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Weed management and fertilization limit the potential of cassava productivity in subtropical environment

Manejo de plantas daninhas e fertilidade limitam o potencial de produtividade da mandioca em ambiente subtropical

Paula de Souza Cardoso[1*] (ORCID 0000-0002-0406-2909), Alexandre Ferigolo Alves[1] (ORCID 0000-0002-6610-3104), Eduardo Daniel Friedrich[1] (ORCID 0000-0001-5142-5496), Luana Fernandes Tironi[2] (ORCID 0000-0001-6479-9606), André da Rosa Ulguim[1] (ORCID 0000-0002-8850-4670), Nereu Augusto Streck[1] (ORCID 0000-0002-2495-0823), Alencar Junior Zanon[1] (ORCID 0000-0002-7194-9833)

[1]Universidade Federal de Santa Maria, Santa Maria, RS, Brasil. *Author for correspondence: paulasouza_1993@hotmail.com
[2]Assistência Técnica e Extensão Rural e Social, Santa Maria, RS, Brasil.

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ABSTRACT

The objectives of this study were to evaluate the response to fertilization and different weed control periods in the accumulation of dry matter of cassava leaves, stems, roots, and fresh mass roots yield. Two experiments were carried out on commercial fields in Ibarama, and Santa Maria municipalities located at the Rio Grande do Sul State, South Brazil, during the 2018/2019 growing season. Five treatments, varying chemical fertilizer applications and herbicides were used to represent management practices commonly used by farmers in Southern Brazil. The Simanihot process-based model simulated cassava growth, development, and productivity under potential conditions. Results show that the recommended dose of fertilizers and liming combined with pre-emergent herbicide and three mechanical weed clear management showed a 72% increase in root productivity compared to the management used by the average yield of smallholder farmers. Therefore, it is possible to reach 80% of the potential productivity by keeping the cassava crop free from weed interference and applying fertilizers. The presence of weeds during the first 100 days after planting reduced about 50% of the plant dry matter production in Ibarama and Santa Maria. Interestingly, it also affects 79.2% of fresh roots productivity in Ibarama.

KEYWORDS: *Manihot esculenta* Crantz; fertility; s-metolachlor; Simanihot; weed.

RESUMO

Os objetivos deste trabalho foram avaliar a resposta à adubação e diferentes épocas de controle de plantas daninhas no acúmulo de matéria seca de folhas, hastes, raízes e produção de massa fresca de raízes de mandioca. Dois experimentos foram conduzidos em campos comerciais nos municípios de Ibarama e Santa Maria localizados no Rio Grande do Sul, Sul do Brasil, durante a safra 2018/2019. Cinco tratamentos, com aplicações variadas de fertilizantes químicos e herbicidas foram utilizados para representar as práticas de manejo comumente utilizadas pelos agricultores do Sul do Brasil. O modelo baseado no processo Simanihot foi usado para simular o crescimento, desenvolvimento e produtividade da mandioca sob condições potenciais. Os resultados mostram que a dose recomendada de fertilizantes e calagem combinados com herbicida pré-emergente e três manejos mecânicos de limpeza de plantas daninhas apresentaram um aumento de 72% na produtividade de raízes em relação ao manejo utilizado pela produtividade média dos pequenos agricultores. Portanto, é possível atingir 80% do potencial de produtividade mantendo a cultura da mandioca livre de interferência de plantas daninhas e com aplicação de fertilizantes. A presença de plantas daninhas durante os primeiros 100 dias após o plantio reduziu cerca de 50% da produção de matéria seca da planta em Ibarama e Santa Maria e 79,2% da produtividade de raízes frescas em Ibarama.

