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Planting methods and depths for yacon (*Smallanthus sonchifolius*) crops

Métodos y profundidades de siembra para el cultivo de yacón (*Smallanthus sonchifolius*)

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Planting depths and methods for *Smallanthus sonchifolius* crops in Brazil.

Photo: M.A.L. Quaresma

ABSTRACT

Crop management is vital to sprouting, cycle and productivity in most plants of commercial interest. However, recommendations and information are scarce for yacon cultivation, especially for possible interferences form planting method and depth in crop development and production. Therefore, the objective was to study the influence of the planting methods and depths on yacon tuberous root development and production under high altitude conditions. This experiment used a randomized complete block design, with four replications, in a subdivided plot scheme. The plots consisted of three planting methods (groove, pit and ridge), and the subplots had four planting depths (5, 10, 15, and 20 cm). Evaluations were carried out starting with the sprouting process of the rhizophores to the yield of tuberous roots. The planting methods pit and ridge had lower seedling mortality rates (27.5 and 20.2% lower than groove) and higher yields of tuberous roots (31.2 and 21.4% higher than groove). The planting depths 5 and 10 cm for the rhizophores were more suitable for yacon cultivation with the three planting methods.

Additional keywords: plantation crops; spacing; root vegetables; altitude; ridge tillage; planting depth.

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RESUMEN

El manejo del cultivo es decisivo en la brotación, el ciclo y productividad de la mayoría de las plantas de interés comercial. Sin embargo, para el cultivo de yacón las recomendaciones e información son escasas, especialmente en lo que respecta a los posibles efectos del método y la profundidad de siembra en el desarrollo y la producción del cultivo. Por lo anterior, el objetivo de este trabajo fue conocer la influencia de los métodos y profundidades de siembra en el desarrollo y producción de raíces tuberosas de yacón en condiciones de gran altitud. El diseño experimental adoptado fue en bloques al azar, con cuatro repeticiones, en un esquema de parcelas divididas, las parcelas principales consistieron de tres métodos de siembra (surcos, hoyos y camas) y las subparcelas fueron las cuatro profundidades de siembra (5, 10, 15 y 20 cm). Las evaluaciones se llevaron a cabo desde el proceso de brotación de los rizóforos hasta el rendimiento de las raíces tuberosas. Los métodos de siembra en hoyos y camas mostraron las tasas de mortalidad de plántulas más bajas (27,5 y 20,2% más bajas que la siembra en surcos) y los rendimientos más altos de raíces tuberosas (31,2 y 21,4% más altas que plantación de surcos). Se demostró que las profundidades de 5 y 10 cm de rizóforos fueron las más adecuadas para el cultivo de yacón para los tres métodos de plantación.

Palabras clave adicionales: siembra de cultivos; espaciamiento de plantas; vegetales de raíz; altitud; labranza en camas; profundidad de plantación.

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INTRODUCTION

Yacon [*Smallanthus sonchifolius* (Poepp. & Endl.) H. Robinson] confers several benefits, such as constipation relief, increased mineral absorption, strengthened immune system (Genta *et al*., 2010), decreased development of colon cancer (Santana and Cardoso, 2008) and disease inhibition, such as Diabetes Mellitus (Albuquerque and Rolim, 2012). As a result, interest in cultivation has increased, along with demand for a management method that conders bigger and more stable production.

Harvest yield is diverse, ranging from 1 to 41 t ha^{-1} in Ecuador, 7 to 107 t ha^{-1} in Peru, 25 to 90 t ha^{-1} in the Czech Republic and 25 to 35 t ha^{-1} in the United States. In Brazil, yields from 20 to 100 t ha^{-1} were observed in the State of Espírito Santo, Brazil. Silva *et al*. (2018a) observed production variation because of edaphoclimatic conditions, with 97.50 t ha^{-1} (in the mountainous region) and 60.65 t ha^{-1} (in the lowland region).

These variations in productive yield are attributed to issues related to environmental interference, especially temperature (Silva *et al*., 2018b) and water availability (Sumiyanto *et al*., 2012), as well as management, such as the season (Silva *et al*., 2018a), planting depth, nutrition, and spacing, among others (Seminário *et al*., 2003).

In Brazil and in the world, technical recommendations are needed for yacon cultivation, especially the optimal method and planting depth for different edaphoclimatic conditions because they can influence crop productivity and vary according to the characteristics of the region.

