Acta Scientiarum

http://periodicos.uem.br/ojs/acta
ISSN on-line: 1807-8621
Doi: 10.4025/actasciagron.v40i1.39442

CROP PRODUCTION

Growth and development of yacon in different periods of planting and growing regions

Diego Mathias Natal da Silva*, Fábio Luiz de Oliveira, Paulo Cezar Cavatte, Mateus Augusto Lima Quaresma and Bruno Fardim Christo

*Departamento de Agronomia, Centro de Ciências Agrárias e Engenharias, Universidade Federal do Espírito Santo, Alto Universitário, s/n° Guararema, 29500-000, Alegre, Espírito Santo, Brazil. *Author for correspondence. E-mail: diegoufvjm@yahoo.com.br*

ABSTRACT. The increasing interest in the commercial exploitation of yacon has demanded adequate technological knowledge for the implantation and management of the crop, including planting periods and cultivation regions that contribute to the satisfactory growth and development of the species. This study was conducted in two different locations, one in a mountainous region and another in a lowland region. In each location, yacon was planted in four different seasons, fall (April), winter (July), spring (September) and summer (December). We collected primary dry matter accumulation data for different parts of the plant and the leaf area at 30 day intervals. We used these values to calculate the following morphophysiological indexes: specific leaf area, leaf area index, tillage growth rate and net assimilation rate. We concluded that planting in the fall in mountainous or lowland sites favoured the growth and development of yacon. Cultivation in mountainous regions, regardless of the planting season, promoted a greater mass accumulation of tuberous roots, which may be reflected in higher productivity. Both fall and winter planting in the mountainous region allows root harvesting at the same time.

Keywords: *Smallanthus sonchifolius*; growth analysis; production.

Crescimento e desenvolvimento de yacon em diferentes períodos de plantio e regiões de cultivo

RESUMO. O crescente interesse pela exploração comercial da yacon tem demandado conhecimentos tecnológicos adequados para a implantação e manejo da cultura, incluindo períodos de plantio e regiões de cultivo que contribuam para o crescimento e o desenvolvimento satisfatório da espécie. Este estudo foi realizado em dois locais diferentes, um em uma região montanhosa e outro em uma região de terras baixas. Em cada local, a yacon foi plantada em quatro estações diferentes, outono (abril), inverno (julho), primavera (setembro) e verão (dezembro). Foram coletados dados de acumulação de massa seca primária para diferentes partes da planta e a área foliar a intervalos de 30 dias. Esses valores foram utilizados para calcular os seguintes índices morfofisiológicos: área foliar específica, índice de área foliar, taxa de crescimento da cultura e taxa de assimilação líquida. Concluiu-se que o plantio no outono em locais montanhosos ou baixos favoreceu o crescimento e o desenvolvimento da yacon. O cultivo em regiões montanhosas, independentemente da estação de plantio, promoveu maior acumulação em massa de raízes tuberosas, o que pode refletir-se em maior produtividade. Tanto o plantio de outono como o plantio de inverno na região montanhosa permitem a colheita de raízes ao mesmo tempo.

Palavras-chave: *Smallanthus sonchifolius*; análise de crescimento; produção.

Introduction

Yacon (*Smallanthus sonchifolius*) is a member of the Asteraceae family and sequesters large amounts of carbohydrates in the roots, many of which are fructans, primarily fructo-oligosaccharides (FOS), which are not metabolizable carbohydrates in the human digestive tract (Vilhena, Câmara, & Kakihara, 2000).

The presence of FOS contributes to several human health benefits that have been attributed to yacon consumption, such as an immunostimulatory effect (Vaz-Tostes et al., 2014), prebiotic effect (Campos et al., 2012) protection against colon cancer (Moura et al., 2012), a role in the reduction of serum lipids (Habib, Honoré, Genta, & Sánchez, 2011), intestinal regularization (Moura et al., 2012), modulation of fasting insulin (Genta et al., 2009), control of chronic diseases such as diabetes, and blood pressure and cholesterol level control (Oliveira, Braga, & Fernandes, 2013).

Yacon consumption has increased because of these benefits, which has led to expectations that it will be cultivated as a new product for commercial exploitation (Santana & Cardoso, 2008).

However, technological knowledge about the management of the commercial exploitation of yacon is necessary, including the best seasons for planting, growth and development under different cultivation conditions.

Yacon has been cultivated in its region of origin (the Andes) mainly during the rainy season; however, it has also been planted outside this season with irrigation. Although the plant occurs in Pacific Coast regions up to 3,600 metres, the best tuberous root production has been noted at medium altitudes between 1500-2000 metres (Seminario, Valderrama, & Manrique, 2003).

In the Andean region, yacon shoots emerge between 30 and 50 days after planting and grow slowly during the first four months such that the diameter of the stem and leaf production reach a maximum at 170 days. Then, root formation and coarsening accelerate (Seminario et al., 2003).