PALAVRAS-CHAVE: *Manihot esculenta* Crantz; fertilidade; plantas daninhas; s-metolachlor; Simanihot

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is the third-largest source of energy to human diet in developing countries, being widely cultivated at tropical and subtropical regions of Africa, Latin America, and Asia

(HOFFMAN 2014). Cassava was chosen by the Food and Agriculture Organization (FAO) of the United Nations (UN) as the 21st century food through the project “Save and Grow: Cassava” to guarantee food security for more than 800 million people around the world (HOWELER et al. 2013, TRACHTA et al. 2020). Brazil emerges in a prominent position in cassava production, as the fourth largest world producer, after Nigeria, Thailand and Indonesia (FAO 2019). Despite the high diversity of uses for cassava plant parts, greater added value is concentrated at the roots, which are used for food, both human and animal, process industries and medicines. It is important to note that cassava plants are cultivated mainly on family smallholdings (TAGLIAPIETRA et al. 2019).

Brazil's yield roots average of cassava in the last five years was 15.0 Mg ha^{-1} (IBGE 2022). However, it is below the yield potential for this crop, close to 55 Mg ha^{-1} (VISSES et al. 2019). The low yield could be associated mainly with low fertility soils, acidic soils, inadequate planting time, and inadequate weed control (ALBUQUERQUE et al. 2014, TIRONI et al. 2015, TIRONI et al. 2017, TIRONI et al. 2019). Time to start control and the weeding frequency along the crop development straightly interferes on the roots yield for cassava (PERESSIN et al. 2013). In studies carried out at the Democratic Republic of the Congo central region was observed that when the first weeding is applied until the first month after planting, roots yield increased in comparison to the weeding on the second, third and seventh months after planting (KINTCHÉ et al. 2017). The mains damages caused by the interference of weeds on cassava crop are associated with water, light and nutrients competition (ALVES FILHO et al. 2015, WERLE et al. 2021), that can lead to losses up to 90% on the yield and in addition, to increasing production costs and harvest operational difficulty (KINTCHÉ et al. 2017). Another important limiting factor for cassava yields is the nutrients availability, once cassava crop extracts from the soil large amounts of nutrients, mainly potassium (K), nitrogen (N), and phosphorus (P). For instance, to produce 25 Mg ha^{-1} of cassava roots is required 146 kg K Mg^{-1}, 123 kg N Mg^{-1} and 27 kg P Mg^{-1} (MATTOS et al. 2003), nutrients that at the proper amount, favor the starch accumulation and consequently increases on the roots yield (RÓS et al. 2013, THOMÁS et al. 2016). Considering that weed management and fertilization are important factors that cause cassava yield gaps, it is necessary to quantify their effects. This study's objective was to evaluate cassava's response to fertilizers application and weed control periods on the accumulation of dry matter of leaves, stems, and roots and in the yield of fresh mass of tuberous roots.

MATERIALS AND METHODS

Experiments were carried out in two commercial fields from October 2018 to May 2019, at the municipalities of Ibarama (29 ° 25'S, 53 ° 08'W and altitude of 317 m above sea level) and Santa Maria (29 ° 41'S, 53 ° 43'W and altitude of 113 m above sea level), on Rio Grande do Sul State (RS), Brazil. In Ibarama, the soil was classified as “entisol”, with the A top horizon sitting straight into the C horizon. Therefore, at this kind of soil, a low root developed is expected due shallow and well-drained soil conditions. On the other hand, the soil at Santa Maria is a “sandy loam typic paleudalf” being deep and well-drained (STRECK et al. 2018). Table 1 shown soil laboratory analysis for both study locations.

Table 1. Soil laboratory analysis at the 0-20 cm layer for experimental locations on Ibarama and Santa Maria, RS, Brazil.

Soil properties	Ibarama	Santa Maria
pH (1:1 H_2O)	5.2	4.6
Base saturation (%)	83.6	12.0
Saturation Al (%)	2.9	46.7
Clay (%)	16.0	13.0
Organic matter (%)	1.5	0.9
CTC[1] pH7 ($cmol_c/dm^3$)	28.7	7.0
P (mg/dm^3)	50.8	6.6
K (mg/dm^3)	236.0	36.0
Ca ($cmol_c/dm^3$)	17.57	0.5
Mg ($cmol_c/dm^3$)	5.83	0.2

[1]CTC = Cation-exchange capacity.

