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Growth of yacon under artificial shading

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ABSTRACT

Yacon is a tuberous root cultivated in mild climate regions with high altitudes, but the crop shows the capacity to develop at low altitudes. The objective of this study was to evaluate growth rates and the partition of photoassimilates in yacon plants under different levels of artificial shading. The experiment was conducted in four shading levels (0%, 30%, 50% and 70%), and seven monthly harvests in a completely randomized design. We evaluated the accumulation of total dry mass on the whole plant and its parts; leaf area; leaf area ratio; leaf mass fraction; stem mass fraction; rhizophores mass fraction; tuberous roots mass fraction; estimates of relative growth rate, absolute growth, and net assimilation. The lower accumulation of total dry biomass and the lowest growth rates indicate that conditions of noticeable light restriction (70% shading) restrict the growth of yacon. Yacon plants grown under moderate shading levels (30 to 50%) showed greater capacity of accumulation of total biomass, directing part of this biomass to the tuberous roots, which directly reflects gains in the agronomic productivity of this crop, indicating that yacon has the potential to be associated with other crops, which promote a moderate shading.

Keywords: *Smallanthus sonchifolius*, light restriction, physiological indexes, growth analysis.

RESUMO

Crescimento de yacon sob sombreamento artificial

Yacon é uma raiz tuberosa cultivada em regiões de clima ameno com grandes altitudes, com capacidade também de se desenvolver em baixas altitudes. O objetivo deste estudo foi avaliar as taxas de crescimento e a partição de fotoassimilados em plantas de yacon sob diferentes níveis de sombreamento artificial. O experimento foi conduzido em quatro níveis de sombra (0%, 30%, 50% e 70%) e sete coletas mensais, em delineamento inteiramente casualizado. Avaliou-se o acúmulo de massa seca total e por partes da planta; área foliar; razão de área foliar; fração de massa foliar; fração de massa caulinar; fração de massa de rizóforos; fração de massa de raízes tuberosas; estimativas de valores instantâneos da taxa de crescimento relativo, de crescimento absoluto, e de assimilação líquida. O menor acúmulo de biomassa seca total e as menores taxas de crescimento indicam que condições de restrição perceptível à luz (70% de sombreamento) restringem o crescimento de yacon. As plantas de yacon cultivadas com níveis moderados de sombreamento (30 a 50%) apresentaram maior capacidade de acumulação de biomassa total, direcionando parte dessa biomassa para as raízes tuberosas. Esse comportamento reflete diretamente em ganhos na produtividade agronômica dessa cultura, indicando que o yacon tem potencial de ser associado a outras culturas, que promovem um sombreamento moderado.

Palavras-chave: *Smallanthus sonchifolius*, restrição de luz, índices fisiológicos, análise de crescimento.

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Yacon, also known as a diet potato, is considered a functional food with nutraceutical potential, which has aroused interest in the food and pharmaceutical industry, mainly due to the presence of fructooligosaccharides. These compounds promote several human health benefits, such as decreasing cholesterol and diabetes control (Saeed *et al*., 2017).

It is a native species of the Andes, a region with tropical mountain climate, with high altitudes. Therefore, with milder temperatures, abundant rains concentrated in the summer and fog during a great part of the year. Winter is relatively dry and cold, lasting around 2 to 4 months, ideal for the production of tuberous roots (*Seminario et al.*, 2003).

In order to potentiate yacon cultivation in regions other than the Andes, it is necessary to seek management strategies that favor conditions more favorable to the growth and production of tuberous roots in plants. Therefore, shading can be a promising strategy, considering the possibility of microclimate formation (higher levels of moisture, soil and air, with lower temperatures and lower intensity of radiation). It is important to note that yacon is a plant with a physiological C3 cycle, a group of plants that best adapt to environments with a lower luminous intensity (Taiz *et al.*, 2018).

According to Seminario *et al.* (2003), yacon behaves well when associated with herbaceous, shrub and arboreal species, including the possibility of being a component for agroforestry systems. Tomazini Neto *et al.* (2009) obtained a yield in tuberous roots of 54.83 t ha^{-1} in full sun and 100.13 t ha^{-1} under 50% shading. Thus, there are notes that shading may be favorable to the growth and yield of yacon.

