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Biomass Production and Mineral Nutrient Accumulation by Weeds and Sweet Orange Trees in the Amazonian

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Abstract

Accumulation of biomass and competition for nutrients can be used as parameters to identify species with higher potential for competition and, thus, with larger interference in crops. Consequently, studies addressing these parameters are important to weed science since they are the main factors that negatively affect the growth and productivity of cultivated plants. The objective of this research was to identify the species of weed plants with the largest potential of biomass production and accumulation of mineral nutrients in their leaves, which in turn, lead to higher interference in orange crops. In the floristic survey, 30 species of weed plants were identified and 14 botanic families, totaling 1341 sampled specimens. The phytosociological analysis showed, as per the importance value (IV), that the most representative weed species in the study area were as follows: *Conyza bonariensis* (L. (Cronquist)), *Spermacoce latifolia* Albl., *Paspalum conjugatum* PJ Bergius, *Pueraria phaseoloides* (Roxb.) Benth., *Mollugo verticillate* L., *Peperomia pelucida* (L.) Kunth, *Euphorbia heterophylla* L., *Paspalum multicaule* Poir and *Waltheria corchorifolia* Pers. Among these, the species with the highest production of biomass and accumulation of mineral nutrients in their tissues were *S. latifolia, P. phaseoloides, P. conjugatum* and *C. bonariensis.* This result suggests that these species are of high competitive potential against orange crops due to their high capacity for biomass and micronutrients accumulation.

Keywords: *Citrus sinensis* L., competition, mineral nutrition, weed community

1. Introduction

In agricultural ecosystems, interference of natural weed populations usually causes direct and indirect damage to crops, as a result of competition for environmental resources required for the growth of the cultivated plants. Weeds often have competitive advantages over agricultural crops. Weeds almost always have a high growth rate, high reproductive capacity and high capacity for exploitation of soil nutrients, which ensures their survival in places which are frequently disturbed (Grime, 1982). In addition, weed development depends on the same factors required by crops, thus establishing competition when they coexist. There are many weed species that coexist in the same environment with orange plants under the conditions of the state of Amazonas. Species which are frequently found include: *Paspalum conjugatum* Berg, *Peperomia pellucida* (L.) Kunth., *Pueraria phaseoloides* (Roxb.) Benth., *Sida rhombifolia* L., and *Spermacoce latifolia* Aubl (Monteiro, 2011). Other less frequent species are *Stachytarpheta cayennensis* (Split) Vahl. and *Paspalum multicaule* Poir. However, according to (Acuña, 2000; Souza Cruz, Rodrigues, Dias, Alves, & Albuquerque, 2010), the floristic composition of the weed community may vary according to type and intensity of soil and weed management.

In tropical conditions, it is estimated that for ‘Pera’ sweet orange plants, productivity losses caused by crop-weed competition can reach 35% (Gonçalves et al., 2018). In other research studies on subtropical conditions, crop-weed competition reduced productivity of fruits by 63% and 40%, respectively (Jordan, 1983; Durigan, 1996).

Citrus plants store a large amount of nutrients in their tissues. These nutrients can be redistributed in the plant, contributing to the formation of new parts, such as roots, leaves, flowers and fruits. For this reason, the decrease of soil nutrients, especially nitrogen, may not affect the production of fruit immediately. However, when N rates are lower than those exported by crops, there may be losses in fruit production in subsequent years (Boaretto, Mattos Junior, Trivelin, Muraoka, & Boaretto, 2007).

The levels of nutrients in weed leaves vary, depending on the species, thus indicating differentiated capacity of nutrient cycling (Fialho et al., 2012). Digitaria *horizontalis*, for example, is very efficient in absorbing P and Fe, *Urochloa plantaginea* in absorbing P, Mg, Mn and Zn, and *Merrenia aterrima*, N, Ca and Zn. These plants have a high capacity for extracting nutrients from the soil, and they may be highly competitive against crops. As a consequence, agricultural productivity is reduced.