Soil tillage was conducted by conventional method, plowing and harrowing the soil surface layer. Cassava planting was performed on October 24 and October 26, 2018 at Ibarama and Santa Maria, respectively. Five different management practice scenarios were evaluated, varying from without fertilizer or lime application to proper soil fertilizer and lime application, following the agronomic advice from both regions, and herbicides applying/not applying (Table 2). These treatments were based on cassava smallholdings reality for southern Brazil to assess the interaction between fertilizers and weed management.

Table 2. Five treatments, varying chemical fertilizer applications, and herbicides were used in the experiments conducted in Ibarama and Santa Maria, RS, Brazil.

Management practices	Treatments				
	T1	T2	T3	T4	T5
Liming	[1]Applied, only with lack of Ca and Mg	Not applied	Not applied	Not applied	Not applied
Fertilization	Full advice dose[2]	Half advice dose[2]	Half advice dose[2]	Not applied	Not applied
Herbicide	Pre-emergent[3]	Not applied	Not applied	Not applied	Not applied
Weeding	3 (69/67*,99/107* ,137/137* DAP)	3 (69/67*,99/107*, 137/137* DAP)	2 (69/67*,99/107*)	3 (69/67*,99/107*, 137/137*DAP)	1 (69/67* DAP)

Note: Days after planting (DAP); [1]Liming applied at the municipality of Santa Maria; [2]According to soil analysis and following advice from "Manual de Adubação e Calagem para os Estados do Rio Grande do Sul e Santa Catarina", 2016. [3]Application of s-metolachlor with a dose of 2.0 gi.a.ha^{-1}, and spray volume of 200 L ha^{-1}. *Dates differ for each location, on the right Ibarama and Santa Maria's left.

The "Vassourinha" cassava cultivar was used, one of the most planted cultivar on Brazil southern, which present a large number of stems per plant and lateral sprouting, white pulp, easy peeling and fast cooking (TIRONI et al. 2019). The Randomized Complete Block Design (RCBD) with four replicates was used, were planting was carried out into 280 m^2 plots, 1m x 0.8 m spacing, and a plant density of 12,500 plants ha^{-1}. For planting were used manioc propagules (stem cuttings) with 5 to 7 axillaries buds. There was carried out fertilization management (T1, T2 and T3 treatments) following the agronomic technical advice available for Santa Catarina and Rio Grande do Sul states (CQFS RS/SC 2016). At the Santa Maria experimental plots, lime was applied three months before planting with 1.96 Mg ha^{-1} of dolomitic limestone (TRNP 100%) and the fertilizer rates at planting were 12 kg N ha^{-1}, 65 kg P_2O_5 ha^{-1} and 50 kg K_2O ha^{-1}. At the Ibarama experimental plots were applied rates of 6 kg N ha^{-1}, 25 kg P_2O_5 ha^{-1} and 25 kg K_2O ha^{-1}. In addition, a cover fertilization was applied with rates of 64 kg N ha^{-1} and 128 kg N ha^{-1} for Ibarama and Santa Maria, respectively, when plants had between 25 and 30 leaves. S-metolachlor herbicide was sprayed rather pre-emergence for T1 treatment using 640g a.i ha^{-1}, by a sprayer equipped with 110.015 tips type, applying 200 L ha^{-1}. Total rainfall precipitation during cassava season for Ibarama and Santa Maria was 1755 mm and 1248 mm, respectively (Figure 1).