This plant enters the reproductive period between six and ten months after planting, when it blooms, and the onset of flowering depends on the region where the plant is grown - it matures earlier at lower altitudes (Santana & Cardoso, 2008). This stage is followed by a period in which the carbohydrate content in the rhizophores and the tuberous roots increases, leading to a senescence phase of the shoots and the numbness of the underground parts (Vilhena et al., 2000). According to Oliveira and Nishimoto (2004), the tuberous roots and rhizophores should be harvested between the beginning of shoot flowering and senescence.

Despite widespread information about yacon, we have noted that its growth and development varies depending on its growing conditions, including the ability to change the ideal point for harvesting the roots, thus changing the commercial returns. In this context, scientific knowledge could be used to optimize farming practices (tillage).

Therefore, the aim of this study was to evaluate the growth and development of yacon when planted on different dates in two farming regions.

Material and method

The experiment was conducted in two locations in the south of Espírito Santo, Brazil, from April 2013 to April 2014, one in a mountainous region, in the municipality of Ibatiba, at 20° 17 ' south latitude and 41° 37 ' west longitude at an altitude of 837 m; and the other in the lowland region in the municipality of Alegre, 20° 45' south latitude and 41° 29' west longitude at an altitude of 113 m.

The weather in the south of Espírito Santo has two well defined seasons during the year as follows: a hot and rainy season between October and March and a cold and dry season between April and September. The annual rainfall is approximately 1,200 mm. However, the southern region has micro-regions due to the relief, which mainly affects the temperature. The Microrregião Sul-Serrana region includes Ibatiba and is characterized by a mountain climate (tropical altitude) with milder temperatures, and the Vale do Rio Itapemirim region includes Alegre and has a warm tropical micro-region (lowland) with higher temperatures (Pezzopane, Castro, Pezzopane, & Cecílio, 2012).

The monthly average maximum and minimum temperatures were obtained from the automatic weather stations closest to the experimental sites from INMET, Alegre, Espírito Santo State (Itapemirim Valley) and INCAPER, in Iúna, Espírito Santo State (Southern Mountain) (20.357° South, 41.557° West longitude and 758 metres above sea level) (Figure 1).

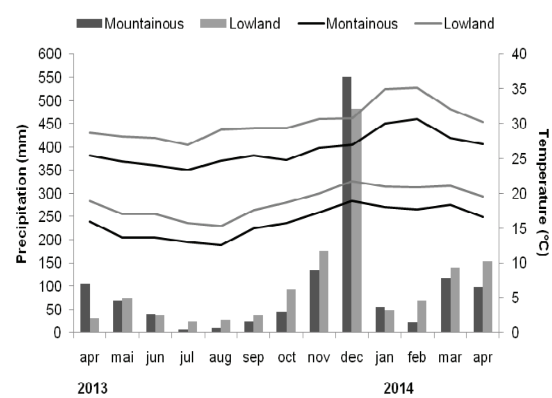

Figure 1. Precipitation and monthly temperature average, maximum and minimum observed during the assessments in mountainous and lowland regions in the state of Espirito Santo, Brazil. Source: INCAPER (2014).

The soil at both sites was classified as Red Yellow Latosol, with a medium texture (sand 68%, Silt 4%, and clay 28%) in the mountain region, and a clayey texture (sand 60%, Silt 5%, and clay 35%) in the lowland (Embrapa, 2014). A sample collected from 0-20 cm, was analysed and showed the following characteristics. Mountain region: pH (water) - 6.20; Phosphorus Mehlich 1 - 53.99 mg dm^{-3}; Potassium - 80.00 mg dm^{-3}; Calcium - 2.12 $cmol_c$ dm^{-3}; Magnesium - 0.87 $cmol_c$ dm^{-3}; Aluminium - 0.0 $cmol_c$ dm^{-3}; Sum of bases - 3.24 $cmol_c$ dm^{-3}; CTC effective - 3.24 $cmol_c$ dm^{-3}; Total organic carbon - 1,83%; total nitrogen - 0.15%; Lowland region: pH (water) - 6.37; Phosphorus Mehlich 1 - 36.99 mg

dm^{-3}; Potassium - 57.00 mg dm^{-3}; Calcium - 1.50 $cmol_c$ dm^{-3}; Magnesium - 0.71 $cmol_c$ dm^{-3}; Aluminium - 0.0 $cmol_c$ dm^{-3}; Sum of bases - 2.36 $cmol_c$ dm^{-3}; CTC effective - 2.36 $cmol_c$ dm^{-3}; total organic Carbon - 1.08%; total Nitrogen - 0.10%.

At each site was conducted by planting yacon in four dates of the year 2013: fall (April), winter (July), spring (September) and summer (December). At each planting date, the experiment was set up according to the randomized block design, with four replications. The treatments were constituted by collection times within each planting date. In each planting date, four experimental units were established, consisting of 8 m long with five lines of plants, with a total of 16 plants per line (Figure 2).

