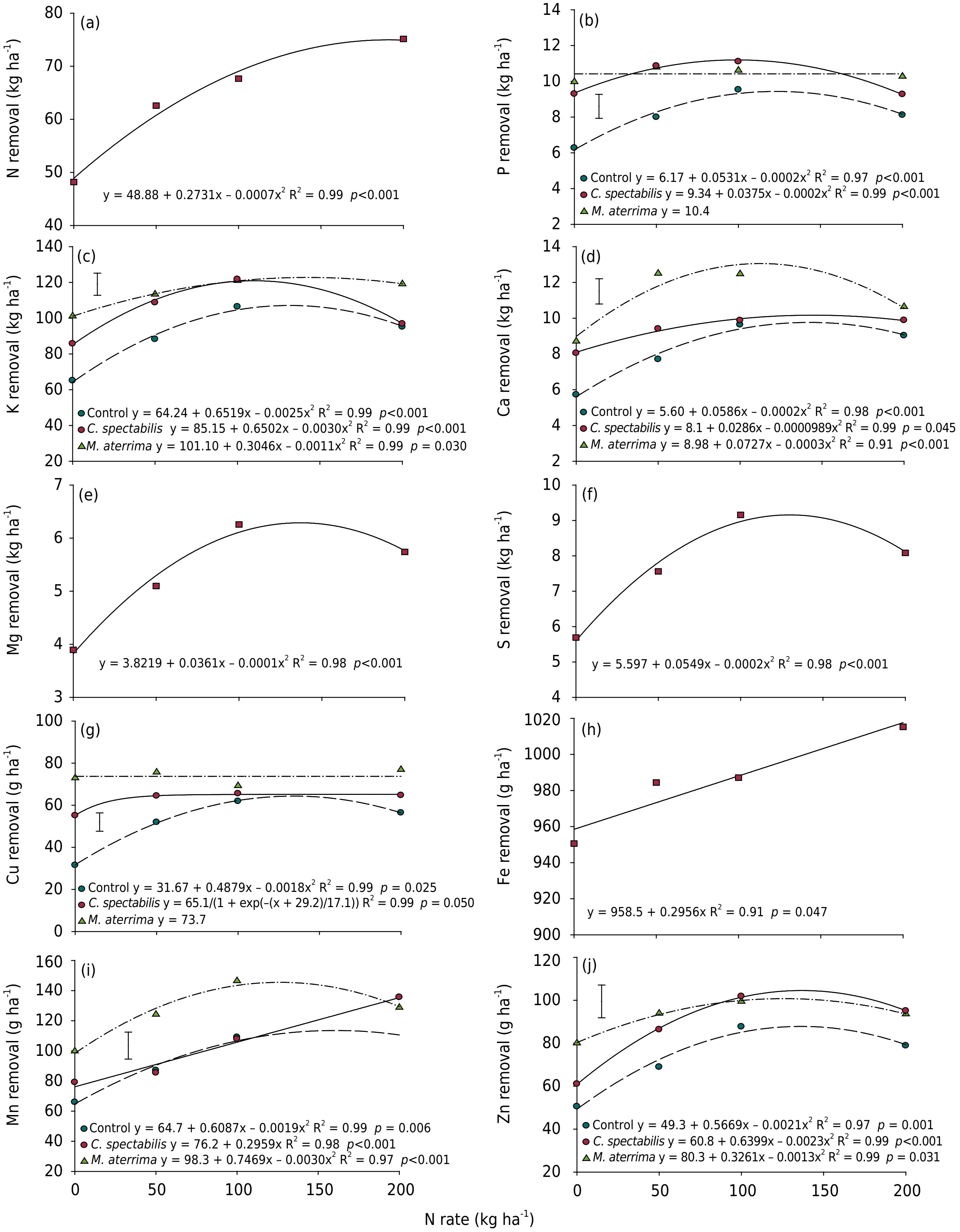

Figure 5. Nutrient removal by sweet potato in response to green manures cultivation and N application rate. Square: mean of the three green manure treatments (Control, *C. spectabilis*, and *M. aterrima*). Vertical bars represent the least significant difference at $p \leq 0.05$ according to LSD test. Data are the means of the two agricultural years.

