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Planting recommendations for yacon (*Smallanthus sonchifolius*) in lowland conditions

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Abstract

The purpose of this work was to test yacon planting practices in low elevation conditions. The experimental design was a randomized block design (RBD) with subdivided plots and four replications. Treatments comprised of three planting methods: furrow; ridges and pits; each treatment was divided into subplots, which were four planting depths: 5, 10, 15, and 20 cm. The following variables were tested: sprouting speed, vigorous sprouting rate, average time for sprouting, rhizophore mortality rate, soil temperature and moisture, shoot dry weight, and yield of rhizophores, tuberous roots, total yield, and marketable tuberous roots. The planting methods using pits and furrows had lower seedling mortality rates (30,2 and 41,4% compared to ridges), while furrow led to a higher total tuber yield (17,5 and 18,9% higher than ridges and pits), using depths of 5 and 10 cm. The system with pits also achieved significant yields at 10 cm depth. Using ridges as the planting method would be possible, at depths of 10 and 15 cm, but yields would be lowered. For the conditions of this study, the highest yield of marketable roots was obtained using furrow at 5 and 10 cm of panting depth.

Keywords: *Smallanthus sonchifolius*; *Polymnia sonchifolia;* diet potato; production system.
Abbreviations: RBD_randomized block design; DAP_days after planting; GT_ green tip; OB_open bud; AST_average sprouting time; SRI_sprouting rate index; FSR_final sprouting rate; VSR_vigorous sprouting rate; MR_mortality rate.

Introduction

Worldwide demand for functional foods is rising for various factors, including their nutraceutical properties, which are described as bioactive compounds offering health benefits (Sacramento et al., 2017). These compounds include inulin, fructooligosaccharides (FOS), and their derivatives (Sumiyanto et al., 2012).
The ongoing trend of adopting non-typical vegetables with nutraceutical properties, combined with the increased demand of these products by both the pharmaceutical and food industry, spotlight plants originated in South America, such as the tweedie's catsear (Hypochaeri schillensis), arrowroot (Maranta arundinacea) and yacon (Smallanthus sonchifolius). These plants are great candidates to deliver raw materials to the pharma and food industries (Hauly and Moscatto, 2002; Magalhães, 2017).
Yacon is included in this group of functional foods for the presence of bioactive (inulin and FOS) and phenolic compounds, such as chlorogenic acid, ferulic and caffeic acid, and flavonoids such as quercetin (Ojansivu et al., 2011). This crop is produced from low (close to sea level) to very high altitudes (from 1000 to 3400 meters), with substantial fluctuations in yield (Vitali et al., 2015), which highlights the demand for improved crop management practices. Due to the increase in the demand for yacon, better cropping practices, such as optimized planting recommendations, are demanded for different edaphoclimatic conditions where this crop is being established (Silva et al., 2018a; Vanini et al., 2009).
Defining optimal planting techniques is essential considering their influence on plant development and yield, as previously detailed for potatoes by Martini et al. (1990); for Peruvian carrot (Arracacia xanthorriza Bancroft.) by Gomes et al. (2010); for peanuts by Grotta et al. (2008) and others.
Planting method and depth directly affect seedling emergence and initial development, affecting crop performance and yield. These interactions are, in most situations, linked to the temperature and moisture variation in distinct soil layers, and likewise to soil physical restrictions for seedling germination (Dantas et al., 2020; Pequeno et al., 2007; Agbede, 2010). Planting conditions also interfere in the requirement for water and nutrients and root interactions with macro and microorganisms (Taiz and Zeiger, 2013).
The first report of yacon production in Brazil, conducted by Kakihara et al. (1996), already exposed the scarcity of crop management recommendations. Vilhena et al. (2000) proposed using planting beds measuring 1 m wide and 0.30 m height for yacon production in Brazil, diverging with

planting techniques adopted in the Andean region where the crop is planted in furrows (Seminario et al, 2003).
These deviations in planting recommendations for yacon show the demand for enhanced crop management practices. The aim of this work was to assess different planting methods and depths, and their effect on crop development and yield of tuberous roots, under low elevation conditions.