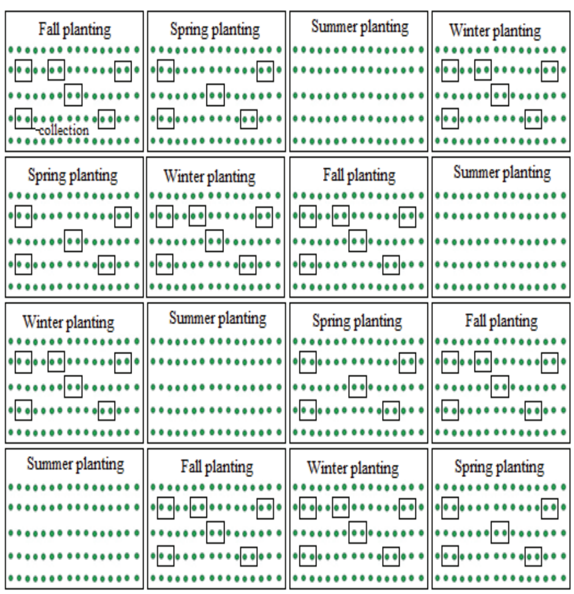

Figure 2. Sketch of the experimental area, in both locations, with the distribution of the experimental units.

Every 30 days, two plants per experimental unit, randomly chosen within the central lines, except for the borders, were collected for evaluation. The leaves, stems, rhizophores and tuberous roots were separated. The collections began 30 days after bud emergence and were discontinued at flowering on 80% of the standing plants. Thus, the number of treatments (collection times) varied according to the site and the planting date, being: 30, 60, 90, 120, 150, 180, and 210 days after emergence (DAE) for the fall planting in mountain; 30, 60, 90, 120, 150, and 180 DAE for the winter plantings in mountain and fall and spring in lowland; and 30, 60, 90, 120, and 150 DAE for spring planting in mountain and winter planting in lowland.

Rhizophores weighing approximately 35 g were planted in grooves at a depth of 10 cm with 1.0 m spacing between the rows and 0.5 m between the plants. The grooves were fertilized with 180 g of tanned bovine manure per linear metre. The manure had the following nutritional composition: 14.21 g kg^{-1} N, 4.75 g kg^{-1} P, 5.28 g kg^{-1} K, 4.29 g kg^{-1} Ca, and 1.92 g kg^{-1} Mg. Throughout the growing season, weeds were controlled by hoeing. Irrigation was performed by applying 30 mm weekly water blades.

The leaf area was obtained by means of a photoelectric meter Licor Area Meter 3100 (LiCor, EUA), and each plant part was oven-dried with forced air at 70 ± 5°C to constant weight, and the dry mass was subsequently obtained.

The leaf mass fraction was the ratio of the leaf dry mass to the total dry mass, the stem mass fraction was the ratio of the stem dry mass to the total dry mass, the rhizophore mass fraction was the ratio of the rhizophore dry mass to the total dry mass, and the tuber root mass fraction was the ratio of the tuber root dry mass to the total dry mass. The specific leaf area was the ratio of leaf area to the leaf dry mass. The leaf area index was the ratio of the leaf area in m^2 contained in 1 m^2 of occupied land by planting.

The dry matter and leaf area data were submitted to analysis of variance by the 5% probability F test, using the statistical program SISVAR (Ferreira, 2014). The natural logarithms of the averages of the original data were adjusted by multiple linear regression to different growth models, with time as an independent variable. The growth rate was estimated by the functional method of growth analysis (Hunt, 1982). To derive a model adjusted to the total dry mass data (W) and the leaf area (A), instantaneous values of the culture growth rate were estimated (CBT = dW / dT), where dW / dT is the derivative of the dry weight accumulation (W) with time and the liquid absorption rate [TAL = (1 / A) x (dW / dT)] at time T.

Result

The satisfactory emergence and growth of the yacon shoots did not occur at either cultivation area during the summer planting; thus, the evaluations presented here are based on the other planting seasons.

The emergence time of the yacon shoots varied with cultivation area and planting season. In the mountainous region, shoot emergence was observed at 60 days after the fall and winter planting (DAP) and 30 DAP during the spring. In the lowland, the emergence of shoots occurred at 60 DAP in the fall and 30 DAP in the winter and spring.

The yacon cultivation cycle also varied by area and planting season. In the mountainous region, flowering, which determined the end of the cultivation cycle, occurred 210 days after emergence (DAE) for the fall planting, at 180 DAE for the winter planting and at 150 DAE for the spring planting. The cycle duration shortened as planting was done closer to the hottest time of the year (summer). In the lowland region, the behaviour was similar. However, the time duration of each cycle was shorter for the fall planting (180 DAE) and the winter planting (150 DAE), but the same for the spring planting (180 DAE).

In the adjustment of dry mass and leaf area data, the exponential polynomial model of the 3rd degree was chosen because it had the highest coefficient of determination (R^2), and all the regression coefficients were significant (Table 1).

The highest total dry mass accumulation (TDM) occurred for the fall planting in both cultivation regions, but in the mountainous region, the cumulative maximum (1,898.38 g m^{-2}) occurred later (210 DAE) than in the lowland region (1,823.75 g m^{-2} at 150 DAE) (Figure 3A).

Another interesting point was related to the spring plantings. In the lowland region, a lower TDM accumulation (599.23 g m^{-2}) was noted than in the mountainous region (1,399.80 g m^{-2}), but the cycle was longer in the mountains (Figure 3A).