However, shade provided to the plants should be at an ideal level for each species, according to the need of each one, knowing that there are plants adapted to full sun and others to shade (Taiz *et al.*, 2018). This is due to the fact that the adoption of intense shading can promote limitation in the photosynthetic activity, and consequently lead to a lower biomass production (Ballaré &Pierik, 2017).

Thus, since little is known about the morphological and physiological responses of yacon subjected to shaded environments, the objective of this study was to evaluate the growth rates and the partition of photoassimilates in yacon plants under different levels of artificial shading.

MATERIAL AND METHODS

The experiment was carried out in the experimental area of IFES in the municipality of Alegre-ES (20°46'S, 41°27'W, 128 m altitude), from May to December 2015.

During the conduction period, the maximum temperatures varied from 21 to 27°C and the minimum was from 19 to 25°C, with accumulated rainfall of 451.6 mm (data acquired from the automatic meteorological station of the National Institute of Meteorology of Brazil-INMET, located near the experiment).

The experimental design was completely randomized in a plot scheme subdivided in time, with five replications. The plots were composed of four shading levels (0%, 30%, 50% and 70%), and the subplots had seven collection times [30, 60, 90, 120, 150, 180 and 210 days after planting (DAP)].

Each plot was composed of seven pots numbered randomly according to the collection time. The pots were placed inside wooden structures (assembled with eucalyptus stakes) with a square shape, and a lateral dimension of 1.00 m, and 1.70 m height, that were totally covered with sombrite type of plastic with different light restriction (30%, 50% and 70%). The control treatment was the plants kept in full sun (0% shading).

Black plastic pots with 25 L capacity, filled with substrate obtained by homogeneous mixing the soil, sand and organic compost in the ratio 3:1:1 (v/v) were used. The soil used to prepare the substrate was classified as red yellow oxisols, medium texture (Embrapa, 2018), collected at horizon B, 20 cm depth, then air-dried and sieved with a 5 mm mesh (Laboratory of Soils, Center of Agrarian Sciences and Engineering, UFES). The soil presented the following chemical and granulometric characteristics: pH in water 5.71; 4.13 mg dm^{-3} P; 20.0 mg dm^{-3} K; 1.47 $cmol_c$ dm^{-3} Ca; 0.69 $cmol_c$ dm^{-3} Mg; 0.0 cmolc dm^{-3} Al; 2.89 $cmol_c$ dm^{-3} sum of base; 2.20 $cmol_c$ dm^{-3} effective CEC; 43.19% base saturation; 60% sand, 5% silt and 35% clay.

The pH was corrected by raising the base saturation to 60%, with limestone 90 PRNT, mixing the soil evenly. Liming was obtained by applying dolomitic limestone (0.1 t ha^{-1}). The organic compound was analyzed and presented 20.3 g kg^{-1} total N, 3.40 g kg^{-1} P, 6.30 g kg^{-1} K, 12.30 g kg^{-1} Ca, 4.40 g kg^{-1} Mg, 2.60 g kg^{-1} S, 62.06 mg kg^{-1} B, 55.90 mg kg^{-1} Zn, 307.4 mg kg^{-1} Mn, 1770 mg kg^{-1} Fe. N/K ratio = 3.22, N/C= 1.65, N/S= 7.81, P/K= 0.54, P/S= 1.3.

Planting occurred on May 3, 2015. The yacon propagation material used were sections of rhizophores with approximately 35 g, planted at 6 cm depth. During the experiment, daily irrigations were carried out to replace the evapotranspirated water and maintain the field capacity of the soil.

The samples were collected every 30 days. Each month, a plant was collected per treatment. The plants were cut close to the soil and the aerial part separated into stem, leaves, and the underground part in rhizophores, roots absorption and tuberous roots. The leaf area of the plants was obtained by photoelectric meter (LI-3100C area meter). Each part of the plant was dried in a forced air circulation oven at 70±5°C until constant mass, and afterwards the dry mass was obtained.