For perennial crops, studies relative to different capacities of crop-weed competition for nutrients are restricted to certain crops such as coffee (*Coffea arabica*), physic nut (*Jatropha curcas* L.) and guarana (*Paullinia cupana*) (Fialho et al., 2012; Ferreira, Silva, Carvalho, Silva, & Santos, 2013; Fontes & Nascimento Filho, 2013). Compared to the plants of guarana, *Amaranthus retroflexus* and *Pueraria phaseoloides*, they accumulate at least twice as much N, P, K, Ca, Mg and S in their tissues (Fontes & Nascimento Filho, 2013). In comparison with coffee plants, *Bidens pilosa* can accumulate six times as much N as coffee, 15 times as much P, seven times as much K and Ca, nine times as much Mg and 21 times as much S. *Sida rhombifolia* accumulates twice as much N, Mg and S, six times as much P and Ca, and five times as much K (Ronchi et al., 2003).

In Brazil, there are few studies that have addressed the capacity for competition and accumulation of nutrients between weeds and orange crops. Comparative studies on the accumulation of dry mass and nutrients between cultivated and non-cultivated plants enable an analysis of growth potential and absorption of nutrients of each species. Based on this comparison, inferences can be made about the competitive capacity of a species over another when they compete for environmental resources while they are growing (Carvalho, S. Bianco, & M. Bianco, 2014).

Therefore, the objective of this paper is to identify, by means of a floristic and phytosociological study, the most important weed species in an area cultivated with orange trees and to determine the potential of these plants to accumulate biomass and nutrients.

2. Material and Methods

The experiment was conducted in the agricultural year of 2013 and repeated in 2014, in an area of commercial production of sweet orange cv. 'Pera' trees, in soil classified as a Dystrophic Yellow Latosol (Embrapa, 2013). According to the Köppen classification, the climate of the region is Af, hot, humid, with constantly high temperatures, a minimum temperature of 23.5 ºC and a maximum of 31.2 ºC, and precipitation around 2200 mm yr^{-1} (Alvares et al., 2013).

The analysis of the fertility of the soil in the experimental area, in the layer from 0 cm to 20 cm, indicated the following attributes: pH (H_2O) 4.45; 5.0 Mg dm^{-3} P; 36 mg dm^{-3} of K; 0.15 $cmol_c$ dm^{-3} Al; 5.03 $cmol_c$ dm^{-3} H + Al; 2.1 $cmol_c$ dm^{-3} Ca; 0.8 $cmol_c$ dm^{-3} Mg; 3.64 dag kg^{-1} Mo; 0.96 mg dm^{-3} Zn; 321 mg dm^{-3} Fe; 2.2 Mg dm^{-3} Mn; and 0.3 mg dm^{-3} Cu. Particle size distribution had the following composition: sand, 214 g kg^{-1}; silt 136 g kg^{-1} and clay 650 g kg^{-1}.

The orange trees presented healthy plants, spaced at 6.0 m × 4.0 m, with approximately nine years of age. In recent years, weed control of the crop rows involved three applications of glyphosate at the rate of 1720 g ha^{-1} a.i. and two to three mechanized mowings per $year^{-1}$ in the interrows.

Studies on floristic composition and phytosociology of weeds were performed with the square inventory method (Braun-Blanquet, 1979), with the aid of samplers with an area of 0.12 m², randomly thrown 64 times in the orchard area, covering a total of 7.68 m² of sample area. The plants of the area bounded by the square were cut close to the ground, separated, counted and identified. They were identified by scientific name, common name and family. The plants were dried in a forced air circulation oven at 72 ºC until constant weight was reached. The weight of total dry matter of the plants was expressed in g $plant^{-1}$ and in t ha^{-1}. The following phytosociological parameters were calculated: frequency, density, abundance and importance value index (IVI), according to formulas proposed by (Ellenberg & Mueller-Dombois, 1974).

Based on the calculation of IVI, nine weed species were selected as the most representative ones of the study area. Of each species, four samples were collected. They were composed of shoots of the plants (stem and leaf in sufficient quantity to compose the sample) in order to determine the levels of macronutrients and micronutrients in the composition of their tissues. At the time of court, all weed species were at the stage of flowering and/or fruiting. Four samples composed of fully expanded and healthy leaves of orange trees (3rd or 4th leaf of fruitless branches, in four quadrants, in the median position of the plant) were also collected for comparison.