increased up to N rates of 135, 139, and 125 kg N ha^{-1} in the control, *C. spectabilis*, and *M. aterrima* treatments, respectively (Figure 5j). In the control treatment, the removal of Cu, Mn, and Zn increased by 104, 75, and 78 % with N fertilization, but in the *C. spectabilis* treatment, these increases were 17, 78, and 73 %, respectively (Figures 5g, 5i, and 5j). In the *M. aterrima* treatment, N fertilization did not increase Cu removal but increased Mn and Zn removal by 47 and 25 %, respectively.

DISCUSSION

The high capacity for biomass production and nutrient uptake in *C. spectabilis* did not lead to significant increases in all nutrient concentrations in the sweet potato leaves grown in succession. The green manure with *C. spectabilis* was more efficient in increasing the concentrations of P, K, Mg, and S in the sweet potato leaves than the *M. aterrima* green manure. Neither legume treatment significantly improved the sweet potato nutritional status of Fe, Mn, or Zn when compared to those in the control treatment. However, the concentrations of P, K, Ca, Mg, S, Mn, and Zn were within the range considered adequate by Lorenzi et al. (1997) for this crop which is 2.3-5.0 g kg^{-1} for P, 31-45 g kg^{-1} for K, 7-12 g kg^{-1} for Ca, 3-12 g kg^{-1} for Mg, 4-7 g kg^{-1} for S, 40-250 mg kg^{-1} for Mn, and 20-50 mg kg^{-1} for Zn. The leaf Fe concentrations were above the range considered adequate by Lorenzi et al. (1997) (40-100 mg kg^{-1}), but there were no symptoms of Fe toxicity in the sweet potato plants.

In the absence of N fertilization, the green manure with *M. aterrima* led to higher N concentration in the sweet potato leaves than the *C. spectabilis* green manure, but when N was supplied, both legumes resulted in the same N concentration in the sweet potato leaves. In both legume treatments, the N concentration in the sweet potato leaves was within the range considered adequate by Lorenzi et al. (1997) (33-45 g kg^{-1}), regardless of the N fertilization rate. However, when no N was added, the sweet potato plants presented deficient N concentrations in their leaves, which shows that legumes provided N for sweet potato grown in succession. The use of *M. aterrima* improved the Cu nutrition of the sweet potato plants regardless of the N fertilization rate, which was reflected in the adequate concentrations of Cu in the leaves, i.e., between 10-20 mg kg^{-1} (Lorenzi et al., 1997). In other treatments, although visual Cu deficiency in plants was not found, the Cu concentrations in the sweet potato leaves were below the range considered appropriate by Lorenzi et al. (1997), especially at N rates above 50 kg ha^{-1}.

The response of sweet potato growth and yield to N application was dependent on the previously grown green manure species, which coincides with previous findings in which the potential effect of green manure on sweet potato production varied according to the source of the green manure (Okpara et al., 2004). Although *M. aterrima* produced less biomass and consumed fewer nutrients than *C. spectabilis*, the sweet potato plants grown after these two legumes had the same biomass and root yields, regardless of the N applied. However, when there was a low N supply, the sweet potato in both legume treatments had a higher biomass and root yield when compared to those the control treatment, which shows that green manure increases sweet potato growth and yield when N is either not applied or applied at a low rate. These results show that it is possible to reduce the mineral N fertilization of sweet potato when green manure was previously grown in the area. In wheat, green manuring with legumes such as forage pea, forage turnip and common vetch provided yields equivalent to those obtained with the application of 80 kg N ha^{-1} in treatments without green manure (Viola et al., 2013). This outcome is in agreement with the results of the current study and other studies that show that green manure contributes to substantial reductions in N fertilizer use (Teodoro et al., 2011).