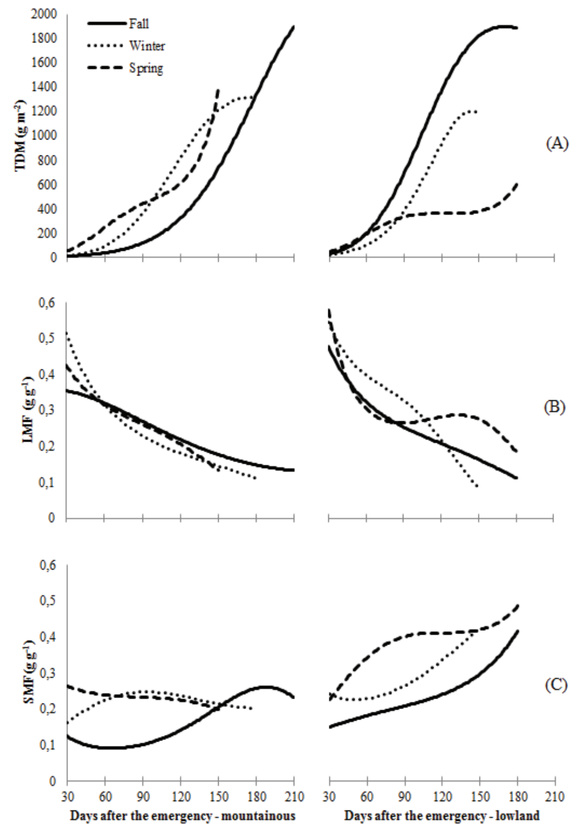

Figure 3. Total dry mass (TDM), leaf mass fraction (LMF) and stem mass fraction (SMF) along the ontogeny of yacon in different planting dates and two growing regions.

In general, the leaf mass fraction (LMF) decreased throughout the yacon cultivation cycle in both locations and planting seasons, except for the spring planting in the lowland region, where the LMF remained somewhat stable between 60 and 150 DAE (Figure 3B).

Table 1. Coefficients of the exponential model polynomial of 3° degree, $Y = \exp(a+bt+ct^2+dt^3)$, fitted to the data of yacon plants grown under different planting dates and two growing regions.

Characteristic	Regions	Planting dates	a	b	c	d	R^2
Total dry mass	Mountainous	Fall	1.01**	0.05**	-2.82e-5**	-2.08e-7*	0.99
		Winter	-0.14**	0.10**	-4.81e-4**	6.84e-7**	1.00
		Spring	0.78**	0.14**	-1.34e-3**	4.49e-6**	0.99
	Lowland	Fall	0.57**	0.11**	-5.61e-4**	9.41e-7**	1.00
		Winter	1.72**	0.04**	1.66e-4**	-1.48e-6**	1.00
		Spring	1.00**	0.12**	-9.95e-4**	2.72e-6**	0.98
Leaf area	Mountainous	Fall	5.11*	0.06**	-1.80e-4**	1.41e-7**	0.99
		Winter	4.88*	0.11*	-7.13e-4*	1.60e-6*	0.98
		Spring	6.59*	0.08*	-7.09e-4*	2.27e-6*	1.00
	Lowland	Fall	6.15**	0.06**	-1.96e-4**	-1.88e-7**	0.98
		Winter	8.46**	-0.04**	1.16e-3**	-5.46e-6**	0.99
		Spring	7.37*	0.04*	-3.17e-4*	8.59e-7*	0.89

** Significant at 1%.* Significant at 5%.

In general, the stem mass fraction (SMF) was lower in plants grown in the mountainous region, independent of the planting time. The SMF reached a later maximum in the fall planting, close to 180 DAE (Figure 3C).

However, in the lowland region, SMF was larger in both planting seasons, and it increased until the end of the cycle. Importantly, the spring planting showed the highest SMF (Figure 3C).

The rhizophores mass fraction (RiMF) always decreased according to the cultivation cycle in the mountainous region, independent of planting season. In contrast to the lowland region, higher values were observed during the initial stage of the cycle, which decreased during the intermediate phase, and increased again at the end of the cycle (Figure 4A).

The tuberous roots mass fraction (TBMF) increased during the yacon cultivation cycle in the mountainous region, except for the fall planting in which a decrease from 120 to 180 DAE occurred, and the plants growth was retaken later (Figure 4B).

In general, in the lowland region, an initial increase in TBMF followed by subsequent decrease was observed. In the fall and winter planting, the maximum was at approximately 120 DAE and 105 DAE for spring planting (Figure 4B). However, a decrease in TBMF between 30 and 60 DAE was observed in the winter, which might have been related to the death of the roots.

Under both cultivation conditions, the specific leaf area (SLA) decreased throughout the yacon cultivation cycle for the fall and the winter plantings. An SLA decrease at the beginning of the cultivation cycle was seen in the spring plantings, followed by an increase beginning at 75 DAE (mountainous region) and 90 DAE (lowland region) (Figure 5A).