In order to evaluate growth and developmental variables, 12 plants were sampled during the cycle, regarding the border effects and the harvest area. The first plant sampling was collected 69 days after planting (DAP), and the following plant samples were collected at intervals of each 30 days after the first sampling. For these periods, cassava plants had 10 to 15, 25 to 30, and 40 to 45 leaves. At Santa Maria location, the experiments were interrupted on 4/8/2019 (167 days after planting) due to anthracnose (*Colletotrichum gloeosporioides*) and brown eye spot (*Cercosporidium henningsii*) diseases, what turn up impracticable harvesting, due to excessive number of death plants. Therefore, weed control was carried out at critical moments during cassava developmental cycle based on the number of leaves when plants of T1, T2, and T4 treatments presented from 10 to 15, 25 to 30, 40 to 45 leaves, T3 treatment presented from 10 to 15 and from 25 to 30 leaves, and T5 treatment presented between 10 to 15 leaves.

The yield was calculated according to the methodology proposed by TIRONI et al. (2015), determining fresh mass (FM) of cassava roots. The sampled cassava plants were partitioned into leaves, stems, and roots for each collection and dried out at 65 ºC until reaching a constant mass. The fresh weight was determined by separating marketable roots (MR) and non-marketable (NMR) roots, assuming that MR is greater than 10 cm length and than 2 cm diameter and NMR has a diameter between 1 and 2 cm and a length less than 10 cm (SCHONS et al. 2007).

To estimate the potential yield of cassava, the Simanihot, a process-based model, was already calibrated and validated for the Rio Grande do Sul State (GABRIEL et al. 2014, TIRONI et al. 2017, BORGES et al. 2020). The Simanihot model simulates cassava roots' growth, development, and yield for potential conditions. For the simulations, automatic station meteorological data belonging INMET institute were used. For Ibarama, the station located at the municipality of Tupanciretã (Latitude: -29.0893814º, Longitude: -53.82665025º, Altitude: 462 m) was used because it meets the standards of proximity and altitude similarity. To evaluate the effect of interaction between fertilization and weed control, the experimental plots yield (Mg ha^{-1} of fresh roots) was compared with the potential crop's yield. The results were submitted to a analysis of variance (ANOVA), a means test by Tukey ($p \leq 0.05$) and Scheffé test for the analysis of contrasts. All statistical analyzes were performed using SISVAR software (Copyright Daniel Furtado Ferreira 1999-2018), version 5.7.