However, the excess of N increased the growth of the shoots more than the growth of storage roots, which was reflected in a significant reduction in HI at N rates above

95 kg ha^{-1}. Santos Neto et al. (2017), in a study of N fertilization in three sweet potato genotypes, verified that one of the genotypes showed a reduction in HI starting at the lowest N rate applied, and the other two genotypes had a significant decrease in HI starting at 59 kg N ha^{-1}. Other studies have also shown that a high N supply stimulates the shoot growth of sweet potato plants, to the detriment of the formation of storage roots (Hartemink et al., 2000; Oliveira et al., 2006; Prabawardani and Suparno, 2015). Sweet potato responses to N application may also vary by cultivar (Oliveira et al., 2006; Duan et al., 2018).

The amount of nutrients taken up by the sweet potato was directly related to biomass production and nutrient concentration in the shoots and storage roots, and these variables were positively correlated (Table 7). Regardless of the N fertilization rate, the sweet potato plants grown after *M. aterrima* had a higher N uptake and the same amount of S uptake when compared to the plants grown after *C. spectabilis*, which accumulated the highest amounts of N and S in their biomass. Thus, the excess of N, either from mineral fertilizer or from green manure, does not necessarily lead to higher plant growth and N uptake by sweet potatoes grown in succession.

Nitrogen fertilization increased the uptake of all nutrients by the sweet potato; however, the increases in the uptake were dependent on the previously cultivated species, with lower increases in nutrient uptake after *M. aterrima* cultivation. In the *M. aterrima* treatment, N fertilization increased the P uptake by a maximum of 7 %, the K, Ca, and Mg uptake by 21 to 32 %, and the micronutrient uptake by less than 31 %. However, the growth and yield of sweet potato plants in the *M. aterrima* treatment were similar to those of the *C. spectabilis* treatment. In the *C. spectabilis* treatment, the increases in nutrient uptake in response to N application were greater, i.e., exceeding 70 and 80 % for some macro- and micronutrients, respectively. This result shows that *M. aterrima* is more suitable for green fertilization of sweet potato since even with lower biomass production and nutrient accumulation, it is able to supply nutrients more synchronously with the demands of sweet potatoes grown in succession, especially when N fertilization does not exceed 50 kg N ha^{-1}. Ambrosano et al. (2003) evaluated N mineralization of the incorporated residues of *Crotalaria juncea* (*C. juncea*), *M. aterrima*, and beans and found that, initially, *M. aterrima* and *C. juncea* had a similar mineralization rate, but after a few days, the mineralization of *M. aterrima* was higher and occurred over a longer period. For the supply of nutrients from green manure to be used efficiently, it is essential that the nutrient release from the crop residues and the nutrient demand of the crop grown in

Table 7. Correlations of whole plant dry matter (DM) accumulation and nutrient concentrations in shoot and storage root with total nutrient uptake and correlations of DM accumulation and nutrient concentrations in storage root with nutrient removal by sweet potato

Nutrient uptake	Whole plant DM accumulation	Concentration of each nutrient in shoot	Concentration of each nutrient in storage root	Nutrient removal	Storage root DM accumulation	Concentration of each nutrient in storage root
N	r = 0.75**	r = 0.38**	r = 0.65**	N	r = 0.67**	r = 0.76**
P	r = 0.77**	r = 0.14ns	r = 0.55**	P	r = 0.74**	r = 0.64**
K	r = 0.89**	r = -0.10ns	r = 0.41**	K	r = 0.82**	r = 0.61**
Ca	r = 0.86**	r = 0.47**	r = 0.60**	Ca	r = 0.77**	r = 0.82**
Mg	r = 0.76**	r = 0.46**	r = 0.23*	Mg	r = 0.65**	r = 0.61**
S	r = 0.24*	r = 0.60**	r = 0.77**	S	r = 0.14ns	r = 0.86**
Cu	r = 0.73**	r = 0.11ns	r = 0.91**	B	r = 0.66**	r = 0.94**
Fe	r = 0.66**	r = 0.54**	r = 0.84**	Cu	r = 0.45**	r = 0.97**
Mn	r = 0.42**	r = 0.52**	r = 0.45**	Mn	r = 0.44**	r = 0.68**
Zn	r = 0.67**	r = 0.84**	r = 0.92**	Zn	r = 0.65**	r = 0.93**

*, **, and ns significant at p≤0.05, p≤0.01, and not significant, respectively. Variables and units are presented in figures 3, 4, and 5, and tables 5 and 6.

succession be synchronized (Stute and Posner, 1995; Viola et al., 2013). Otherwise, nutrient losses by leaching may occur (Lara-Cabezas et al., 2000), especially in sandy soils with low CEC, similar to those in the present study (Table 1).