Interpretation of results was based on the calculation of the relative content of nutrients in the leaves of orange plants and weeds. The value of 100% was assigned to the content of nutrients found in orange plants. This reference value was used for calculation of the values for the other species (Ronchi et al., 2003), which may assume values below or above 100%, thus indicating a greater or lesser capacity to extract nutrients from the soil, or a higher or lower competitive potential of weeds. The data on the characteristics being studied were submitted to analysis of variance and subsequent comparison of means by the Scott-Knott test ($p \leq 0.05$) with the aid of the software, *Assistat*.

3. Results and Discussion

In the floristic survey, 30 weed species were identified. They belonged to 14 botanical families, with a total of 1341 specimens (Table 1). The most representative families in number of species were: Asteraceae, Euphorbiaceae and Poaceae which, together, accounted for 40% of the identified species and about 50% of the total number of specimens (Table 2). The least representative families were: Cleomaceae, Convolvulaceae, Loganiaceae and Molluginaceae, which had only one species each.

Table 1. Weeds identified in the floristic survey in an area with orange trees

Family	Species	International Code	Common name
Asteraceae	*Acanthospermum hispidum* DC.	ACNHI	Bristly starbur
	Ageratum conyzoides L.	AGECO	Billygoat-weed
	Conyza bonariensis L.	ERIBO	Hairy fleabane
	Emilia sonchifolia (L.) DC.	EMISO	Lilac tasselflower
Cleomaceae	*Cleome affinis* DC.	CLEAF	Spider weed
Convolvulaceae	*Ipomoea triloba* L.	IPOTR	Common morning-glory
Cyperaceae	*Cyperus* spp.		Sedge
	Rhynchospora nervosa (Vahl) Boeckeler	DICCI	Bata Cotorra
Euphorbiaceae	*Chamaesyce hirta* L.	EPHHI	Asthma plant
	Chamaesyce prostrate (Aiton) Small	EPHPT	Prostrate sandmat
	Euphorbia heterophylla L.	EPHHL	Mexican fireplant
	Phyllanthus niruri L.	PYLNI	Stonebreaker
Fabaceae	*Pueraria phaseoloides* (Roxb.) Benth.	PUEPH	Tropical kudzu
	Stylosanthes sp.		Pencilflower
Loganiaceae	*Spigelia anthelmia* L.	SPKAN	Wormgrass
Malvaceae	*Sida rhombifolia* L.	SIDRH	Arrowleaf sida
	Waltheria corchorifolia Pers.	WALCO	Buff coat
Molluginaceae	*Mollugo verticillata* L.	MOLVE	Green carpetweed
Piperaceae	*Peperomia pellucida* L.	Inexistent	Pepper elder
	Piper peltatum L.	Inexistent	Cordoncillo
Poaceae	*Digitaria horizontalis* Willd.	DIGHO	Jamaican crabgrass
	Eleusine indica L.	ELEIN	Crowfoot grass
	Paspalum conjugatum P.J. Bergius	PASCO	Hilograss
	Paspalum multicaule Poir.	PASPA	Crowngrass
Rubiaceae	*Spermacoce latifolia* Aubl.	BOILF	Oval-leaf false buttonweed
	Spermacoce verticillata L.	BOIVE	Shrubby false buttonweed
Solanaceae	*Solanum americanum* Mill.	SOLAM	American black nightshade
	Solanum paniculatum L.	SOLPA	Nightshade
Verbenaceae	*Stachytarpheta cayennensis* (Rich.) Vahl	STCDI	Cayenne porterweed

Conyza bonariensis, commonly known as hairy fleabane, was notably the species with the highest density and the highest frequency in the study area, with approximately 34 plants m^{-2}. It was present in more than 60% of the sampled plots (Table 2).

These characteristics, especially its high frequency, must have led to the higher value of IVI for that species (39.02), which is known to infest abandoned areas (vacant lots and roadsides), grassland, perennial crops (citrus and coffee) and annual crops (cotton, corn, soybean and wheat) (Thebaud & Abbott, 1995).

