Planting methods and depths for the yacon (Smallanthus sonchifolius) crop

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

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

**Additional key words:** *Smallanthus sonchifolius*; plantation crops; spacing; root vegetables; altitude; ridge tillage; planting depth.

**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:** *Smallanthus sonchifolius*; siembra de cultivos; espaciamiento de
plantas; vegetales de raíz; altitud; labranza en camas; profundidad de plantación.

INTRODUCTION

There are different benefits of yacon [Smallanthus sonchifolius (Poepp. & Endl.) H. Robinson] roots consumption, such as constipation relief, increased mineral absorption, strengthens the immune system (Genta et al., 2010), decreases the development of colon cancer (Santana and Cardoso, 2008) and fights against diseases such as Diabetes Mellitus (Albuquerque and Rolim, 2012). This has increased the interest in its cultivation and, consequently, the demand to know more about its management in order to obtain bigger and more stable production.

Harvest yield of yacon tuberous roots is very 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 due to the edaphoclimatic conditions of cultivation, being 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 the temperature (Silva et al., 2018b) and water availability (Sumiyanto et al., 2012), as well as to the management, in relation to the season (Silva et al., 2018a) and planting depth, nutrition, spacing, among others (Seminário et al., 2003).

In Brazil and in the world, it is important more technical recommendations for yacon cultivation, especially on the optimal method and planting depth in different edaphoclimatic conditions, since these can influence crop productivity and vary according to the characteristics of the region.

The variations of the method and the planting depth can bring significant interference in the
budding process and initial development of the plants (Grotta et al., 2008), and, consequently, in the crop production. The shape and depth of propagation of the propagules can expose them to different microenvironment conditions, interfering in the development of the future plant (Rós, 2017), and, consequently, affecting crop productivity (Modolo et al., 2010).

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

**MATERIAL AND METHODS**

The experiment was carried out in 2016, in the area of the "Flor e Mel" located in Patrimônio da Penha, a district of Divino de São Lourenço in the state of Espírito Santo, Brazil, with geographic coordinates of 20°35'6.0" south latitude and 41°46'18.2" west longitude, and an altitude of 1,098 m a.s.l.. The 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 season in April to September (Pezzopane et al., 2012). The maximum monthly temperatures ranged from 26 to 28°C, and minimum temperatures of 12 to 18°C, and the total rainfall during the experiment was 760 mm, but with uneven distribution, with little volume of rainfall between the months of May to August (INMET, 2016).

The area used for planting was fallow for nine months, where crops were rarely cultivated, with a high number of ferns (*Pteridium arachnoideum* (Kaulf.) Maxon), a species considered as a soil indicator with high acidity. For the initial soil tillage, a weeding with a costal brush was done 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 its chemical and physical analysis had 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\(^{-3}\) de T; 36.76% of V; 23% of sand, 26% of silt, 51% of clay and 1.20 dag kg\(^{-1}\) of OM.

For planting, yacon rhizophores from a production area of the municipality of Santa Maria do Jetibá/ES were harvested three days before planting. After being harvest, the rhizophores were selected and fractionated in pieces of 40-50 g. They were washed in running water and immersed in sodium hypochlorite solution (5% v/v) was carried out for 10 minutes. After treatment, the rhizophores were dried for two days in a ventilated and shaded place.

Yacon planting was carried out April, which is a more productive period observed by Silva et al. (2018a), in crops in the same region, with the cultivation extending until December, culminating with the harvest. The fertilization was carried out by applying tanned bovine manure in the amounts of 200 g in the planting and 150 g in cover fertilization, 90 days 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\(_2\)O and 0.35% P\(_2\)O\(_5\)).

After planting, monthly weeding was done during the following months, using costal brush cutters, cutting the lines and between the plant lines, keeping the residues below the soil surface. Sprinkler irrigations were used in an additional way to 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, during those months.

The experimental design was a randomized complete block design, with four replications, in a subdivided plots scheme. The plots consisted of three planting methods: grooved; in a pit; and in ridges; and the subplots by four planting depths, 5, 10, 15, and 20 cm.
The planting grooves had dimensions of 20 cm wide by 20 cm deep, and the ridges, dimensions 50 cm wide and 40 cm high (both done with the aid of hoes). The pits were 10 cm in radius and depth of 20 cm (made with the aid of hand diggers).

The experimental subplot had 28 plants, with an area of 11.2 m\(^2\) (3.5 x 3.2 m), providing 10 useful plants for evaluations. Totaling 600 useful plants out of 1,680 plants, in 672 m\(^2\). 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 description of the largest 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 days 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, tuberous roots yield (TRY).