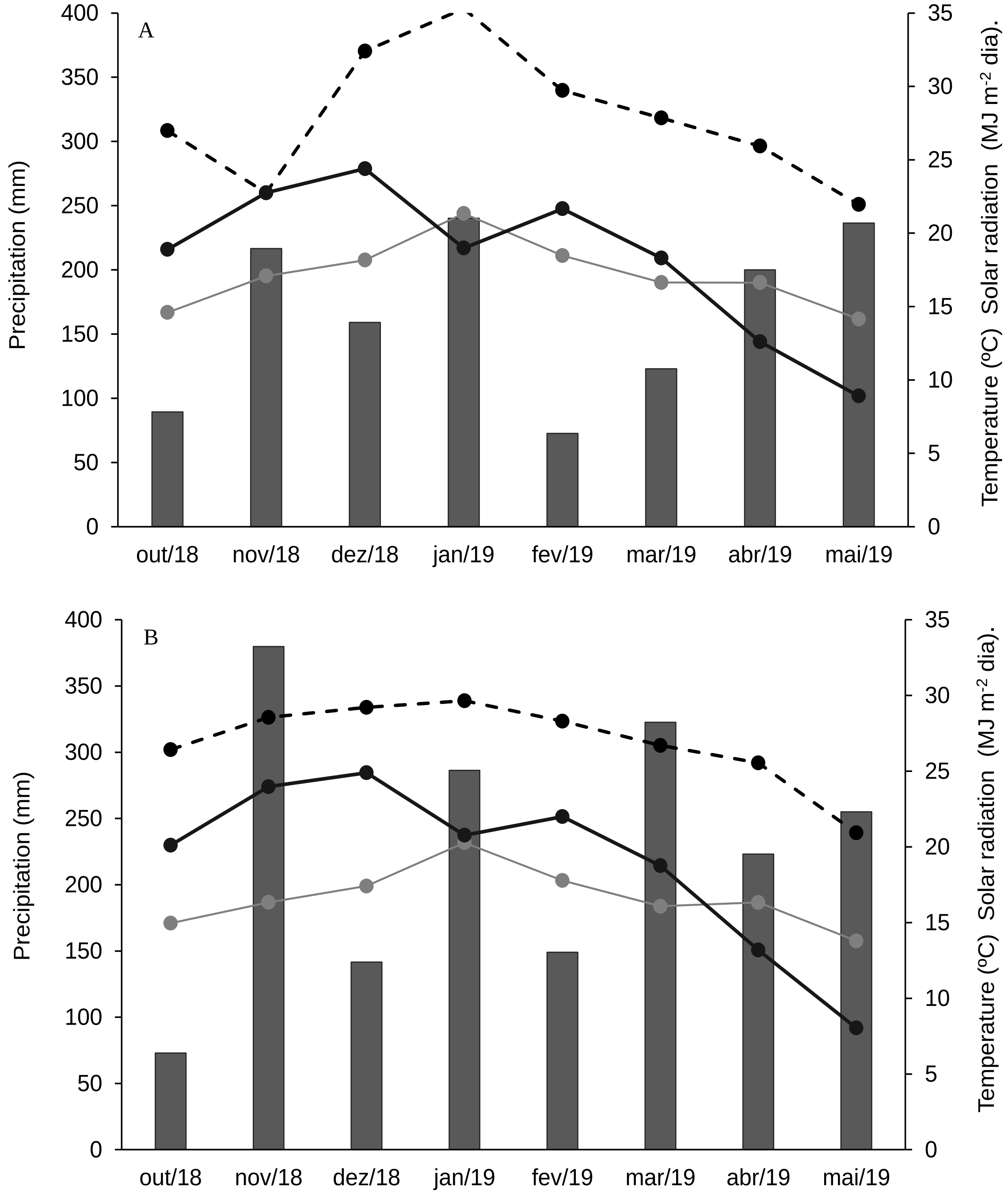

Figure 1. Accumulated monthly rainfall (mm), average maximum and minimum temperatures (ºC) and average incoming solar radiation flux density (MJ m^{-2} day) from October/2018 to May/2019 during the experimental period in Ibarama (A) and Santa Maria (B), RS, Brazil. Source: INMET 2019. (Station code: [A886] Santa Maria and [A886] Tupanciretã).

RESULTS AND DISCUSSION

The 2018/2019 growing season was influenced by the warm phase of the ENOS Phenomenon El Niño, which resulted in rainfall precipitation above normal climatological conditions because of sea surface temperature anomalies in the Equatorial Pacific region (PAULA et al. 2010). The excess of humidity induced to low temperatures on the soil (16 °C), and as result, there was a delay for plants sprouting (SCHONS et al. 2007). In addition, for Santa Maria, excess soil moisture had an impact on diseases such as anthracnose (*Colletotrichum gloeosporioides*) and brown eyespot (*Cercosporidium henningsii*, *Cercospora vicosae*) affecting root harvesting. Problems with water stress are recurrent on El Niño years, what indicate that producers should intensify soil drainage and avoid areas with issues by excess sil moisture. The minimum and maximum temperatures along of the cassava cycle were greater than 14 °C and less than 30 °C, respectively (Figure 1). Higher temperatures and major solar radiation are typical conditions during Summer (December, January, and February) at subtropical regions. For both locations, the solar radiation peak occurred in December, with 24 MJ m^{-2} day^{-1}.