Factors that may have contributed to successful growth of *C. bonariensis* in the study area include the production of a large number of seeds and their facilitated dispersal. A single plant of hairy fleabane can produce, on average, 110 thousand viable seeds (Wu & Walker, 2004) that can be carried distances greater than 100m from the mother plant. According to Vargas, Bianchi, Rizzardi, Agostinetto, and Dal Magro (2007), this species has structural adaptations in the seeds, called *pappi*, to facilitate wind dispersal (Dauer, Mortensen, & Vangessel, 2007).

Table 2. Phytosociological characteristics of the weed community in the orange orchard

Species	TNS	Den	Fre	Abu	Dom	RD	RF	RAb	RDo	IVI
	-	Plants m^{-2}	%	Plants $plot^{-1}$	g m^{-2}	------------------------------- % -------------------------------				
C. bonariensis	369	34.17	61.11	6.71	10.30	27.52	16.52	8.01	14.49	39.02
S. latifolia	146	13.52	27.78	5.84	15.20	10.89	7.51	6.98	21.38	35.86
P. conjugatum	147	13.61	45.56	3.59	11.30	10.96	12.31	4.28	15.89	32.49
P. phaseoloides	38	3.52	35.56	1.19	12.50	2.83	9.61	1.42	17.58	28.61
M. verticillate	226	20.93	14.44	17.38	1.60	16.85	3.90	20.77	2.25	26.92
P. pellucida	113	10.46	20.00	6.28	0.80	8.43	5.41	7.50	1.13	14.03
E. heterophylla	48	4.44	18.89	2.82	2.50	3.58	5.11	3.37	3.52	11.99
W. corchorifolia	41	3.80	16.67	2.73	1.80	3.06	4.50	3.27	2.53	10.30
P. multicaule	19	1.76	14.44	1.46	2.20	1.42	3.90	1.75	3.09	8.74
D. horizontalis	31	2.87	12.22	2.82	1.00	2.31	3.30	3.37	1.41	8.08
L. camara	26	2.41	6.67	4.33	0.20	1.94	1.80	5.18	0.28	7.26
R. nervosa	17	1.57	7.78	2.43	1.50	1.27	2.10	2.90	2.11	7.11
A. hispidum	12	1.11	4.44	3.00	1.50	0.89	1.20	3.58	2.11	6.89
S. anthelmia	9	0.83	2.22	4.50	0.30	0.67	0.60	5.38	0.42	6.40
C. hirta	16	1.48	14.44	1.23	0.60	1.19	3.90	1.47	0.84	6.22
P. peltatum	19	1.76	6.67	3.17	0.40	1.42	1.80	3.78	0.56	6.15
S. rhombifolia	13	1.20	11.11	1.30	0.80	0.97	3.00	1.55	1.13	5.68
Cyperus spp.	12	1.11	10.00	1.33	0.50	0.89	2.70	1.59	0.70	5.00
S. cayennensis	8	0.74	5.56	1.60	1.10	0.60	1.50	1.91	1.55	4.96
A. conyzoides	9	0.83	6.67	1.50	0.80	0.67	1.80	1.79	1.13	4.72
E. indica	5	0.46	5.56	1.00	1.00	0.37	1.50	1.19	1.41	4.10
Stylosanthes sp.	3	0.28	2.22	1.50	0.40	0.22	0.60	1.79	0.56	2.96
S. paniculatum	3	0.28	3.33	1.00	0.60	0.22	0.90	1.19	0.84	2.94
I. trilobal	2	0.19	2.22	1.00	0.60	0.15	0.60	1.19	0.84	2.64
C. prostrata	3	0.28	3.33	1.00	0.20	0.22	0.90	1.19	0.28	2.38
S. verticillate	2	0.19	2.22	1.00	0.30	0.15	0.60	1.19	0.42	2.22
E. sonchifolia	1	0.09	2.22	0.50	0.40	0.07	0.60	0.60	0.56	1.76
S. americanum	1	0.09	2.22	0.50	0.30	0.07	0.60	0.60	0.42	1.62
C. affinis	1	0.09	2.22	0.50	0.30	0.07	0.60	0.60	0.42	1.62
P. niruri	1	0.09	2.22	0.50	0.10	0.07	0.60	0.60	0.14	1.34
TOTAL	1341	124.17	370.00	83.71	71.10	100.00	100.00	100.00	100.00	300.00