Results and discussion

Vegetative stage evaluations
The planting method influenced average sprouting time (AST), with the best AST observed when the crop was planted in ridges, reflecting in lower average sprouting time (Table 1).
The vigorous sprouting rate (VSR) showed variation due to planting depths for only one method. When using ridges, the highest VSR was observed with depths of 10 and 15 cm. For furrows and pits, there was no VSR variation due to planting depths (Table 1).
For furrow planting, depths of 5 to 15 cm led to lower seedling mortality rates. When the method of planting in pits was chosen, the smallest seedling mortality values were noted at 10 cm. For ridges, the lowest mortality rates occurred from 10 to 20 cm, implying that using lower depths (5 cm) increased seedling mortality rate in this approach (Table 1).
These results illustrate a demand for an adjustment in planting depth for each method, to provide optimal emergence conditions. These planting recommendations combined with optimal soil temperature and moisture will be the major drivers of the initial yacon establishment.
The ridges method promoted the least vigorous sprouting rate and highest seedling mortality, regardless of the planting depth (Table 1). This result may be a consequence of higher soil temperatures (Fig 1.) and lower soil moisture (Fig 2.), registered for this system during the crop cycle. This variation led to the larger mortality rate noted for this approach when rhizophores were grown in shallower layers (5 cm).
The results again highlight the effect of planting methods in the relation between temperature and soil moisture. When using ridges as a planting method, due to increased soil solarization and temperature increment, the speed of bud sprouting was boosted, resulting in a smaller average sprouting time compared to other approaches. Temperature and soil moisture play a considerable role in controlling several physiological processes connected to budding and/or the emergence of most plant species (Taiz and Zeiger, 2013). However, increases in soil temperature favor water evaporation and water loss, which would rise the mortality rate of the seedlings, as observed for sugarcane (Carvalho et al., 2012) and corn (Cortez et al., 2015).

Production and yield of yacon
When evaluating the plant development via plant dry weight, the highest readings for shoots in the furrow system were observed for planting depths of 5 to 10 cm. The ridges method led to a higher dry weight at 10 cm, whereas no planting depth effects were observed when using pits. Similar results were observed for the dry weight of rhizophores (Table 2).
The dry weight of tuberous roots was higher when using planting depths of 5 and 10 cm in furrows. For both ridge and pit methods, higher dry weight was noted at depths of 10 cm (Table 2).
Furrow promoted higher dry weight of shoots and tuberous roots, regardless of planting depths (Table 2), pointing out this approach as the most suitable for the development and production of yacon roots under lowland cropping conditions.
The greatest yield of tuberous roots using furrows was registered at depths of 5 and 10 cm. For both ridges and pits, the highest yields were obtained when planting at depths of 10 cm (Table 3).
In the case of marketable roots, the highest yields were reported at depths of 5 and 10 cm for both furrows and pits. For ridges, higher yields were observed at 10 and 15 cm (Table 3).
These results propose that, for each planting system, an optimal depth is recommended to maximize the yacon yield. These divergences are due to their interference on key soil conditions for crop development, such as lower thermal amplitudes and higher soil moisture, as noticed in the crop establishment stage. Optimal environmental conditions may display not simply in more robust plant growth but as well in greater yields (Rós et al., 2014; Silva et al., 2018b).
Using furrow as the planting method, regardless of planting depths, promoted higher yields of total and commercial yacon tuberous roots (Table 3), possibly pertained to further beneficial conditions for crop growth, such as lower thermal amplitude and higher moisture content in the soil, which are optimal conditions for yacon production (Silva et al., 2018b).
Under lowland conditions in the Itapemirim river valley, the furrow planting method promotes higher yields, especially at depths of 5 and 10 cm. The pit method also produces significant yields at 10 cm depth. Using ridges as the planting program would be conceivable, with depths of 10 and 15 cm, but not justified due to reduced yields.

Materials and methods

Experimental area
Field trials were conducted in 2015 in the CCAE-UFES Research Farm, in Rive, a village of Alegre, in Southern Espírito Santo state, Brazil. The field geographical coordinates are 20°46'2.8'' S and 41°27'39.2'' W, with 128 m of elevation. This zone, which is in the Itapemirim river valley, is classified as a hot tropical micro-region (lowlands) (Pezzopane et al., 2012). The highest monthly temperatures vary from 26.5 to 31.4° C, and the lowest from 19.5 to 23.1° C, with 514 mm of accumulative rainfall during field experiments (INMET, 2015).