The studied variables were: 1) leaf area ratio (dividing total leaf area by total dry mass); 2) leaf mass fraction (ratio between leaf dry mass and total dry mass); 3) stem mass fraction (ratio between dry mass and total dry mass); 4) rhizophores dry mass fraction (ratio between the rhizophore's dry mass and total dry mass); 5) tuberous roots mass fraction (ratio between dry weight of tuberous roots and total dry mass).

The soil temperature was measured at 10 cm depth. The readings were done using a digital thermometer (Solo Term 1200 model), with the use of a metal probe. Soil moisture was also measured at 10 cm, with the aid of the Electronic Soil Moisture Meter (HFM2030). The readings were performed at 03:00 p.m. from 60 days after planting.

Growth rates were estimated by the functional method of growth analysis (Hunt, 1982). The natural logarithms of the means of the original data obtained were adjusted by multiple linear regression to different growth models, considering time as an independent variable. The second degree polynomial exponential model was chosen because it presents a higher coefficient of determination (R^2) and is significant for all analyzed parameters (Table 1).

By models derivation fitted to the data of total dry mass (TDM) and leaf area (LA), we estimated instantaneous values of relative growth rate (RGR) = (lnTDM2 - lnTDM1) / (T2-T1) = g g^{-1} day^{-1}, absolute growth rate (AGR) = (TDM2-TDMT1) / (T2-T1) = g day^{-1}, net assimilation rate (NAR) = (TDM2 - TDM1) (lnL2 - lnL1) / (L2-L1) (T2-T1) g d/m^2 day^{-1}, leaf area ratio (LAR) = A/ TDM cm^2 g^{-1}.

RESULTS AND DISCUSSION

The soil temperature in the pots increased throughout the cycle in all treatments, following the local air temperature; however, the lowest values were always noticed at the 70% shading level (Figure 1). For soil moisture, the highest values are found at the 70% level and lower at the 0% level (Figure 1). The shade provided a microclimate with lower temperatures, which contributed to the maintenance of soil moisture, an interesting condition to favor the plant growth, besides showing a possibility of less need to complement the water demand through irrigation.

The shading did not interfere in the seedling emergence time, due to uniformity of the propagating material used (sections of the rhizophores), which was selected with same sizes and number of buds (35 g and with 2 to 3 buds), therefore, with similar capacity of reserve and supply.

There is a clear increase in total dry matter accumulation (DMA) in the plants grown under 50% and 30% shading conditions along the yacon ontogeny (Figure 2A).

There is also a change in the leaf area (LA) of the shaded plants, which present a more evident growth during their ontogeny. The condition of 50% shading was observed, which presented plants at 210 DAP (final moment of the evaluations), with the highest value of 8741.48 cm^2 of LA, higher than presented by plants grown under the conditions of 70% (7173.15 cm^2), 30% (2666.97 cm^2) and 0% (177.204 cm^2) shading (Figure 2B).

It should be noted that plants grown in full sun (0%), started a decrease in the LA, from 120 DAP, showing almost complete leaves senescence at 210 DAP, demonstrating the end of the productive cycle of yacon in this condition. This would represent a greater cycle precocity and with less accumulation of biomass in these plants.

50% shading showed to be the most favorable condition for yacon plants. Plants grown in 30% shading, although presenting a smaller leaf area, presented the second largest accumulation of total biomass in the plants, showing that this condition can also be favorable in yacon growth (Figure 2).

The behavior to increase LA is observed in some plant species that have the capacity to develop under a certain light restriction. Oliveira *et al*. (2011) observed similar results with taro (*Colocasia esculenta*). It is possible for the plant to obtain better liquid photosynthesis indexes, which may contribute to the accumulation of biomass in the reserve organ. Wang *et al*. (2014) observed that the increase of LA favored the vegetative growth of plants such as sweet potatoes and the formation of tuberous roots when shaded at 40%.