The method and planting depth can significantly interfere with the budding process and initial development of the plants (Grotta *et al*., 2008) and, consequently, crop production. The shape and depth of propagule propagation can expose them to different microenvironment conditions, interfering with the development of future plants (Rós, 2017) and affecting crop productivity (Modolo *et al*., 2010).

Therefore, the objective was to study the influence of planting methods and depths on yacon tuberous root development and production under high altitude conditions.

MATERIAL AND METHODS

The experiment was carried out in 2016 in "Flor e Mel", Patrimônio da Penha, a district of Divino de São Lourenço in the State of Espírito Santo, Brazil, with the geographic coordinates 20°35'6.0" South latitude and 41°46'18.2'' West longitude, and an altitude of 1,098 m a.s.l. This municipality is in the mountain region of Espírito Santo, which has a mountain climate (tropical altitude) with two well-defined seasons during the year, one hot and rainy in October to March and the other cold and dry in April to September (Pezzopane *et al*., 2012). The maximum monthly temperatures ranged from 26 to 28°C, and the minimum temperatures were 12 to 18°C. The total rainfall during the experiment was 760 mm, with uneven distribution and low volume between the months of May to August (INMET, 2016).

The area was fallow for nine months, with a high number of ferns (*Pteridium arachnoideum* (Kaulf.) Maxon), a soil indicator of high acidity. For the initial soil tillage, weeding was done with a costal brush, and, after one week, the soil was plowed three times to about 20 cm using a hoe, incorporating the weed biomass to the soil.

The soil of the area was classified as Cambisolo Tb Distrophic, loamy clay texture (Santos *et al*., 2013), and the chemical and physical analysis showed the following characteristics in the 0 to 20 cm layer: pH 5.21 in water; 3.58 mg dm^{-3} of P (Mehlich$_1$); 22.00 mg dm^{-3} of K; 2.59 cmol$_c$ dm^{-3} of Ca; 0.84 cmol$_c$ dm^{-3} of Mg; 0.05 cmol$_c$ dm^{-3} of Al; 7.59 cmol$_c$ dm^{-3} of H$^+$ Al; 4.41 cmol$_c$ dm^{-3} of SB; 4.46 cmol$_c$ dm^{-3} of t; 12.00 cmol$_c$ dm^{-3} of T; 36.76% V; 23% sand, 26% silt, 51% clay and 1.20 dag kg^{-1} of OM.

Yacon rhizophores from a production area in the municipality of Santa Maria do Jetibá/ES were harvested 3 d before planting. The rhizophores were selected and fractionated into 40-50 g pieces, washed in running water and immersed in a sodium hypochlorite solution (5% v/v) for 10 min. After treatment, the rhizophores were dried for 2 d in a ventilated and shaded place.

The yacon was planted in April, which is a more productive period Silva *et al.* (2018a), in crops in this region, with cultivation extended to December, ending with the harvest. The fertilization was carried out by applying 200 g of tanned bovine manure at planting and 150 g for the cover fertilization, 90 d after sowing. This amount was equivalent to 152.24 kg ha^{-1} of nitrogen (approximating the 150 kg ha^{-1} recommended by Amaya (2000) based on nutrient contents in manure (1.74 N, 0.63 K_2O and 0.35% P_2O_5)).

After planting, monthly weeding was done with costal brush cutters, cutting between the plants, keeping residues below the soil surface. Sprinkler irrigation was used to supplement the monthly precipitation. However, during the months of May to August, there was a severe drought in the region that limited the use of irrigation.

The experiment design was a randomized complete block design, with four replications, in a subdivided plot scheme. The plots consisted of three planting methods: grooved, pit, and ridges. The subplots had four planting depths: 5, 10, 15, and 20 cm.

The planting grooves were 20 cm wide and 20 cm deep, and the ridges were 50 cm wide and 40 cm high (both done with hoes). The pits had a radius of 10 cm and depth of 20 cm (made with hand diggers).

The experiment subplot had 28 plants, with an area of 11.2 m^2 (3.5 x 3.2 m), providing 10 useful plants for the evaluations, for a total of 600 useful plants out of 1,680 plants in 672 m^2. The planting was carried out at a spacing of 0.8 m between cultivation lines and 0.5 m between plants, representing a planting density of 25,000 plants/ha, based on the planting densities described by Seminário *et al*. (2003).