Soil description and analysis
The field plot design adopted for this experiment was utilized for vegetable production and left under fallow for four months before the beginning of field trials. Plots were mowed using a handle trimmer and after a week; soil was plowed to a depth of 20 cm and disked twice, incorporating weed in the topsoil layer.
The soil in the experimental plot was classified as red-yellow oxisol, medium texture (Santos et al., 2013). Chemical and physical analysis were conducted, resulting in the following for the 0-20 cm layer: pH: 6.89 (water); P: 80.34 mg dm^{-3} (Mehlich); K: 227.00 mg dm^{-3}; Ca: 3.29 cmolc dm^{-3}; Mg: 1.83 cmolc dm^{-3}; Al: 0.05 cmolc dm^{-3}; H + Al: 1.15 cmolc dm^{-3}; BS: 5.93 cmolc dm^{-3}; t: 5.95 cmolc dm^{-3}; T: 7.08 cmolc dm^{-3}; V: 78.39%; sand: 56%, silt: 33% and clay: 11%.

Table 1. Sprouting speed, the average time for sprouting, vigorous sprouting rate, and rhizophore mortality rate in yacon with different planting methods. Alegre – ES, 2015.

	Planting Method					
	Furrows	Ridges	Pits	Furrows	Ridges	Pits
	Sprouting rate index (buds/day)			Average sprouting time (days)		
Mean	1.45 B[1]	1.63 A	1.47 B	65.84 A	56.51 B	66.81 A
CV	18.62			19.16		
Depth	Vigorous Sprouting Rate (%)			Mortality Rate (%)		
5 cm	78.85 a[2]	57.20 b	78.68 a	5.9 b	16.7 a	8.8 a
10 cm	83.95 a	75.14 a	88.32 a	5.7 b	11.2 b	6.9 b
15 cm	74.94 a	66.78 ab	85.48 a	7.1 ab	8.3 b	7.2 a
20 cm	82.20 a	55.83 b	74.66 a	9.5 a	11.9 b	10.7 a
Mean	79.98 A[1]	63.74 B	81.78 A	7.05 B	12.03 A	8.40 B
CV	11.91			18.52		

[1]Means related to planting methods independent of depths. Means followed by the same upper case in the same row and lower case do not differ by Tukey's test at a 5% probability level. [2]Means followed by the same lower case in the same column do not differ by Tukey's test at a 5% probability level

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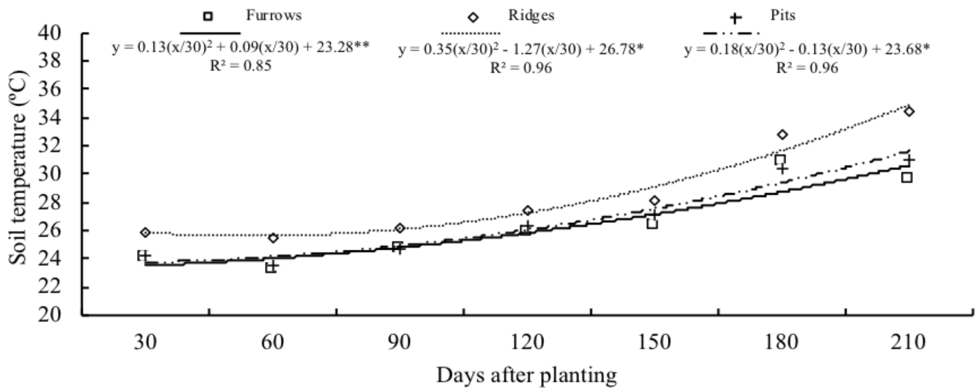

Fig 1. Soil temperature in the 0-20 cm layer in a yacon crop area with different planting methods. Alegre – ES, 2015. *P≤0.01; **P ≤ 0.05.

Table 2. Dry weight of shoots, rhizophores, and tuber roots of yacon plants with different methods and depth of planting. Alegre – ES, 2015.