The initial development was evaluated every 15 days, always at the same time (8 h), during 75 days after planting (DAP). The evaluation methodology followed Maguire (1962), according to the vegetative stages "Green Tip" (GT) appearance of modifications in the coloring of the gems, 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 modifications in the coloration of the buds, with the greenish tip);
- Sprouting rate index (SRI): occurrence of sprouting buds due to the sprouting time given the equation:

\[
SR = S\left(\frac{ni}{ti}\right) \text{ (buds per day)}
\]  

(1)

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

- 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). In the analyzed period, given by the equation:

\[
VSR = \left( \frac{\text{% of rhizophores section with GT stages}}{\text{TF}} \right) \times 100
\]  

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

The leaf area measurements were performed in an indirect way, using the width and length of each leaf, obtaining the estimate of 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 in a digital scale, with a precision of 0.01 g, from oven dried samples with forced air circulation at a temperature of 65ºC until constant mass.

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

RESULTS AND DISCUSSION

Analyzing the effect of the planting depths in each method, it was observed that rhizophores sprouting rate index (SRI) were higher in the depths of 5 and 10 cm, in the planting ridges and pits, and at 5 cm in the grooves. This result reflected in 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 methods and depth of planting. UFES, Divino de São Lourenço, ES, 2016.

| Depth (cm) | Grooves | Ridges | Pits | Grooves | Ridges | Pits |
|------------|---------|--------|------|---------|--------|------|
|            | Sprouting rate index (buds/d) | Average sprouting time (d) | | | | |
| 5          | 1.50 a¹ | 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 B² | 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 a¹ | 23.75 a | 15.16 b | 13.54 b |
| 10         | 58.31 a  | 25.83 a | 12.45 b | 10.82 b |
| 15         | 39.31 b  | 28.80 a | 28.12 a | 26.04 a |
| 20         | 37.18 b  | 30.25 a | 30.94 a | 28.32 a |
| Mean       | 49.98 B² | 27.16 A | 21.67 B | 19.68 B |
| CV (%)     | 13.05    |        | 18.52   |        |
| SE²        | 2.56     |        | 3.48    |        |

¹Means with different lower letter on depth and ²capital letter in planting methods, indicate a significant statistical difference according Tukey’s test (P≤0.05) (n = 4); ³CV: coefficients of variation; ⁴SE: standard error of estimates.

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

In the crop development, it is noticed that when the planting methods in a row or grooves, there are no significant differences for the total plant leaf area (LA), compared to the studied planting depths (5 to 20 cm). However, when using the ridge planting method, higher LA were observed in plants grown in the depths of 5 and 10 cm (Tab. 2).
Table 2. Leaf area of yacon plants with different methods and depth of planting, on two dates during the cycle. UFES, Divino de São Lourenço, ES, 2016.

| Depth (cm) | Grooves 120 days after planting | Ridges 120 days after planting | Pits 120 days after planting | Grooves 240 days after planting | Ridges 240 days after planting | Pits 240 days after planting |
|------------|--------------------------------|-------------------------------|-----------------------------|--------------------------------|-------------------------------|-------------------------------|
| 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^3                      | 141.26 A                      | 131.16 A                    | 119.03 A                       | 146.90 A                      | 153.47 A                      |
| CV^3 (%)   | 11.45                          |                              |                             | 10.66                          |                               |                               |
| SE^4 (%)   | 7.12                           |                              |                             | 7.30                           |                               |                               |

1Means with different lower letter on depth and 2capital letter in planting methods, indicate a significant statistical difference according Tukey’s test (P≤0.05) (n = 4); 3CV: coefficients of variation; 4SE - standard error of estimates.

It is also observed that, in general, only the plants cultivated in the groove 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 plant aerial part and rhizophores were planted at 5 cm depth, and while the plant depth increased, the values decrease (Tab. 3).
Table 3. Dry mass of aerial part, tuber roots, rhizophores and number of rhizophores of yacon plants with different methods and depth of planting. UFES, Divino de São Lourenço, ES, 2016.

| Depth (cm) | Grooves | Ridges | Pits | Grooves | Ridges | Pits |
|------------|---------|--------|------|---------|--------|------|
|            | Aerial part dry mass (t ha⁻¹) | Tuberous roots dry mass (t ha⁻¹) | Number of rhizophores |
| 5          | 0.18 a¹ | 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 A² | 0.17 A | 0.14 A | 0.11 B | 0.14 AB| 0.16 A |
| CV³ (%)    | 13.20   | 15.81  | 0.02   |        |        |       |
| SE⁴        | 0.01    | 0.03   | 0.10   |        |        |       |

Means with different lower letter on depth and capital letter in planting methods, indicate a significant statistical difference according Tukey’s test (P≤0.05) (n = 4); ³CV: coefficients of variation; ⁴SE - standard error of estimates.