Observing the photoassimilates partitioning of the plants, through the

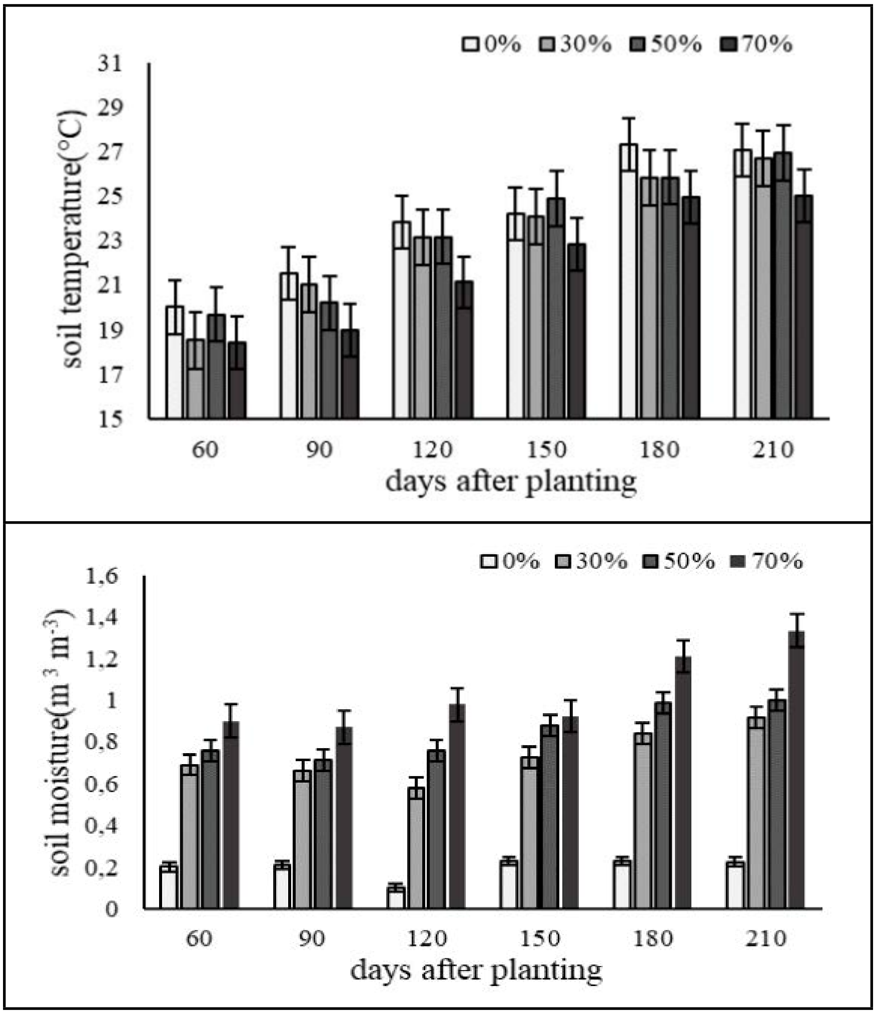

Figure 1. Soil temperature and moisture in the pots, along the yacon ontogeny in the four shading levels. Alegre, UFES, 2015.

Table 1. Coefficients of the 2nd degree polynomial exponential model, Y = exp ($a+bt+ct^2$), adjusted to the data of yacon plants grown under different shading levels. Alegre, UFES, 2015.

Characteristic	Shading levels	Coefficients			
		a	b	c	R^2
Total dry mass	0%	-0.7312	0.0601	-0.0002	0.944
	30%	0.2347	0.0484	-0.0001	0.809
	50%	-0.1318	0.0523	-0.0001	0.914
	70%	-1.0679	0.0589	-0.0002	0.983
Leaf area	0%	4.2953	0.0462	-0.0002	0.804
	30%	5.1797	0.0339	-1.00E-04	0.736
	50%	4.9388	0.0407	-0.0001	0.926
	70%	4.5311	0.0417	-0.0001	0.893

mass fractions accumulated in each organ, it is noted that leaf mass fraction (LMF) decreased in all conditions except in the first 60 DAP, in the condition of 70% shading (Figure 3A). The highest investments in the LMF were observed under conditions of 70% and 50% shading, therefore the higher LAs observed in these conditions, possibly were stimulated by the need to compensate for the lower light availability.

The investment in the stem mass fraction (SMF) was increasing along the ontogeny of the plant for all treatments, highlighting that in the shading conditions, the investment was greater from 120 DAP until the end of the cycle (Figure 3B).