Depth	Planting Method					
	Furrows	Ridges	Pits	Furrows	Ridges	Pits
	Shoot dry weight (t ha^{-1})			Rhizophores dry weight (t ha^{-1})		
5 cm	2.10 a[1]	1.45 b	1.43 a	2.34 ab	1.78 b	2.19 a
10 cm	2.02 ab	1.88 a	1.42 a	2.46 a	2.38 a	1.92 a
15 cm	1.61 bc	1.58 b	1.56 a	1.99 bc	2.45 a	2.07 a
20 cm	1.29 c	1.47 b	1.49 a	1.76 c	1.77 b	2.34 a
Mean	1.75 A[2]	1.59 B	1.48 C	2.14 A	2.10 A	2.13 A
CV	14.25			10.90		

Depth	Furrows	Ridges	Pits
	Tuber dry weight (t ha^{-1})		
5 cm	4.49 a[1]	2.49 b	3.04 b
10 cm	4.78 a	3.62 a	3.86 a
15 cm	3.28 b	2.94 b	2.36 c
20 cm	1.65 c	2.64 b	2.30 c
Mean	3.55 A[2]	2.92 B	2.89 B
CV	10.08		

[1]Means followed by the same lower case in the same column do not differ by Tukey's test at a 5% probability level. [2]Means related to planting methods independent of depths. Means followed by the same upper case in the same row and lower case do not differ by Tukey's test at a 5% probability level.

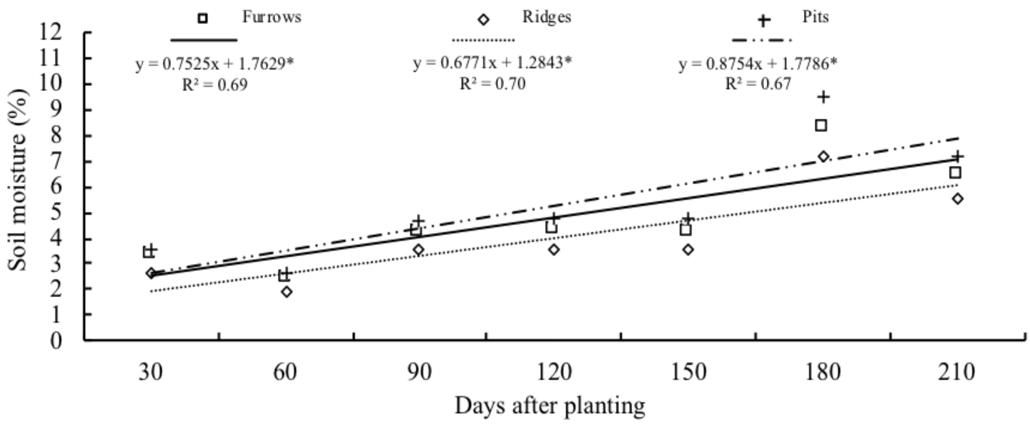

Fig 2. Soil moisture in the 0-20 cm layer in a yacon crop area with different planting methods. Alegre – ES, 2015. *P≤0.01; **P ≤ 0.05.

Table 3. Marketable and total (unmarketable + marketable) tuber yield of yacon plants with different methods and depth of planting. Alegre – ES, 2015.

Depth	Planting Methods					
	Furrows	Ridges	Pits	Furrows	Ridges	Pits
	Total tuber yield (t ha^{-1})			Marketable tuber yield (t ha^{-1})		
5 cm	49.16 a[1]	26.62 b	32.04 b	33.25 a	17.29 b	23.29 a
10 cm	50.21 a	39.21 a	41.02 a	33.33 a	26.58 a	27.97 a
15 cm	35.08 b	31.21 b	25.06 c	25.66 b	23.50 ab	13.87 b
20 cm	17.80 c	28.54 b	24.79 c	10.16 c	19.08 b	13.71 b
Mean	38.06 A[2]	31.39 B	30.87 B	25.60 A	21.61 B	19.71 B
CV	10.53			16.30		

[1]Means followed by the same lower case in the same column do not differ by Tukey's test at a 5% probability level. [2]Means related to planting methods independent of depths. Means followed by the same upper case in the same row and lower case do not differ by Tukey's test at a 5% probability level.

Fig 3. Sketch of planting methods, the arrows indicate the planting location for *Smallanthus sonchifolius* crop. Alegre – ES, 2015. Photo: Quaresma MAL

Yacon planting and crop management

Yacon rhizophores, collected from a production field in the city of Santa Maria do Jetibá (Espírito Santo state, Brazil), were adopted as propagative materials. The rhizophores were collected three days before planting. Rhizophores were selected and fractionated in 40-50 g portions and afterward cleaned using water followed by a solution of sodium hypochlorite solution (5% v/v) for 10 minutes. After treatment, rhizophores were dried for two days in a ventilated and shaded space.