Similar behavior occurred with the dry mass of tuberous roots, however, the highest values presented in all cultivation methods were when planted at 5 and 10 cm depth. It is noteworthy that the grooves method, regardless of the depths, was the one that presented the lowest accumulation of dry root mass (Tab. 3).

All cultivation methods also showed a decrease in the amount of rhizophores per plant, as the planting depth increased. However, the grooves planting, regardless of the depth, was the one that presented the lowest number of rhizophores (Tab. 3).

Tuber root numbers per plant were also higher in all methods in the shallower layers. For grooves and ridge cultivation, the highest number of tuberous roots per plant was observed at 5 cm depth, while for the pit planting method was 5 and 10 cm depth (Tab. 4).
Table 4. Number and productivity of tuberous roots of yacon plants with different methods and depth of planting. UFES, Divino de São Lourenço, ES, 2016.

| Depth (cm) | Grooves  | Ridges  | Pits     | Grooves  | Ridges  | Pits    |
|-----------|----------|---------|----------|----------|---------|---------|
|           | Number of tuberous roots | Tuberous roots productivity (t ha\(^{-1}\)) |       |          |          |         |
| 5         | 3.69 a\(^1\) | 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\(^2\) | 3.39 A  | 2.53 B   | 1.19 B   | 1.46 AB | 1.59 A  |
| CV\(^3\) (%) | 13.30 |         | 14.65 |         |          |         |
| SE\(^4\)  | 0.10     |         | 0.07    |          |          |         |

\(^1\)Means with different lower letter on depth and \(^2\)capital letter in planting methods, indicate a significant statistical difference according Tukey’s test (\(P\leq0.05\)) (\(n=4\)); \(^3\)CV: coefficients of variation; \(^4\)SE - standard error of estimates.

The plants had a higher productivity when cultivated in grooves, planted at 5 cm depth and in ridges and pits when planted in 5 and 10 cm depth (Tab. 4). Comparing the plants cultivated in grooves, those that developed in ridges and in pits showed higher productivity, regardless of the planting depth (Tab. 4).

However, it is noted that the yields obtained, in general, were well below those obtained by Silva \(et\ al\). (2019), they observed an average of 77 t ha\(^{-1}\) (in the same region). This fact is associated with severe drought in the region, generating a condition of extreme stress with the decrease in soil moisture, which is considered the main factor for the formation of tuberous roots (Fernández \(et\ al\.), 2006). Being that, the stress occurred exactly during the phenological stage of the culture, where there is the greatest branching (growth of the aerial part) and beginning of the formation of the tuberous roots (Silva \(et\ al\.), 2018a). Thus, the plants had less shoot development, with less leaf area, and consequently, lower productivity.

Even so, these results indicate that in high altitude conditions, planting shallower in depths (from 5 to 10 cm) may permit more favorable conditions for the initial establishment of the crop, which will directly reflect the productive performance. 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 the crop and reflecting positively on the production (Alves et al., 2014; Rós, 2017).

It is known that the environmental temperature, consequently the soil temperature, besides being able to modify the plant metabolism, also changes the soil moisture dynamics in the soil-plant system, which directly interferes in the plants growth (Kirkham, 2005; Teodoro et al., 2011). Silva et al. (2018b) showed that yacon had a better development and production, lower temperature conditions and increased soil moisture, in different cover crops strategies.

In the cultivation methods, regardless of the planting depths of the rhizophores, it can be observed that 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).

It is believed that these results are related to the better soil condition achieved with the ridge and pit methods, mainly due to the possibility of obtaining a less compacted bed, which may have favored the root growth, with positive effects in the yacon development and production.

Yacon is included in the vegetables group, which produce subterranean reserve organs (roots, rhizomes, tubers and bulbs), and are sensitive to soil compaction, inadequate aeration or poor drainage (Howeler et al., 1993), and therefore respond better to planting methods and soil preparation that avoid these conditions, as shown in studies with potatoes (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 in the success of these crops.
CONCLUSIONS

For high altitude conditions, the planting methods in pits or ridges, propitiated greater productivity of tuberous roots, in relation to the cultivation in grooves.

The depth of the rhizophores plants between 5 and 10 cm were the ones that provided better initial establishment of the plants and higher yacon yields.

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