The accumulation in the rhizophores mass fraction (RiMF) occurred similarly between treatments, increasing until around 150 DAP, and decreasing to 210 DAP. It is noteworthy that there is a difference of investment in the RiMF in the initial phase, because the plants growing in shaded environments presented lower RiMF than those grown in full sun, mainly in the conditions of 50% and 70% shading (Figure 3C).

The tuberous roots mass allocation fraction (TRMAF) occurred in a different way. We observed that plants growing in full sun (0% shade) were the ones that presented the highest TRMAF, from 90 DAP on, showing a peak around 180 DAP (Figure 3D), when a decrease begun. This would be another indication that the plant would be in a senescence state (as shown by the decrease of the leaf area), aiming to accumulate the maximum possible reserve before the total shoot death. Observing the photoassimilates partitioning of the plants, through the mass fractions accumulated in each organ, it can be noted that the reserve organs, such as the tuberous roots, are strong metabolic drains and with great force of assimilated mobilization, which induces an acceleration in the foliar senescence, consequently reducing the LA (Conceição *et al.*, 2005).

Plants grown under 50% shading, presented a peak of leaf area and accumulation of total biomass, at 210 DAP (moment of the last evaluation) (Figure 2A). Plants grown under shade have a lower investment in TRMAF along the ontogeny of the plant (Figure 3D), and for plants grown under 70% shading it may mean losses in the production of tuberous roots, considering that these plants accumulated few biomass (Figure 2A). For plants grown under 50% shading, the most continuous investment in the TRMAF (Figure 3D) does not affect the tuberous root production, considering that these plants presented the largest accumulation of total biomass (Figure 2A). The conditions of 30% shade resemble those of 50%, however, the plants would have lower tuberous root production due to the lower investment in TRMAF (Figure 3D) and the lower accumulation of total biomass (Figure 2A).

Plants grown under 50% shading were in full growth, corroborating that this shading condition would create a microclimate favorable to yacon, prolonging the plant cycle, but in return allowing the increase in tuberous root production, considering that the investment in TRMAF would be maintained.

According to Silva *et al.* (2018), yacon is a plant that responds with cycle prolongation to the best growing conditions. This behavior was also noted by Oliveira *et al.* (2011) with taro culture, which delayed the beginning of the formation of the reserve organs (rhizomes) when exposed to 75%