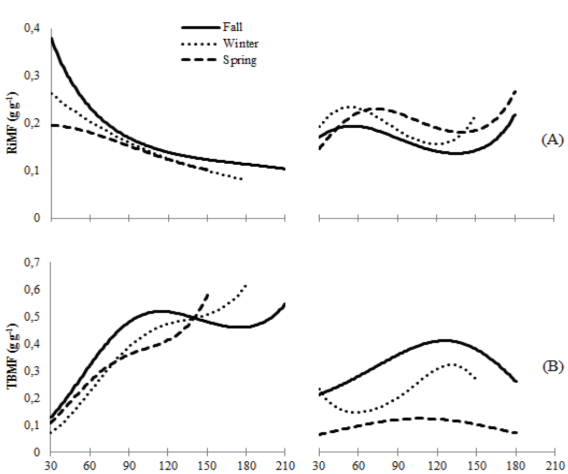

Figure 4. Rhizophores mass fraction (RiMF) and tuberous roots mass fraction (TBMF) along the ontogeny of yacon in different planting dates and two growing regions.

The net assimilation rate (NAR) varied depending on the planting time and growing conditions. In the mountainous region in the fall and winter plantings, the NAR increased during a considerable part of the cycle, at approximately 165 and 105 DAE, respectively. It decreased from that point on, even reaching negative values in the winter planting. For the spring planting the NAR decreased nearly to zero at 90 DAE and began to increase from 120 DAE until the end of the cycle when it had its highest values for the spring planting (Figure 5B).

In general, in the lowland region, the NAR slightly increased at the beginning of the cycle (approximately up to 60 DAE), then decreased until the end of the cycle. The spring planting was an exception in which the decreasing values reached zero. Later, it increased again, from 120 DAE until the end of the cycle, when it had its highest values for the spring planting (Figure 5B).

The leaf area rate (LAI) always increased throughout the cycle in the mountainous region for the fall planting (maximum 3.26 m^2 m^{-2} at 210 days) and the spring planting (maximum 3.10 m^2 m^{-2} at 150 days). For the winter planting, the maximum (2.23 m^2 m^{-2}) occurred earlier (120 days), and this rate persisted until the end of the cycle (approximately 180 days) (Figure 5C).

In contrast to the lowland region, the maximum peaks occurred earlier in the fall plantings (maximum 5.10 m^2 m^{-2} to 138 days) and in the winter (maximum 3.72 m^2 m^{-2} to 119 days), followed by a decrease until the end of the cycle. However, the spring planting showed an increasing LAI, with the maximum (2.11 m^2 m^{-2}) observed at the end of the cultivation cycle (Figure 5C).

The tillage growth rate (CGR) followed a specific pattern in the fall and winter plantings in both growing conditions increasing up to a specific point, reaching a maximum and decreasing until the end of the cycle (Figure 5D).

The maximum point varied, and in the lowland region, the maximum CGR had similar values and occurred at similar times, at 104 DAE in the fall planting (23.42 g m^{-2} day^{-1}) and 112 DAE in the winter planting (19.99 g m^{-2} day^{-1}). In the mountainous region, the maximum (21.40 g m^{-2} day^{-1}) for the fall planting occurred later (177 DAE) than the maximum (16.16 g m^{-2} day^{-1}) in the winter planting (114 DAE) (Figure 5D).

Different behaviour was observed for the spring planting. In both regions, the CGR showed a short decrease in the middle of the cycle and a subsequent increase until the end of the cycle. In the lowland region, the CGR reached zero (120 DAE), then increased and peaked (16.19 g m^{-2} day^{-1}) at 180 DAE.

In the mountainous region, it did not reach zero, and the maximum was much higher (61.18 44 g m^{-2} day^{-1}) and occurred earlier, at 150 DAE (Figure 5D).

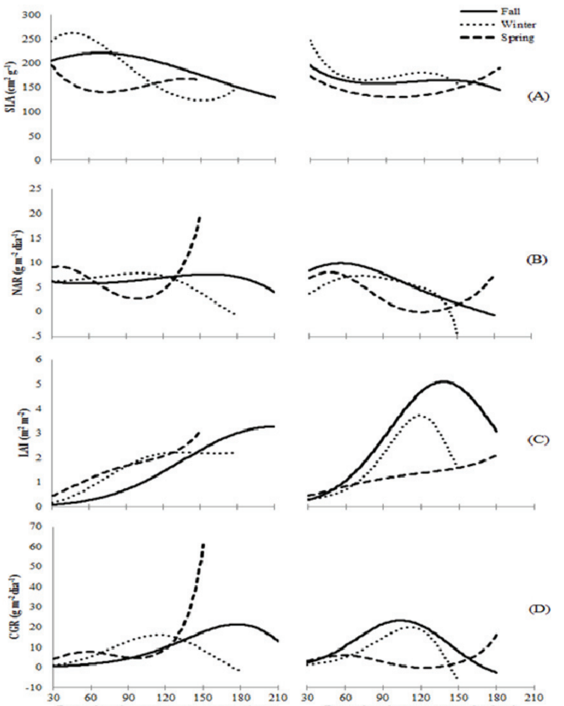

Figure 5. Especific leaf area (SLA), net assimilation rate (NAR), leaf area index (LAI) and crop growth rate (CGR) along the ontogeny of yacon in different planting dates and two growing regions.