Note. TNS = Total number of spciemns; Den = density; Fre = frequency; Abu = abundance; Dom = dominance; RD = relative density; RF = relative frequency; RAb = relative abundance; RDo = relative dominance; IVI = importance value index.

Another factor that may have contributed to the increase of the population of *C. bonariensis* in the studied orchard is its resistance to successive applications of herbicides with the same mechanism of action. In the literature, there are several studies that confirm this resistance, in both areas of soybean monocrops and citrus crops, and in grazing areas (Vargas et al., 2007). In the Amazon, several citrus producers have reported that, on their farms and in surrounding areas, this species is resistant to glyphosate, the main herbicide used by orange producers to combat weeds in the region. In other citrus orchards in which glyphosate was used, massive populations of *C. bonariensis* were present. They were probably selected by the repetitive use of this herbicide. Currently, *C. bonariensis* is one of the most important weed species in Brazil and in the world (Heap, 2014; Dalazen, Kruse, & Machado, 2015) as a result of its characteristics: aggressiveness, wide geographic distribution and high capacity for herbicide resistance.

Other species of great importance in this research were *S. latifolia*, *P. conjugatum*, *P. phaseoloides* and *M. verticillata*, which presented, respectively, the following importance value indices: 35.86; 32.49, 28.61 and 26.92 (Table 2). *S. latifolia*, known as the winged false buttonweed, is a species with great invasive potential and high reproductive capacity. A single plant can produce up to approximately 3000 seeds (Gomez & Rivera, 1987), which demonstrates their aggressiveness both in growth and in coverage. In Brazil, *S. latifolia* has been reported as problematic because it is difficult to control, especially in areas of soybean crops, as a result of resistance to glyphosate (Costa, Alves, & Pavani, 2002; Galon, Agostinetto, & Vargas, 2009). *P. conjugatum* and *P. phaseoloides* have also been reported very often in areas of guarana (Mileo, Bentes, Silva, & Christoffoleti, 2006) and citrus (Gonçalves, 2015) plants. They are considered to be weed plants because they compete with crops for factors of production and are alternative hosts of the fungus *Colletotrichum guaranicola*, the pathogen of the main disease affecting guarana plants (Mileo et al., 2006). *M. verticillata* has been found often in cultivation areas of manioc (Cardoso et al., 2013), citrus (Gonçalves, 2015), cowpea (Corrêa, Alves, Rocha, & Silva, 2016) and pepper (Cunha et al., 2014). It causes significant losses to crops, mainly herbaceous plants, when not controlled.

The species with the highest dry biomass production were *S. latifolia*, *P. phaseoloides, P. conjugatum* and *C. bonariensis*. They have accumulated 15.2; 12.5; 11.3; and 10.3 g m^{-2} in their tissues, respectively (Table 2). It should be noted that when these species are not properly controlled, their biomass is much higher in the infested area. In a study conducted by Gonçalves (2015), *C. bonariensis*, when not properly managed, produced a biomass of up to 2.08 t ha^{-1} of dry matter. According to Kaspary (2014), in adult age, shoot dry mass of a single plant of the said species may reach 388.5 g, while total dry mass may be up to 494 g. In crop areas, *S. latifolia* may reach infestation of 350 plants m^{-2} (Acuña, 2000), a biomass of 23 g $plant^{-1}$ (Costa et al., 2002) and up to 0.77 t ha^{-1} of dry matter (Gonçalves, 2015). *P. phaseoloides*, at a density of 0.69 plants m^{-2}, can accumulate up to 3.2 t ha^{-1} of shoot dry matter, while *P. conjugatum*, can accumulate up to 1.89 t ha^{-1} of dry matter in interrows in coffee growing areas (Moreira et al., 2013).