The management applying the pre-emergent herbicide and three weeding joint with soil fertilization promoted greater dry mass accumulation of leaves, stems and roots cassava crop cycle on the Ibarama location (Table 3). For example, T1 presented respectively 90%, 76%, and 83% increase DM on leaves, stems, and roots compared to T5 treatment in Ibarama. Similar results were reported by MUNYAHALI et al. (2017) in a study carried out in Kalehe, eastern Democratic Republic of Congo, where applying fertilizers in cassava increased by 19% and 21% for root yield. Therefore, lack of weed control practices can compromise the yield and profit of cassava crops, advising that control must be carried out between 18 and 100 days after planting (BIFFE et al. 2010).

Table 3. Cassava dry mass (Mg ha^{-1}) of Vassourinha cultivar for leaves, stems and roots at different developments stages related to management practices for experiments conducted on Ibarama and Santa Maria (2018/2019 season).

	Ibarama				Santa Maria			
	Assessments (leaf)							
T[1]	10 a 15	25 a 30	40 a 45	130	10 a 15	25 a 30	40 a 45	99
	Leaves (Mg ha^{-1})							
T1	0.26a[2]	0.83a	1.83a	-[3]	0.12a	0.24a	0.22b	0,27a
T2	0.11b	0.21b	0.74b	-	0.07a	0.19a	0.37a	0.35a
T3	0.11b	0.21b	0.74b	-	0.07a	0.19a	0.18b	0.29a
T4	0.14b	0.21b	0.49c	-	0.07a	0.24a	0.27ab	0.38a
	Stems (Mg ha^{-1})							
T1	0.25a	1.17a	1.79a	3.64a	0.08a	0.32a	0.62a	0.58ab
T2	0.09b	0.34b	0.84ab	2.75a	0.05a	0.22a	0.65a	1.03a
T3	0.09b	0.34b	0.84ab	0.93b	0.05a	0.22a	0.27bc	1.01a
T4	0.09b	0.23b	0.59b	0.81b	0.05a	0.27a	0.40b	0.50ab
T5	0.09b	0.44b	0.42b	0.75b	0.05a	0.15a	0.11c	0.34b
	Roots (Mg ha^{-1})							
T1	0.15a	2.50a	5.68a	14.04a	0.01a	0.26a	0.52ab	1.16ab
T2	0.03b	0.41b	3.04b	8.11b	0.02a	0.27a	0.83a	0.35c
T3	0.03b	0.41b	3.04b	4.95c	0.02a	0.27a	0.51ab	1.82a
T4	0.04b	0.34b	1.75bc	3.91c	0.01a	0.29a	0.54ab	0.87bc
T5	0.04b	0.52b	0.95c	1.99c	0.01a	0.17a	0.24b	1.17b

[1]Treatments; T1: fertilizer and liming application according to technical advice, pre-emergent herbicide and three weeding; T2: fertilizer application (half dose) according to the technical advice, no liming and three weeding; T3: fertilizer application (half dose) according to the technical advice, no liming and two weeding; T4: fertilizer and liming absence and three weeding; T5: without fertilizer liming and weeding. [2]Means followed by the same letter in the column do not differ significantly by the Tukey test ($p \leq 0.05$). [3]Natural senescence of all leaves due to low temperatures in the last sampling (harvest).

In the Santa Maria experimental field, when plants had 40 to 45 leaves, a significant difference of 11.1% was identified for leaf DM accumulation on T2 treatment compared to T1 and T5. For the stem DM accumulation, T1 and T2 showed difference from the other treatments, with an increase of 83.0%, 38.5% and 58.5% in relation to T5, T4 and T3 treatments, respectively. The calculated root DM had a significant difference from T2 to T5, increasing 71.08% for roots yield (Table 3). In March (167 DAP), the Santa Maria's experiment showed DM decrease for every plant part, due to the incidence of diseases (Table 3). In Ibarama, the T5 had a significant difference of 0.3 Mg ha^{-1} for leaves DM compared to T4 treatment. Sampling leaves, stems, and roots at the periods that the plant had 10 to 15 and 25 to 30 leaves showed that the T1 significantly increased the other treatments. Comparing T1 with T5, there was a difference at the first dry matter sampling of 0.1 Mg ha^{-1}, 0.2 Mg ha^{-1} and 0.1 Mg ha^{-1} and at the second sampling with difference of 0.6 Mg ha^{-1}, 0.7 Mg ha^{-1} and 2.0 Mg ha^{-1}, respectively for leaves, stems and roots (Table 3). For a resampling made up on 40 to 45 leaves, the T1 measurements were also significantly higher than other treatments for leaf DM and Stem DM differing from T4 and T5. For the roots DM, the T1 treatment, which presented higher significant differences, resulted in the highest yield, as well as at the first 130 sampling leaves (Table 3). These differences are justified by soil fertility and weed control, which explains the results of higher MS for T1 treatment, because it's had more nutrients available for growth and less water, light and nutrients competition due to the weed control (STRECK 2014).