The following characteristics were analyzed: sprouting rate index (SRI), vigorous sprouting rate (VSR), average sprouting time (AST), seedling mortality rate (SMR), leaf area at 120 and 240 d after planting (LA1 and LA2), dry mass of tuberous roots (DMTR), number of rhizophores and tuberous roots per plant (NR and TRP), leaf dry matter, and tuberous root yield (TRY).

The initial development was evaluated every 15 d, always at the same time (8 h), for 75 d after planting (DAP). The evaluation methodology from Maguire (1962) was used, according to the vegetative stages: "Green Tip" (GT), appearance of bud coloring modifications, with a greenish tip), and "Open Bud" (OB), based on these vegetative stages. The following variables were calculated:

- Average sprouting time (AST): mean number of days spent between experiment setup on each date and detecting the vegetative stages "Green Tip" (GT) (appearance of bud coloring modifications, with the greenish tip);

- Sprouting rate index (SRI): occurrence of sprouting buds in time given the equation (1):

$$SRI = S(\frac{ni}{ti})(\text{buds per day}) \quad (1)$$

where, ni is number of buds that reached the GT stage at time "i" and ti time in days after the test setup (i = 1 to 45);

- Final sprouting rate (FSR): percentage of rhizophores sections with buds that reached the GT stage;

- Vigorous Sprouting Rate (VSR): percentage of rhizophores sections with buds in the GT stage that progressed to the "Open Bud" (OP) stage (open leaf appearance), during the analysis, given with the equation (2):

$$\text{VSR} = (\text{\% of rhizophores section with GT stages}) \times 100/\text{TF} \quad (2)$$

- Mortality rate (MR): percentage of rhizophores sections that remained alive and vigorous until the end of the evaluations.

The leaf area measurements were taken indirectly using the width and length of each leaf, estimating the total leaf area per plant according to the model of indirect determination proposed by Erlacher *et al.* (2016).

The plant dry matter mass of each plant part was obtained with a digital scale, 0.01 g precision, and oven-dried samples, done with forced air circulation at a temperature of 65°C until constant mass.

The data were initially tested for normality assumptions of the residues (Shapiro-Wilk test) and homogeneity among variances (Bartlett's test). Then, an analysis of variance was performed. The averages were compared with the Tukey test. In all tests (t and F), $P<0.05$ was used as the main significance value.

RESULTS AND DISCUSSION

When analyzing the effect of the planting depths in each method, it was observed that the rhizophore sprouting rate index (SRI) were higher in the depths 5 and 10 cm in the planting ridges and pits and at 5 cm in the grooves. This result reflected the average sprouting time (AST) for the same planting methods and depths (Tab. 1).

Table 1. Sprouting rate index, average sprouting time, vigorous sprouting rate and rhizophore mortality rate in yacon with different planting methods and depths. UFES, Divino de São Lourenço, ES, 2016.

Depth (cm)	Planting method					
	Grooves	Ridges	Pits	Grooves	Ridges	Pits
	Sprouting rate index (buds/d)			Average sprouting time (d)		
5	1.50 a	1.98 a	1.64 a	42.49 b	28.54 b	35.11 c
10	1.31 a	1.51 b	1.53 a	43.38 b	32.86 b	48.80 b
15	0.93 b	1.02 c	1.02 b	63.54 a	50.10 a	67.40 a
20	0.81 b	0.76 c	0.87 b	70.10 a	60.67 a	74.94 a
Mean	1.14 B	1.32 A	1.26 A	54.88 AB	43.04 B	56.56 A
CV(%)	10.87			13.05		
SE	0.04			3.01		
Depth (cm)	Vigorous sprouting rate (%)			Mortality rate (%)		
5	65.12 a[1]	67.19 a	85.74 a	23.75 a	15.16 b	13.54 b
10	58.31 a	68.47 a	87.46 a	25.83 a	12.45 b	10.82 b
15	39.31 b	33.75 b	62.66 b	28.80 a	28.12 a	26.04 a
20	37.18 b	32.31 b	52.35 b	30.25 a	30.94 a	28.32 a
Mean	49.98 B	50.68 B	71.80 A	27.16 A	21.67 B	19.68 B
CV(%)	13.05			18.52		
SE	2.56			3.48		

Means with different lowercase letters for depth and capital letters for planting methods indicate a significant statistical difference according to the Tukey's test ($P \leq 0.05$) (n = 4); CV: coefficients of variation; SE: standard error of estimates.