The fertilizer recommendation was based on the work by Amaya Robles (2000). Composted cow manure was applied in doses of 170 g at planting and 750 g in a subsequent application, which was conducted 90 days after planting. This amount was comparable to 104.37 kg ha^{-1} of nitrogen, based on manure nutrient levels (1.67% N2, 0.59% K2O, and 0.38% P2O5). Yacon was planted in late April, recognized to be the most productive season, conforming to the work by Silva et al. (2018a), studying yacon in the same region.

Weeds were managed between rows bi-weekly using a string trimmer up to four months after planting and weed biomass was left protecting the soil. A sprinkler system was utilized for supplementary irrigations, adding 110 mm to the present rainfall (520 mm) during the crop period, amounting to 600 mm, which is the demand for yacon crop, according to Grau and Rea (1997).

Experimental design

The experimental design was a randomized block design (RBD) with subdivided plots and four replications. Treatments included three planting methods: furrows, ridges and pits (Fig 3.); subplots were four planting depths: 5, 10, 15, and 20 cm.

Planting furrows were concave, shaped with an opening of 20 cm wide by 20 cm deep. Ridges were convex, with a base of 50 cm wide and 40 cm high (both built using gardening hoes). The pit radius measured 10 cm with a depth of 20 cm (built using soil diggers).

Each experimental subplot was constituted of 28 plants, enclosing a section of 11.2 m2 (3.5 x 3.2 m), providing 10 plants for evaluation, totaling 600 tested plants from 1680 grown in 672 m2. The distance between rows was 0.8 m and 0.5 m between plants, producing a plant population of 25,000 ha^{-1}. These planting instructions are based on the work by Seminario et al. (2003), recommending higher plant populations.

Evaluations

The following parameters were tested: sprouting speed, vigor sprouting rate, the average time for sprouting, rhizophore mortality rate, soil temperature and moisture in the 0-20 cm layer, shoot dry weight, and yield of rhizophores, tuberous roots, total yield, and marketable tuberous roots.

Initial assessments were performed every 15 days, always at the same time (8 h), 75 days after planting (DAP). The evaluation method followed Maguire (1962), according to the vegetative stages "Green Tip" (GT), which is described as the 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): average number of days spent between experiment beginning 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:

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

Where:
ni = number of buds that reached the GT stage at time "i";
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). In the analyzed period, given by the equation:

$$VSR = (\%\ of\ rhizophores\ section\ with\ GT\ stages)\ x\ 100$$

Mortality rate (MR): percentage of rhizophores sections that remained alive and vigorous until the end of the evaluations.
Soil temperature was checked from 30 to 210 DAP, between plants within planting rows, at depths of 0-20 cm, from 2:00 and 3:00 p.m. The readings were collected in real-time using a digital thermometer attached to a metal probe (SoloTerm 1200; SOLOTEST, São Paulo, SP, Brazil). Soil moisture (volumetric) was measured between 10:00 and 11:00 a.m., between plants within planting rows, in the same soil layer, and dates used for temperature. The moisture data were collected using an electronic reader (HidroFarm; Falker, Porto Alegre, RS, Brazil), supporting direct volumetric moisture measuring.
The dry weight for each plant part was obtained after drying samples in the oven with forced air circulation at 65ºC until a continuous weight was reached. Dried plant material was weighed on a digital scale, with an accuracy of 0.01 g. Tuberous roots were classified as commercial when equal or greater than the ideal for fresh consumption, consisting of roots from 10 to 20 cm, with 120 to 300 g of weight (Oliveira, 2016).

Statistical analysis

Using the Shapiro-Wilk test, means were initially tested assuming residue normality and later assuming homogeneity among variances using Bartlett's test. For data suggesting the existence of a functional relationship between two variables over time, regression tests were conducted, and the polynomial quadratic equation best fit these data relationships were determined. Additional data were contrasted using the Tukey test. All statistical analyses (t and F) used $p < 0.05$.

Conclusions

The highest yields of yacon tuberous roots under lowland conditions were achieved with the furrow system, at depths of 5 and 10 cm of planting.

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