Except for Fe, the nutrient uptake values obtained in this study were lower than those reported by Echer et al. (2009) in a study carried out under Brazilian conditions with the same sweet potato cultivar. These authors obtained nutrient uptake values of 350 kg N ha^{-1}, 41 kg P ha^{-1}, 226 kg K ha^{-1}, 174 kg Ca ha^{-1}, 42 kg Mg ha^{-1}, 38 kg S ha^{-1}, 143 g Cu ha^{-1}, 184 g Fe ha^{-1}, 713 g Mn ha^{-1}, and 237 g Zn ha^{-1}. The differences between both studies in the amounts of nutrients taken up by the sweet potato are related to the growing conditions and the biomass production of sweet potato plants, which was smaller in the present study. Although N fertilization stimulated nutrient uptake by the sweet potato, when there was no N supply, the cultivation of *M. aterrima* provided P, K, Ca, Mg, Cu, Fe, Mn, and Zn uptake values that were similar or even higher than the values obtained in the control treatment with N rates above 126 kg N ha^{-1}. These results agree with other findings showing that green manure may contribute to saving mineral fertilizer (Teodoro et al., 2011) and increasing the yield (Viola et al., 2013) and mineral nutrition of crops grown in succession.

The removal of N and S increased with green manure treatment; however, it did not differ among the studied species. This result shows that although *M. aterrima* provided a higher N uptake, there was no increase in the N partition to the sweet potato storage roots. According to Silva et al. (2006), the partition of N taken up from the soil by the plants is a trait of high heritability and it is more dependent on the genotype than on the external environmental conditions or the amount of N taken up.

The *M. aterrima* green manure favored Mg removal, even without increasing the uptake of Mg by the sweet potato when compared to the uptake under *C. spectabilis*, showing that *M. aterrima* favors Mg allocation to the storage roots. However, the removal of N, S, and Mg increased with N fertilization due to the positive influence of the applied N on the biomass accumulated in the roots and the concentration of these nutrients in the roots of plants grown mainly after legume cultivation.

Since nutrient removal was positively correlated with the biomass and nutrient concentration in the roots, it was observed that N fertilization increased the nutrient removal mainly because it significantly increased the storage root biomass. However, not all nutrients showed increased removal under N fertilization. In potato (*Solanum tuberosum* L.) crops, studies have shown that higher tuber yield is not always related to higher nutrient removal (Fernandes et al., 2011) since there may be significant differences in the nutrient concentrations in the tubers (Srek et al., 2010; Haynes et al., 2012).

When the sweet potato was cultivated after *M. aterrima*, the removal of P and Cu was not influenced by N fertilization due to the reduction in the concentration of these nutrients in the roots; however, the removal of these nutrients was not lower than the removal under *C. spectabilis*. In both legume treatments, the removal of P and Cu was higher than that in the control treatment. The use of *M. aterrima* was very efficient in increasing the removal of Ca and Mn by the sweet potato, especially at N rates between 50 and 100 kg N ha^{-1}. With the application of these N rates, the biomass and the concentrations of Ca and Mn in sweet potato plants were increased. However, both legume treatments provided higher P, K, and Cu removal under lower N supply conditions, whereas, in the absence of N fertilization, the use of *M. aterrima* as the green manure resulted in a Zn removal higher than that in the control due to the higher biomass and Zn concentration in the roots. These results show that green manure, by improving the chemical, physical and biological properties of the soil, increases nutrient cycling, which allows better utilization of the applied fertilizers (Espíndola et al., 1997), resulting in greater uptake and allocation of nutrients to the sweet potato storage roots.