The presence of weeds and fertilizer absence on the T5 treatment caused a reduction of 12 Mg ha^{-1} in root yield, 1.6 Mg ha^{-1} for leaves DM and 2.9 Mg ha^{-1} for stems DM, compared to T1 (Table 3). The degree of weed interference could be observed by lower roots yield and plant growth reduction, evidencing that there is a hard plant competition for environmental resources such as water, light, and nutrients (ALVES FILHO et al. 2015). The T1 treatment showed significantly the best performance regarding other ones, presumably one of the reason was because it had the proper weed control during the crop cycle (Table 3). Weed control is one of the main management in a cassava crop getting clear at the T5 treatment on Ibarama location, where the competition between crop and weeds caused a loss of approximately 50% at root yield verified on the resampling of "130 leaves" (Table 3).

The yield potential (YP) estimated by the Simanihot model was 55.3 Mg ha^{-1} for Ibarama (Figure 2). At this location, the yield achieved of 79% of YP for the T1 treatment demonstrates that the weed control and fertilizers application are the main limiting factors of cassava yield, and that there is a real possibility to increase cassava yield at current smallholders farms agricultural area with some fine adjustments and improvements on agronomic management practices.

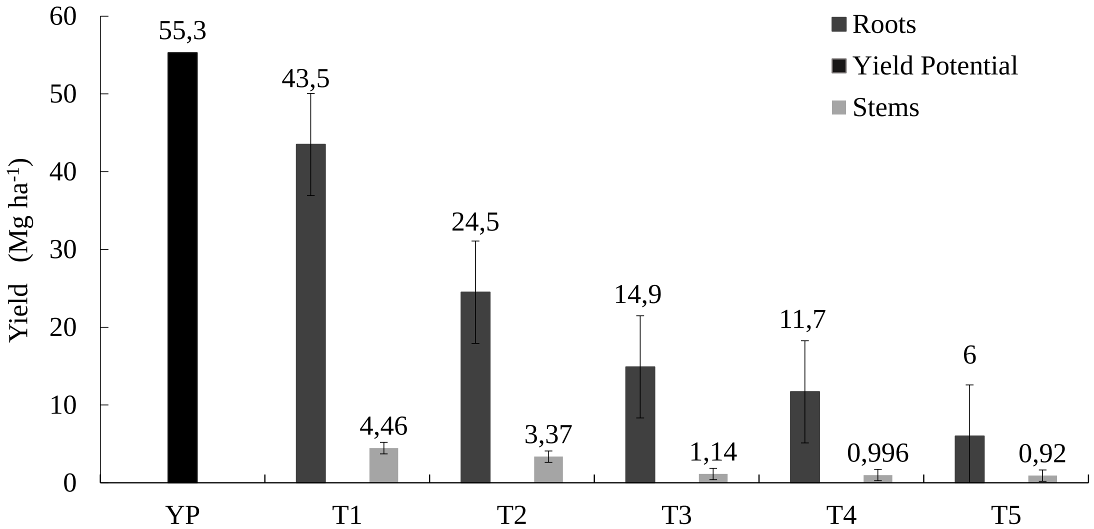

Figure 2. Yield potential (YP) estimated by the Simanihot model and observed stems and roots yield for the five treatments (T1; T2; T3; T4; and T5) at the Ibarama experiment, RS.