Tables 3 and 4 show the total amounts of nutrients present in the leaves of orange plants and weeds and their relative content.

Table 3. Absolute and relative content of macronutrients in the shoot of the main weeds occurring in the orange production area

Species	N		P		K		Ca		Mg		S	
	g kg^{-1}	%	g kg^{-1}	%	g kg^{-1}	%	g kg^{-1}	%	g kg^{-1}	%	g kg^{-1}	%
C. sinensis	28.4b	100	1.8b	100	11.6c	100	21.9a	100	4.3d	100	2.4e	100
C. bonariensis	30.7a	108	3.1a	177	21.2a	183	12.6b	57	4.6d	107	2.6d	110
D. horizontalis	13.1i	46	1.0c	59	13.0b	112	2.9d	13	4.6d	107	1.2g	51
E. heterophylla	27.4c	97	3.4a	195	12.0c	103	11.1b	51	4.0d	93	3.3c	135
M. verticillate	18.0f	63	1.5c	83	7.2d	62	7.2c	33	16.6b	388	2.3e	96
P. conjugatum	14.4h	51	1.8b	100	8.6d	74	4.4d	20	5.4d	126	1.8f	76
P. pellucida	16.1g	57	2.9a	165	15.9b	137	11.2b	51	19.3a	452	3.6b	149
P. phaseoloides	30.8a	109	2.1b	118	7.2d	62	11.6b	53	5.1d	120	1.9f	78
S. latifolia	19.7e	69	1.8b	105	5.2e	45	13.2b	60	6.0d	141	6.1a	254
W. corchorifolia	20.9d	74	2.9a	168	5.0e	43	12.7b	58	6.4c	149	2.4e	101
CV (%)	10.60		16.46		12.95		14.99		19.05		10.07	

Note. Values in the column followed by the same lowercase letter do not differ significantly from each other by the Scott-Knott test at 5% probability ($p \leq 0.05$).

Table 4. Absolute and relative content of micronutrients in the shoot of some of the main weeds occurring in the orange production area

Species	B		Cu		Fe		Mn		Zn	
	mg kg^{-1}	%	mg kg^{-1}	%	mg kg^{-1}	%	mg kg^{-1}	%	mg kg^{-1}	%
C. sinensis	89.0a	100	4.1f	100	128.7d	100	3.9d	100	12.3f	100
C. bonariensis	61.5b	69	15.7a	391	3969.1b	3085	25.0b	645	89.6c	857
D. horizontalis	13.7i	15	5.3e	132	1173.0c	912	22.9b	592	54.4d	521
E. heterophylla	38.2f	43	8.2d	205	1699.2c	1321	13.2c	341	41.7e	399
M. verticillate	39.8e	45	3.8f	94	1442.0c	1121	13.2c	340	112.5b	1076
P. conjugatum	18.9h	21	7.1d	177	1673.4c	1301	15.0c	388	68.9d	660
P. pellucida	38.3f	43	13.1b	329	6632.5a	5155	45.0a	1163	155.7a	1490
P. phaseoloides	46.2c	52	8.7c	217	1611.5c	1253	13.6c	350	39.1e	374
S. latifolia	25.8g	29	10.1c	253	3518.5b	2735	26.0b	672	52.5d	502
W. corchorifolia	45.9d	52	8.5c	212	1842.9c	1432	20.8b	538	58.6d	560
CV (%)	10.01		11.93		26.74		19.05		17.42	

Note. Values in the column followed by the same lowercase letter do not differ significantly from each other by the Scott-Knott test at 5% probability ($p \leq 0.05$).