M. aterrima better supplied the nutrient demands of the sweet potato storage roots, since, in this cultivation, the maximum increase in nutrient removal in response to N was 49 %, whereas in the *C. spectabilis* and control treatments, these values reached 78 and 104 %, respectively, for some nutrients. This shows that the higher and more prolonged mineralization of *M. aterrima* residues (Ambrosano et al., 2003) may have provided nutrients during the increase in cambial activity and the bulking of the sweet potato storage roots, thus favoring nutrient accumulation in the roots.

Except for N and P, which in this study, had removal values similar to those recorded by Echer et al. (2009), the remaining nutrients were removed in greater amounts than those obtained by these authors, which is a reflection of the higher root biomass in our study (9-10 Mg ha^{-1}) when compared to that in the study of Echer et al. (2009) (6.3 Mg ha^{-1}). Echer et al. (2009) obtained sweet potato nutrient removal values of 129 kg N ha^{-1}, 16 kg P ha^{-1}, 81 kg K ha^{-1}, 23 kg Ca ha^{-1}, 7.4 kg Mg ha^{-1}, 9.6 kg S ha^{-1}, 52 g Cu ha^{-1}, 61 g Fe ha $^{-1}$, 136 g Mn ha^{-1}, and 82 g Zn ha^{-1}.

CONCLUSION

The species *M. aterrima* is more suitable for use as green manure in the sweet potato than *C. spectabilis*. Nitrogen application rates causes a greater increase in the biomass of the storage root, nutrient uptake and removal in the sweet potatoes unfertilized with green manure. In the sweet potato fertilized with *M. aterrima*, mineral N supply in excess (above 50 kg ha^{-1}) increases the nutrient uptake and removal without a significant increase in the biomass of the storage root. In the sweet potatoes unfertilized with green manure, high rates of N (greater than 120 kg ha^{-1}) must be applied to obtain the utmost biomass of the storage root, nutrient uptake and removal.

ACKNOWLEDGMENTS

The authors would like to thank the São Paulo Research Foundation (FAPESP) for supporting this research (Proc. 2014/22362-4) and the National Council for Scientific and Technological Development (CNPq) for granting awards for excellence in research to the first author.

AUTHOR CONTRIBUTIONS

Conceptualization: Adalton Mazetti Fernandes (lead).

Methodology: Adalton Mazetti Fernandes (lead) and Bruno Gazola (supporting).

Formal analysis: Adalton Mazetti Fernandes (lead).

Investigation: Adalton Mazetti Fernandes (lead) and Bruno Gazola (equal).

Resources: Adalton Mazetti Fernandes (lead).

Data curation: Bruno Gazola (equal) and Nathalia Pereira Ribeiro (equal).

Writing – original draft: Nathalia Pereira Ribeiro (lead), Natália Silva Assunção (equal), and Rudieli Machado da Silva (equal).

Writing – review and editing: Adalton Mazetti Fernandes (lead), Nathalia Pereira Ribeiro (equal), Natália Silva Assunção (equal), Rudieli Machado da Silva (equal), and Bruno Gazola (supporting).

Visualization: Adalton Mazetti Fernandes (lead), Nathalia Pereira Ribeiro (equal), and Natália Silva Assunção (equal).

Supervision: Adalton Mazetti Fernandes (lead).

Project administration: Adalton Mazetti Fernandes (lead) and Bruno Gazola (supporting).

Funding acquisition: Adalton Mazetti Fernandes (lead).

REFERENCES

Ambrosano EJ, Trivelin PCO, Cantarella H, Ambrosano GMB, Muraoka T. Nitrogen mineralization in soils amended with sunnhemp, velvet bean and common bean residues. Sci Agr. 2003;60:133-7. https://doi.org/10.1590/S0103-90162003000100020

Araújo ASF, Teixeira GM, Campos AX, Silva FC, Ambrosano EJ, Trivelin PCO. Utilização de nitrogênio pelo trigo cultivado em solo fertilizado com adubo verde (*Crotalaria juncea*) e/ou uréia. Cienc Rural. 2005;35:284-9. https://doi.org/10.1590/S0103-84782005000200006

Burle ML, Carvalho AM, Amabile RF, Pereira J. Caracterização das espécies de adubo verde. In: Amabile RF, Carvalho AM, editores. Cerrado: adubação verde. Planaltina: Embrapa Cerrados; 2006. p. 71-142.