Between the T1 treatment (pre-emergent herbicide applications followed by three weeding) and the T5 treatment by traditional management (only one weeding) the yield significantly decrease (Figure 2). This decrease can be attributed to inefficient weed control, especially in the early developmental stages when the crop is more sensible and affected by weed competition (AYE 2011, TIRONI et al. 2019).

In Paraná State, phosphate fertilization significantly increased the production of cassava roots by 28% and 39% (FIDALSKI 1999). However, the roots yield reduction caused by interference from uncontrolled weeds at cassava fields can reduce 40% from total yield (WERLE et al. 2021). At the municipalities of Manacapuru, Machadinho, and Cruzeiro do Sul in Amazonia, Rondonia and Acre State, a loss of productivity of 22,9 tons per hectare was reported mainly due to weed infestation (VISSES et al. 2019).

Table 4 shows on "contrast 1" (C1) that the T1 treatment, that follow the technical advice of how much fertilizer must be applied, statistically showed a higher performance than other treatments that did not applied fertilizer (T4 and T5) or those that the treatments only applied half amount of technical advice (T2, T3). Higher cassava roots yield can be attributed to greater soil nutrients availability on the environment. The soil nutrients availability provide ideal conditions to photoassimilates carry from the aerial part to the roots. The C2 contrast showed a significant difference between soil fertility conditions on the experimental treatments. The C3 contrast corroborates the statistical difference between the advised amount of fertilizers against no fertilizer application, showing the relevance of soil fertility management in achieving high cassava yields.

On the other hand, the number of weeding during the cassava cycle showed that is a main limiting factor on cassava yield roots. A statistical difference between the treatments was observed comparing the performance of 3 weed mechanical controls against 1 and/or 2 mechanical interventions, as shown in contrast C4 (Table 4). A study carried out in Democratic Republic of the Congo also showed decrease at root's yield when the management done had less weeding during de cassava cycle (KINTCHÉ et al. 2017).

Table 4. Comparison of cassava Vassourinha cultivar roots yield (Mg ha^{-1}) between treatments for Ibarama, RS.

Contrast Number	Contrast description	Root yield (Mg ha^{-1}) at 219 DAP[1]
C1	T1[2] X T2+T3+T4+T5	43.51* X 14.24
C2	T1 X T4+T5	43.51* X 08.82
C3	T2+T3 X T4+T5	19.98* X 08.82
C4	T1+T2+T4 X T3+T5	22.04* X 18.80
CV	33.63%	

[1]DAP: Days after planting; T1[2]: Full fertilizer and 3 weeding; T2: Half fertilizer and 3 weeding; T3: Half fertilizer and 2 weeding; T4: without fertilizer and 3 weeding; T5: without fertilizer and 1 weeding; CV: Coefficient of variation (%).
*Significantly by the Scheffé test ($p \leq 0.05$)

The results obtained in this study have important practical applications. Cassava farmers can improve yield by fertilizers applications and also by weeds controlling, mainly during critical developmental phases, so that plants can express their yield potential. These two management factors are feasible from a farmer's viewpoint as they mostly depend on farmers' labor and equipment. Future studies are suggested to evaluate the NPK fertilizer response through the crop demand curve for these nutrients, considering each nutrient individually, as well as survey on weed control methods, assessing both physical and chemical control.

CONCLUSION

The presence of weeds during the first 100 days of a cassava crop reduces about 50% of the plant dry matter yield in Ibarama and Santa Maria and 79.2% of fresh root productivity in Ibarama.

The use of advised fertilizer rates, including correcting Ca and Mg levels when necessary, associated with maintaining the crop free from weed competition, are management practices that contribute to achieving 80% of the yield potential in a typical subtropical environment.

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