The evaluated species had significantly lower values than the orange trees for relative accumulation of Ca in the leaf. However, they were significantly higher in the accumulation of micronutrients, except for B. *C. bonariensis* was significantly more efficient in the accumulation of N, P, K, S, Cu, Fe, Mn and Zn. This species was able to accumulate two times more K (Table 3), four times more Cu, 31 times more Fe, six times more Mn and seven times more Zn than the orange trees (Table 4). The grasses (*D. horizontalis* and *P. conjugatum*) showed little efficiency in the relative accumulation of macronutrients, but they were quite efficient in the accumulation of micronutrients, with the exception of B. As for the orange trees, the *heterophylla* accumulated more P and S, and less N, Ca and Mg in their tissues. The *M. verticillata* accumulated significantly fewer macronutrients than the orange trees, except for Mg, and the *P. pellucida* was efficient in the accumulation of macronutrients, with N and Ca. As for micronutrients, *M. verticillata* was able to accumulate 3 times more Cu, 51 times more Fe, 11 times more Mn and 13 times more Zn than the citrus plants. In contrast, *P. phaseoloides* accumulated significantly more N, but less K, Ca and S. This species accumulated 2.1; 12.5; 3.5 and 3.7 times more Cu, Fe, Mn and Zn, respectively, than the orange trees. *S. latifolia* was efficient in the accumulation of N, K and Ca. As for micronutrients, *S. latifolia* as well as *W. corchorifolia* accumulated about 2.0; 27.0; 6.5 and 5 times more Cu, Fe, Mn and Zn in their tissues than the orange trees. Taking into account the extraction of Cu from the soil, all weeds, except for *M. verticillata*, were more efficient than the orange trees. However, the most efficient species were *C. bonariensis* and *P. pellucida*, which accumulated 15.7 mg kg^{-1} and 13.1 mg kg^{-1} in their tissues, respectively. The great demand for Cu by the weeds may have caused the low concentration of this element in the citrus leaves.

The total content of Fe in citrus leaves was 128 mg kg^{-1}, a value which was considered to be adequate for this crop. However, all weeds, especially *C. bonariensis* (3969.1 mg kg^{-1}), *P. pellucida* (6632.5 mg kg^{-1}) and *S. latifolia* (3518.5 mg kg^{-1}) were much more efficient than the crop in the accumulation of Fe in their tissues (Figure 4). Mn and Zn were found in insufficient amounts in the leaves of orange trees (3.9 mg kg^{-1} and 10.5 mg kg^{-1}, respectively). However, all weeds accumulated these nutrients in a quantity well above that of the crop, which may have reduced the supply of these elements in the soil, and, consequently, reduced their absorption by the citrus plants.

As regards accumulation of mineral nutrients in weeds which are common in guarana (*Paullinia cupana*) crops, the species *Alternanthera tenella*, *Amaranthus retroflexus*, *Commelina erecta*, *Lantana camara*, *Pueraria phaseoloides* and *Stachytarpheta cayennenis* are more efficient in nutrient absorption (Fontes & Nascimento Filho, 2013) than guarana plants. However, according to Pitelli (1985), the ability to remove nutrients from the soil and the amount required varies considerably between the weeds involved, between the types of nutrients absorbed and the degree of competition of the species. The weed that accumulated most Fe, Mn and Zn in its leaves was *P. pellucida*, a herbaceous plant of the Piperaceae family, known as pepper elder. This species grows easily in moist, shaded areas with abundant organic matter (Silva, Ribeiro, & Freitas, 2013). Under the canopy of citrus plants, it finds adequate conditions to grow and it competes strongly, mainly for micronutrients, thus limiting the supply of these elements to the crop and reducing production.

As far as the ability of weeds to compete for nutrients is concerned, dry matter accumulation by weeds should also be taken into consideration, rather than only the nutrient levels that these plants accumulate in their tissues (Pitelli, 1985). In a weed community, a certain weed may have the highest nutrient content; however, it may present the lowest nutrient contents if they have low dry biomass production. Thus, under the experimental conditions of this research, the species *S. latifolia*, *P. phaseoloides*, *P. conjugatum* and *C. bonariensis* have a higher potential for competition for soil mineral nutrients, and they can cause considerable decreases in the relative content of nutrients in orange trees.

4. Conclusions

The weeds that accumulated the greatest amount of nutrients were *C. bonariensis*, *S. latifolia*, *P. conjugatum* and *P. phaseoloides*. They were also the ones that extracted the highest levels of micronutrients from the soil and accumulated them in their tissues. These plants were the ones that produced the highest dry matter weight.

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