Carsky RJ, Becker M, Hauser S. Mucuna cover crop fallow systems: potential and limitations. In: Sustaining soil fertility in West Africa. Madison: Soil Science Society of America, Inc. / American Society of Agronomy, Inc.; 2001. p. 111-35. (SSSA Special Publication Number 58).

Djian-Caporalino C, Mateille T, Bailly-Bechet M, Marteu N, Fazari A, Bautheac P, Raptopoulo A, Duong LV, Tavoillot J, Martiny B, Goillon C, Castagnone-Sereno P. Evaluating sorghums as green manure against root-knot nematodes. Crop Prot. 2019;122:142-50. https://doi.org/10.1016/j.cropro.2019.05.002

Duan W, Wang Q, Zhang H, Xie B, Li A, Hou F, Dong S, Wang B, Qin Z, Zhang L. Differences between nitrogen-tolerant and nitrogen-susceptible sweetpotato cultivars in photosynthate distribution and transport under different nitrogen conditions. PLoS One. 2018;13:e0194570. https://doi.org/10.1371/journal.pone.0194570

Echer FR, Dominato JC, Creste JE. Absorção de nutrientes e distribuição da massa fresca e seca entre órgãos de batata-doce. Hortic Bras. 2009;27:176-82. https://doi.org/10.1590/S0102-05362009000200010

Embrapa - Empresa Brasileira de Pesquisa Agropecuária. Manual de métodos de análise de solo. 2. ed. Brasília, DF: Embrapa-CNPS; 1997.

Espíndola JAA, Guerra JGM, Almeida DL. Adubação verde: estratégia para uma agricultura sustentável. Seropédica: Embrapa-Agrobiologia; 1997.

Fageria VD. Nutrient interactions in crop plants. J Plant Nutr. 2001;24:1269-90. https://doi.org/10.1081/PLN-100106981

Fernandes AM, Soratto RP, Silva BL. Extração e exportação de nutrientes em cultivares de batata: I - Macronutrientes. Rev Bras Cienc Solo. 2011;35:2039-56. https://doi.org/10.1590/S0100-06832011000600020

Ferreira DF. Sisvar: a computer statistical analysis system. Cienc Agrotec. 2011;35:1039-42. https://doi.org/10.1590/S1413-70542011000600001

Hartemink AE, Johnston M, O'Sullivan JN, Poloma S. Nitrogen use efficiency of taro and sweet potato in the humid lowlands of Papua New Guinea. Agr Ecosyst Environ. 2000;79:271-80. https://doi.org/10.1016/S0167-8809(00)00138-9

Haynes KG, Yencho GC, Clough ME, Henninger MR, Sterrett SB. Genetic variation for potato tuber micronutrient content and implications for biofortification of potatoes to reduce micronutrient malnutrition. Am J Pot Res. 2012;89:192-8. https://doi.org/10.1007/s12230-012-9242-7

Jenkins PD, Mahmood S. Dry matter production and partitioning in potato plants subjected to combined deficiencies of nitrogen, phosphorus and potassium. Ann Appl Biol. 2003;143:215-29. https://doi.org/10.1111/j.1744-7348.2003.tb00288.x

Kawasaki T. Metabolism and physiology of calcium and magnesium. In: Matsuo T, Kumazawa K, Ishii R, Ishihara K, Hirata H, editors. Science of the Rice plant. Tokyo: Food and Agricultural Policy Research Center; 1995. p. 412-9.

Lara-Cabezas WAR, Trivelin PCO, Kondörfer GH, Pereira S. Balanço da adubação nitrogenada sólida e fluida de cobertura na cultura de milho, em sistema de plantio direto no Triângulo Mineiro (MG). Rev Bras Cienc Solo. 2000;24:363-76. https://doi.org/10.1590/S0100-06832000000200014

Lebot V. Tropical root and tuber crops: cassava, sweet potato, yam, aroids. Cambridge: CABI; 2009.