Discussion

The absence of emergent and satisfactory shoots in the summer planting at both locations was related to the adverse conditions to which the rhizophores were exposed. A heavy rainfall (551 mm provided mountain and 483 mm in the lowland) occurred during the planting month (December/2013), which made the soil excessively wet. Combined with high temperatures (30°C in the mountainous region and 35°C in the lowland region), it caused the death of the rhizophores. This result indicated that the planting yacon in high temperature and humidity conditions (e.g., heavy rain) is risky for the initial establishment of the tillage.

In mild temperatures, the emergence and growth of shoots occur more slowly, as seen in the mountainous region, or when the crop is planted in the fall, which directly affects the cycle duration, which occurs late. This behaviour has been observed in Peru, where the crop cycle can vary between four and ten months, and, at higher altitudes, ripening also occurs late (Seminario, Valderrama, & Manrique, 2003).

According to Finger, Fontes, and Pauiatti (2005), in the rest and dormancy phases of vegetative propagules, there are changes in the concentrations of phytorregulators (inhibitor / stimulator) that control sprouting. These changes are influenced by environmental factors, with emphasis on temperature. The high temperature in pre-dormancy can provide a return to growth, and after the dormancy period, there is a transition period when growth is resumed, and under high temperature the duration of each stage is shortened in comparison with low temperature.

Fall planting in the mountainous or lowland region favoured the accumulation of biomass by the yacon plants because it allowed the plants to grow in mild temperatures during most of the cycle. In general, the closer to the time of the year when higher temperatures occurred (summer) that planting was carried out, the plants accumulated less biomass.

This behaviour was most apparent in the lowland region, particularly for the spring planting. The plants virtually ceased growing between 90 and 150 days. At that time, high temperatures occurred in the region (approximately 35°C in January and February). At this point, the NAR and CGR were close to zero, which indicates that the photosynthetic activity of the plants was nearly equal to the respiratory activity. For this reason, no increase of vegetal biomass per unit of leaf area occurred. There is almost a cessation of the plant growth, which an extension of the cycle and a decreased biomass accumulation by the plants.

A plant changes its ontogeny after a thermal stress, increasing the SLA after a period of high temperature, investing in the expansion of the leafy limbs to optimize light capture. An increased production of photoassimilates increases the NAR and CGR for the plant to continue to grow when the SLA decreased with a shorter investment in the leaf limb expansion. Moreover, thermal stress may have reduced or inhibited the translocation of photoassimilates from the leaf to other parts of the plant (Finger, Fontes, & Pauiatti, 2005), and thus, being accumulated in the leaf, which has its increased weight, reducing the values of SLA (Cancellier et al., 2010).

This behaviour shows that high temperature is detrimental to CO_2 assimilation by the yacon leaves, which reinforces the argument that yacon is sensitive to thermal stress, and if it is planted under high temperature conditions, the rate of photosynthesis per leaf area unit might be considerably reduced. Similar behaviour was also observed in other plants with a reserve habit in subterranean organs, such as taro (Oliveira, Araujo, & Guerra, 2011).

Plants that grow in mild temperatures (as in the fall plantings or the mountainous region) invest less in the stem fraction, mainly the rhizophores, which are a stem portion, and more in the tuberous roots, which can directly impact the harvest yields because the root is the main commercial part.

It is known that the tuberset process is affected by light, mineral nutrition, temperature and endogenous growth regulates level (Finger, Fontes, & Pauiatti, 2005). Yacon has been described as neutral regarding the effect of the photoperiod on stem and root formation (Kerbauy, 2013; Seminario, Valderrama, & Manrique, 2003). The results of this study suggest that temperature process is an environmental factor that affects tuberset and has consequences on the behaviour of yacon during the cultivation cycle because high temperatures harm the formation of the reserve organ, while mild temperatures favour its growth.

It has been noticed in other plants of Andean origin, such as the potato (*Solanum tuberosum*), for example. High temperature reduces the growth of the plant and the assimilated partition for the tubers. The range of 18-22°C is acceptable as an optimum for potato production. However, depending on the cultivar, in the environment of greater luminous density, the optimum moves to larger values. Above 30°C respiration rapidly increases, resulting in a decrease in net photosynthesis and practically no tubercle production (Finger, Fontes, & Pauiatti, 2005; Rodríguez-Falcón, Bou, & Prat, 2006). Among plant hormones, gibberellins have been indicated as controlling for tuberization, since environmental conditions that promote this process cause a decrease in gibberellin activity in stems. High temperatures stimulate the production of gibberellins in stem buds rather than leaves, which may be related to the inhibition of the tubercle caused by high temperatures (Kerbauy, 2013).