The vigorous sprouting rate (VSR) had a similar behavior as the mean sprouting time. The best VSR was observed at the depths 5 and 10 cm in the three applied methods. The mortality rate was always larger at the depths 15 and 20 cm, except for the groove planting, in which there was no significant difference for the different planting depths (Tab. 1).

For crop development, the planting methods with rows or grooves had no significant differences for the total plant leaf area (LA), as compared to the studied planting depths (5 to 20 cm). However, when using the ridge planting method, a higher LA were observed in the plants grown with the depths 5 and 10 cm (Tab. 2).

Table 2. Leaf area of yacon plants with different planting methods and depths on two dates during the cycle. UFES, Divino de São Lourenço, ES, 2016.

Depth (cm)	Planting methods					
	Grooves	Ridges	Pits	Grooves	Ridges	Pits
	120 days after planting			240 days after planting		
	Leaf area (cm²)					
5	93.69 a	173.25 a	143.28 a	122.76 a	168.35 a	164.54 a
10	80.16 a	154.28 a	133.63 a	120.29 a	159.82 ab	152.07 a
15	79.35 a	125.30 b	127.86 a	123.51 a	131.51 bc	148.47 a
20	73.72 a	112.23 b	119.87 a	109.58 a	126.43 c	148.82 a
Mean	81.70 B	141.26 A	131.16 A	119.03 A	146.90 A	153.47 A
CV (%)	11.45			10.66		
SE	7.12			7.30		

Means with different lowercase letters for depth and capital letters for planting methods indicate a significant statistical difference according to the Tukey's test ($P \leq 0.05$) ($n = 4$); CV: coefficients of variation; SE - standard error of estimates.

Table 3. Dry mass of aerial part, tuber roots, rhizophores and number of rhizophores of yacon plants with different planting methods and depths. UFES, Divino de São Lourenço, ES, 2016.

Depth (cm)	Planting method					
	Grooves	Ridges	Pits	Grooves	Ridges	Pits
	Aerial part dry mass (t ha^{-1})			Tuberous roots dry mass (t ha^{-1})		
5	0.18 a	0.25 a	0.20 a	0.17 a	0.19 a	0.22 a
10	0.12 b	0.15 b	0.13 b	0.14 a	0.18 a	0.21 a
15	0.13 b	0.16 b	0.14 b	0.07 b	0.11 b	0.10 b
20	0.11 b	0.14 b	0.11 b	0.06 b	0.07 c	0.9 b
Mean	0.13 A	0.17 A	0.14 A	0.11 B	0.14 AB	0.16 A
CV (%)	13.20			15.81		
SE	0.01			0.02		
Depth (cm)	Rhizophores dry mass (t ha^{-1})			Number of rhizophores		
5	0.20 a	0.31 a	0.34 a	3.10 a	3.84 a	3.87 a
10	0.16 b	0.26 b	0.28 b	2.25 b	3.30 ab	3.23 ab
15	0.14 b	0.27 b	0.26 b	1.51 c	2.43 b	2.42 b
20	0.14 b	0.24 b	0.25 b	1.48 c	2.35 b	2.23 b
Mean	0.16 B	0.27 A	0.28 A	2.09 B	2.98 A	2.91 A
CV (%)	16.79			14.67		
SE	0.03			0.10		

Means with different lowercase letters for depth and capital letters for planting methods indicate a significant statistical difference according to the Tukey's test ($P \leq 0.05$) ($n = 4$); CV: coefficients of variation; SE: standard error of estimates.

It is also observed that, in general, only the plants cultivated in grooves had a lower total LA, up to half of the cycle (120 DAP), but, at the end of the cycle (240 DAP), the plants in all the methods did not present statistical differences (Tab. 2).

In all cultivation methods, the plants that presented the highest aerial part and rhizophores were planted at the 5 cm depth. As the plant depth increased, the values decrease (Tab. 3).

A similar behavior was observed in the dry mass of tuberous roots; however, the highest values were seen in all cultivation methods with the 5 and 10 cm depths. Notably, the groove method, regardless of the depth, presented the lowest accumulation of dry root mass (Tab. 3).

All cultivation methods had a decrease in the amount of rhizophores per plant, as the planting depth increased. However, the groove planting, regardless of the depth, had the lowest number of rhizophores (Tab. 3).