Lorenzi JO, Monteiro PA, Miranda Filho HS, van Raij B. Raízes e tubérculos. In: van Raij B, Cantarella H, Quaggio JA, Furlani AMC, editores. Recomendações de adubação e calagem para o Estado de São Paulo. Campinas: Instituto Agronômico de Campinas; 1997. p. 221-9.

Makarewicz A, Płaza A, Gąsiorowska B, Rosa R, Cybulska A, Górski R, Rzążewska E. Effect of manuring with undersown catch crops and production system on the potato tuber content of macroelements. J Elem. 2018;23:7-19. https://doi.org/10.5601/jelem.2017.22.1.1398

Malavolta E, Vitti GC, Oliveira AS. Avaliação do estado nutricional das plantas: princípios e aplicações. 2. ed. Piracicaba: Potafos; 1997.

Ning YW, Ma HB, Zhang H, Wang JD, Xu XJ, Zhang YC. Response of sweetpotato in source-sink relationship establishment, expanding, and balance to nitrogen application rates. Acta Agron Sin. 2015;41:432-9. https://doi.org/10.3724/SP.J.1006.2015.00432

Okpara DA, Njoku JC, Asiegbu JE. Responses of two sweet potato varieties to four green manure sources and inorganic fertilizer in a humid tropical Ultisol. Biol Agric Hortic. 2004;22:81-90. https://doi.org/10.1080/01448765.2004.9754990

Oliveira AP, Moura MF, Nogueira DH, Chagas NG, Braz MSS, Oliveira MRT, Barbosa JA. Produção de raízes de batata-doce em função do uso de doses de N aplicadas no solo e via foliar. Hortic Bras. 2006;24:279-82. https://doi.org/10.1590/S0102-05362006000300002

Pimentel MS, Lana AMQ, Del-Polli H. Rendimentos agronômicos em consórcio de alface e cenoura adubadas com doses crescentes de composto orgânico. Rev Cienc Agron. 2009;40:106-12.

Prabawardani S, Suparno A. Water use efficiency and yield of sweetpotato as affected by nitrogen and potassium application. J Agr Sci. 2015;7:128-37. https://doi.org/10.5539/jas.v7n7p128

Rodriguez-Delfin A, Posadas A, Leon-Velarde C, Mares V, Quiroz R. Nutrient uptake and yields of four sweet potato cultivars grown in soilless culture at three N, P and K different levels. Acta Hortic. 2015;1062:21-8. https://doi.org/10.17660/ActaHortic.2015.1062.2

Rós AB, Fernandes AM, Montes SMNM, Fischer IH, Leonel M, Franco CML. Batata-doce. In: Leonel M, Fernandes AM, Franco CML, editores. Culturas amiláceas: batata-doce, inhame, mandioca e mandioquinha-salsa. Botucatu: Cerat/Unesp; 2015. p. 15-120.

Rosa R. The effect of winter catch crops on weed infestation in sweet corn depending on the weed control methods. J Ecol Eng. 2015;16:125-35. https://doi.org/10.12911/22998993/1867

Santos JF, Oliveira AP, Alves AU, Brito CH, Dornelas CSM, Nóbrega JPR. Produção de batata-doce adubada com esterco bovino em solo com baixo teor de matéria orgânica. Hortic Bras. 2006;24:103-6. https://doi.org/10.1590/S0102-05362006000100021

Santos HG, Jacomine PKT, Anjos LHC, Oliveira VA, Lumbreras JF, Coelho MR, Almeida JA, Araújo Filho JC, Oliveira JB, Cunha TJF. Sistema brasileiro de classificação de solos. 5. ed. rev. ampl. Brasília, DF: Embrapa; 2018.