In the fall planting in the mountainous region, temperatures of approximately 13 to 25°C were in a good range for yacon development, according to Seminario, Valderrama, and Manrique (2003). Even in the spring planting in the mountainous region, the temperatures during the cycle were approximately 15 to 28°C, which accounted for the best growth of mass accumulation (TDM) and the best development, mainly of the reserve roots (TBMF), as compared to the lowland region.

An important fact related to the cultivation area and, consequently, to temperature is that in fall and winter planting in the lowland region, TDM decreases when the LAI decreases. This can be related to the leaf senescence rate, which would be countered by the rate of the production of new leaves. Additionally, a decrease in the NAR, which indicates an increase in the average age of a leaf, consequently reduces the photosynthetic rate, which in turn imitates a reduction in the TBMF and RiMF. This indicates that the accumulation of mass that the plant is still demonstrating is being invested in a non-marketable organ. This could be an indication that the optimum harvest time for the roots could be before flowering, which was the final evaluation time.

This observation can be corroborated by observing the yacon growth rate (CGR), which also peaked with the LAI. In a similar manner to the CGR maximum, a greater translocation of reserve substances proceeds to the tuberose roots, consequently resulting in less leaf emission and greater leaf senescence, indicating the cycle closure, as has been observed in sweet potatoes (Conceição, Lopes, & Fortes, 2005). According to Hunt (1982) after the CGR peak, a change in the otogenic development stage of the species also occurs, which normally indicates the beginning of the reproductive period and progressing to greater translocation to reserve organs.

Additionally, this behaviour indicates that the yacon has a rhizophore and a reserve organ, which is the organ that will originate a new plant and has the potential for species perpetuation (Seminario, Valderrama, & Manrique, 2003). This organ also contains the reservoir of simple carbohydrates and fructooligosaccharides (Vitali, Sancho, & Katinas, 2015).

However, these signs of cycle closure were not as clear in the plants in the mountainous region because the LAI kept increasing following the TDM and the TBMF until flowering, which was the end of the evaluation. At this time, the plant was still growing and accumulating root reserves. Although the beginning of a decrease in the NAR was noticed after the 120 days, which might have occurred due to possible leaf auto shading, and which contributed to the reduction of this rate (Pohl et al., 2009). With an LAI increase, the NAR would decrease, as occurred in the fall and the winter planting, indicating a decrease in the velocity of accumulation of biomass by local leaf units, but negative values that would allow a mass gain did not occur, which in this case would be in roots as indicated by the TBMF increase.

These results indicate that the harvest point of the roots could be later immediately after flowering, as was reported by Oliveira and Nishimoto (2004) and Seminario, Valderrama, and Manrique (2003).

Another interesting fact that deserves mention is that in the mountainous region, the CGR maximum in the fall planting occurred later (180 days) compared to the spring planting (120 days). This behaviour indicated that the plants began the stage of the greater translocation of reserve substances to the tuberose roots at the same time of year, and this would allow cycle closure and the root harvest point to occur practically simultaneously. This result reinforces field observations in the region. This means that whether the planting in the fall or the winter, the harvest would occur at the same time.

This behaviour is also affected by temperature because it is known that the maximum CGR depends on the genotype and environmental factors (Conceição et al., 2005). Because the genetic material was constant in this study, the change in the maximum CGR occurred due to the environment, mainly because of the temperature.

Conclusion

Planting yacon in the fall in a mountainous or lowland region favours yacon growth and development.

Cultivation in a mountainous region independently of the planting time promotes greater mass accumulation in the tuberose roots, which reflects greater productivity.

Both fall and winter planting in the mountainous region allows root harvesting at the same time.

Acknowledgements

To Capes for my scholarship. To CNPq and FAPES for their the financial help. To FAPES for the Capixaba researcher second author scholarship.

References

Campos, D., Betalleluz-Pallardel, I., Chirinos, R., Aguilar-Galvez, A., Noratto, G., & Pedreschi, R. (2012). Prebiotic effects of yacon (*Smallanthus sonchifolius* Poepp. & Endl), a source of fructooligosaccharides and phenolic compounds with antioxidant activity. *Food Chemistry*, *135*(3), 1592–1599. doi: 10.1016/j.foodchem.2012.05.088

Cancellier, L. L., Adorian, G. C., Rodrigues, H. V. M., Siebeneichler, S. C., & Leal, T. C. A. B. (2010). Doses de potássio nas respostas morfofisiológicas de alface. *Revista Caatinga*, *23*(4), 21-27.

Conceição, M. K., Lopes, N. F., & Fortes, G. R. L. (2005). Análise de crescimento de plantas de batata-doce (*Ipomoea batatas* (l.) lam) cultivares abóbora e da costa. *Revista Brasileira de Agrociência*, *11*(3), 273-278.

Empresa Brasileira de Pesquisa Agropecuária [Embrapa]. (2014). *Sistema brasileiro de classificação de solos*. 4. ed. Rio de Janeiro, RJ: Centro Nacional de Pesquisa de Solos.