The tuber root numbers per plant were also higher in all methods in the shallower layers. For the groove and ridge cultivations, the highest number of tuberous roots per plant was observed at the 5 cm depth, while, for the pit planting method, the highest number was seen at the 5 and 10 cm depths (Tab. 4).

The plants had higher productivity when cultivated in grooves at the 5 cm depth and when cultivated in ridges and pits at the 5 and 10 cm depths (Tab. 4). When comparing the plants cultivated in grooves with those that developed in ridges and pits, higher productivity was observed, regardless of the planting depth (Tab. 4).

However, the yields, in general, were well below those obtained by Silva *et al*. (2019), who observed an average of 77 t ha^{-1} (in the same region), as a result of the severe drought in the region, generating an extreme stress with the decrease in soil moisture, which is the principal factor for the formation of tuberous roots (Fernandéz *et al*., 2006). This stress occurred during the phenological stage of the culture, with the greatest branching (growth of the aerial part) and the beginning of the formation of tuberous roots (Silva *et al*., 2018a). Thus, the plants had less shoot development, less leaf area, and lower productivity.

Even so, these results indicated that, under high altitude conditions, planting at shallower depths (from 5 to 10 cm) may provide more favorable conditions for the initial establishment of a crop, which will directly impact the yield. This behavior may be related to the several factors, such as greater ease of soil disruption above the propagule, higher temperatures and thermal amplitudes that may favor the rhizophores sprouting process, facilitating the initial establishment of a crop and positively influencing production (Alves *et al*., 2014; Rós, 2017).

The environmental temperature and, consequently, the soil temperature, besides being able to modify plant metabolism, change soil moisture dynamics in the soil-plant system, which directly interferes with

Table 4. Number and productivity of tuberous roots of yacon plants with different planting methods and depths. UFES, Divino de São Lourenço, ES, 2016.

Depth (cm)	Planting methods					
	Grooves	Ridges	Pits	Grooves	Ridges	Pits
	Number of tuberous roots			Tuberous roots productivity (t ha^{-1})		
5	3.69 a	5.09 a	2.85 a	1.87 a	2.04 a	2.34 a
10	2.90 b	3.64 b	3.39 a	1.47 b	1.94 a	2.19 a
15	1.42 c	3.14 b	2.07 b	0.77 c	1.17 b	0.94 b
20	1.45 c	1.69 c	1.82 b	0.64 c	0.78 c	0.89 b
Mean	2.34 B	3.39 A	2.53 B	1.19 B	1.46 AB	1.59 A
CV (%)	13.30			14.65		
SE	0.10			0.07		

Means with different lowercase letters for depth and capital letters for planting methods indicate a significant statistical difference according to the Tukey's test ($P\leq0.05$) ($n = 4$); CV: coefficients of variation; SE: standard error of estimates.

plant growth (Kirkham, 2005; Teodoro *et al*., 2011). Silva *et al*. (2018b) showed that yacon had better development and production, with lower temperature conditions and increased soil moisture, in different cover crops strategies.

In the cultivation methods, regardless of the planting depths of the rhizophores, the cultivations in ridges presented the best results (sometimes resembling the pit method) in the initial establishment of the plants (greater sprouting rate index, greater vigorous sprouting rate and lower mortality rates). The same was observed in the final production (greater number and productivity of tuberous roots).

These results are related to the better soil condition achieved with the ridge and pit methods, mainly because of the possibility of obtaining a less compacted bed, which may have favored root growth, with positive effects on the yacon development and production.

Yacon is included in the vegetable group that produces subterranean reserve organs (roots, rhizomes, tubers and bulbs), is sensitive to soil compaction, inadequate aeration or poor drainage (Howeler *et al*., 1993), and, therefore, responds better to planting methods and soil preparation that avoid these conditions, as shown in studies on potato (Fontes *et al*., 2007), cassava (Pequeno *et al*., 2007; Otsubo *et al*., 2012) and sweet potato (Rós, 2017). Thus, the method chosen for soil preparation, as well as the planting method, can directly interfere with the success of these crops.

CONCLUSIONS

Under the high altitude conditions, the planting methods pits and ridges provided greater productivity of tuberous roots than the cultivation in grooves.

The depths 5 and 10 cm provided better initial establishment of the plants and higher yacon yields.

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