Santos Neto AR, Silva TO, Blank AF, Silva JO, Araújo Filho RN. Produtividade de clones de batata doce em função de doses de nitrogênio. Hortic Bras. 2017;35:445-52. https://doi.org/10.1590/s0102-053620170322

Scivittaro WB, Muraoka T, Boaretto AE, Trivelin PCO. Utilização de nitrogênio de adubos verde e mineral pelo milho. Rev Bras Cienc Solo. 2000;24:917-26. https://doi.org/10.1590/S0100-06832000000400023

Silva EC, Muraoka T, Buzetti S, Veloso MEC, Trivelin PCO. Absorção de nitrogênio nativo do solo pelo milho sob plantio direto em sucessão a plantas de cobertura. Rev Bras Cienc Solo. 2006;30:723-32. https://doi.org/10.1590/S0100-06832006000400013

Soil Survey Staff. Keys to soil taxonomy. 12th ed. Washington, DC: United States Department of Agriculture, Natural Resources Conservation Service; 2014.

Soil Survey Staff. Illustrated guide to soil taxonomy, version 1.1, 371. Lincoln, USA: United States Department of Agriculture, Natural Resources Conservation Service, National Soil Survey Center; 2015.

Šrek P, Hejcman M, Kunzová E. Multivariate analysis of relationship between potato (*Solanum tuberosum* L.) yield, amount of applied elements, their concentrations in tubers and uptake in a long-term fertilizer experiment. Field Crop Res. 2010;118:183-93. https://doi.org/10.1016/j.fcr.2010.05.009

Stute JK, Posner JL. Synchrony between legume nitrogen release and corn demand in the upper Midwest. Agron J. 1995;87:1063-9. https://doi.org/10.2134/agronj1995.00021962008700060006

Teodoro RB, Oliveira FL, Silva DMN, Fávero C, Quaresma MAL. Aspectos agronômicos de leguminosas para adubação verde no Cerrado do Alto Vale do Jequitinhonha. Rev Bras Cienc Solo. 2011;35:635-40. https://doi.org/10.1590/S0100-06832011000200032

Uwah DF, Undie UL, John NM, Ukoha GO. Growth and yield response of improved sweet potato (*Ipomoea batatas* (L.) Lam) varieties to different rates of potassium fertilizer in Calabar. J Agr Sci. 2013;5:61-9. https://doi.org/10.5539/jas.v5n7p61

Uzo JO. Mixed cropping of yam, telfairia, maize and okra in a compound farming system of south eastern Nigeria. Acta Hortic. 1983;123:305-18. https://doi.org/10.17660/ActaHortic.1983.123.28

van Raij B, Andrade JC, Cantarella H, Quaggio JA. Análise química para avaliação da fertilidade de solos tropicais. Campinas: Instituto Agronômico; 2001.

Vargas TO, Diniz ER, Pacheco ALV, Santos RHS, Urquiaga S. Green manure-^{15}N absorbed by broccoli and zucchini in sequential cropping. Sci Hortic. 2017;214:209-13. https://doi.org/10.1016/j.scienta.2016.11.028

Villordon A, Clark CA. Variation in virus symptom development and root architecture attributes at the onset of storage root initiation in `Beauregard' sweetpotato plants grown with or without nitrogen. PLoS One. 2014;9:e107384. https://doi.org/10.1371/journal.pone.0107384

Viola R, Benin G, Cassol LC, Pinnow C, Flores MF, Bornhofen E. Adubação verde e nitrogenada na cultura do trigo em plantio direto. Bragantia. 2013;72:90-100. https://doi.org/10.1590/S0006-87052013005000013

Weber G. Legume-based technologies for African Savannas: challenges for research and development. Biol Agric Hortic. 1996;13:309-33. https://doi.org/10.1080/01448765.1996.9754790

Wilkinson SR, Grunes DL, Sumner ME. Nutrient interactions in soil and plant nutrition. In: Sumner ME, editor. Handbook of soil science. Boca Raton: CRC Press; 1999. p. 89-112.

Wilson R, Culp DA, Peterson S, Nicholson K, Geisseler D. Cover crops prove effective at increasing soil nitrogen for organic potato production. Calif Agr. 2019;73:79-89. https://doi.org/10.3733/ca.2019a0005