Ferreira, D. F. (2014). Sisvar: a Guide for its Bootstrap procedures in multiple comparisons. *Ciência e Agrotecnologia*, *38*(2), 109-112. doi: 10.1590/S1413-70542014000200001

Finger, F. L., Fontes, P. C. R., & Pauiatti, M. (2005). Dormência e tuberização. In P. C. R. Fontes (Ed.), *Olericultura teoria e prática*. Viçosa, MG: Suprema Gráfica e Editora.

Genta, S. B., Cabrera, W. M., Habib, N., Pons, J., Carillo, I. M., Grau, A., & Sánchez, S. S. (2009). Yacon syrup: Beneficial effects on obesity and insulin resistance in humans. *Clinical Nutrition*, *28*(2), 182–187. doi: 10.1016/j.clnu.2009.01.013

Habib, N. C., Honoré, S. M., Genta, S. B., & Sánchez, S. S. (2011). Hypolipidemic effect of *Smallanthus sonchifolius* (yacon) roots on diabetic rats: Biochemical approach. *Chemico-Biological Interactions*, *194*(1), 31-39. doi: 10.1016/j.cbi.2011.08.009

Hunt, R. (1982). *Plant growth curves: The functional approach to plant growth analysis*. London, UK: Edward Arnold.

Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural [INCAPER]. (2014). Retrivied on Dec. 20, 2014 from http://hidrometeorologia.incaper .es.gov.br/? pagina=bol

Kerbauy, G., (2013). *Fisiologia vegetal*. 2. ed. Rio de Janeiro, RJ: Guanabara Koogan.

Moura, N. A. de, Caetano, B. F. R., Sivieri, K., Urbano, L. H., Cabello, C., Rodrigues, M. A. M., & Barbisan, L. F. (2012). Protective effects of yacon (*Smallanthus sonchifolius*) intake on experimental colon carcinogenesis. *Food and Chemical Toxicology*, *50*(8), 2902-2910. doi: 10.1016/j.fct.2012.05.006

Oliveira, F. L., Araujo, A. P., & Guerra, J. G. M. (2011). Crescimento e acumulação de nutrientes em plantas de taro sob níveis de sombreamento artificial. *Horticultura Brasileira,* *29*(3), 291-298. doi: 10.1590/S0102-05362011000300006

Oliveira, G. O., Braga, C. P., & Fernandes, A. A. H. (2013). Improvement of biochemical parameters in type 1 diabetic rats after the roots aqueous extract of yacon (*Smallanthus sonchifolius*) treatment. *Food and Chemical Toxicology*, *59*, 256-260. doi: 10.1016/j.fct.2013.05.050

Oliveira, M. A., & Nishimoto, E. K. (2004). Avaliação do desenvolvimento de plantas de yacon (*Polymnia sonchifolia*) e caracterização dos carboidratos de reservas em HPLC. *Brazilian Journal of Food Technology*, 7(2), 215-220.

Pezzopane, J. E. M., Castro, F. S., Pezzopane, J. R. M., & Cecílio, R. A. (2012). *Agrometeorologia: aplicações para o Espírito Santo*. Alegre, ES: CAUFES.

Pohl, S., Lopes, N. F., Braga, E. J. B., Silva, C. P., Silva, F. S. P., & Peters, J. A. (2009). Características de crescimento de plantas de batata, cv. Baronesa, e seu genótipo transformado geneticamente para resistência ao PVY. *Revista Ceres*, *56*(6), 736-743.

Rodríguez-Falcón, M., Bou, J., & Prat, S. (2006). Seasonal control of tuberization in potato: conserved elements with the flowering response. *Annual Review of Plant Biology*, *57*, 151–180. doi: 10.1146/annurev.arplant.57.032905.105224

Santana, I., & Cardoso, M. H. (2008). Raiz tuberosa de yacon (*Smallanthus sonchifolius*): potencialidade de cultivo, aspectos tecnológicos e nutricionais. *Ciência Rural*, *38*(3), 898-905. doi: 10.1590/S0103-84782008000300050

Seminario, J., Valderrama, M., & Manrique, I. (2003). *El yacon: fundamentos para el aprovechamiento de un recurso promisorio*. Lima, Peru: Centro Internacional de la Papa (CIP), Universidad Nacional de Cajamarca, Agencia Suiza para el Desarrollo y la Cooperación (COSUDE).

Vaz-Tostes, M. G., Viana, M. L., Grancieri, M., Luz, T. C. S., Paula, H., Pedrosa R. G., & Costa, N. M. B. (2014). Yacon effects in immune response and nutritional status of iron and zinc in preschool children. *Nutrition, 30*(6), 666-672. doi: 10.1016/j.nut.2013.10.016

Vilhena, S. M. C., Câmara, F. L. A., & Kakihara, S. T. (2000). O cultivo de yacon no Brasil. *Horticultura Brasileira*, *18*(1), 5-8. doi: 10.1590/S0102-05362000000100002

Vitali, M. S., Sancho, G., & Katinas, L. (2015). A revision of *Smallanthus* (Asteraceae, Millerieae), the “yacón” genus. *Phytotaxa*, *214*(1), 1-84. doi: 10.3989/ajbm.2392

Received on September 12, 2017.
Accepted on January 21, 2018.