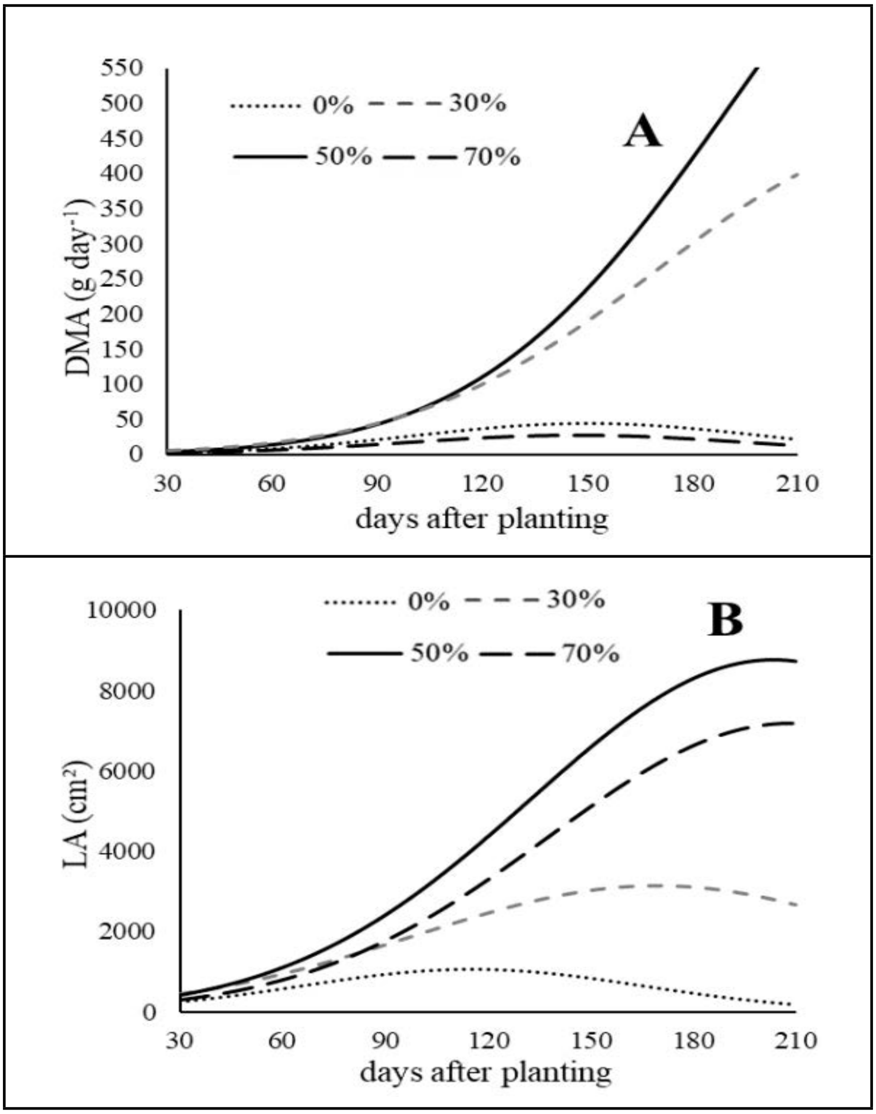

Figure 2. Dry matter accumulation (DMA) and leaf area (LA), along the yacon ontogeny in the four shading levels (0%, 30%, 50% and 70%). Alegre, UFES, 2015.

shading.

Leaf Area Ratio (LAR) decreased along the plant ontogeny, except under 70% shading, which from 90 DAP on presented increasing LAR until the end of the cycle (Figure 4A).

The increase in LAR in plants grown at 70% shading means that they increased the leaf area per unit dry leaf mass, possibly due to the lower liquid photosynthesis, and therefore presented lower accumulation of total biomass (Figure 2A). This shows that this condition of light restriction is harmful in the growth of yacon.

The leaves through photosynthesis are responsible for capturing light energy for the production of biomass, and the rest of the plant depends on the export of the photoassimilates of this biomass. Therefore, the increase in the fraction of dry mass not exported (RAF increases), means that there was a decrease in the export of photoassimilates to the other organs, which may limit the growth of the plant. Mainly from the reserve organs, the tuberous roots (Lima *et al.*, 2007) will reflect a drop in commercial production, which is the case of yacon.

The absolute growth rate (AGR) was higher in plants under 50 and 30% shading levels, reaching 6.5 g d^{-1} and 3.5 g d^{-1}, who occurred around 180 DAP (Figure 4B), which reflected the higher accumulations of total dry mass observed in these plants (Figure 2A).

This greater speed of growth with rate (AGR) of 6.457 g d^{-1} under 50% shading and 2.552 g d^{-1} under 30% shading, is due to the larger leaf area (greater interception of solar radiation). From 150 DAP to AGR, the plants exhibit negative values under 70% shade and full sun, which occurs due to the decrease of the total dry biomass of these plants, showing that these plants stop growing from that point on.

Relative growth rates (RGR) are highest at the beginning of the cycle, with maximum values at 30 DAP (0.05 g g^{-1} day^{-1}), and decreased along the plant ontogeny, a normal behavior and similar at all the treatments (Figure 4C). The main difference lies in the fact that plants grown under 50 and 30% shade present positive RGR throughout the cycle, demonstrating that these plants maintained their mass gain. While plants grown under 70% shade and full sun (0%) only maintained the positive RGR up to 150 DAP (Figure 4C), showing that from that date on, there was no relative mass increase, that is, there is no more net carbon assimilation, and the plant does not increase its carbon accumulation, as already discussed by Wright *et al.* (2004).

Plants grown under 70% shading show a decreasing liquid assimilation rate (NAR) throughout the cycle, until assuming negative values from 120 DAP (Figure 4D), indicating that photosynthetic activity has become less than respiratory. This shows that the largest leaf area observed (Figure

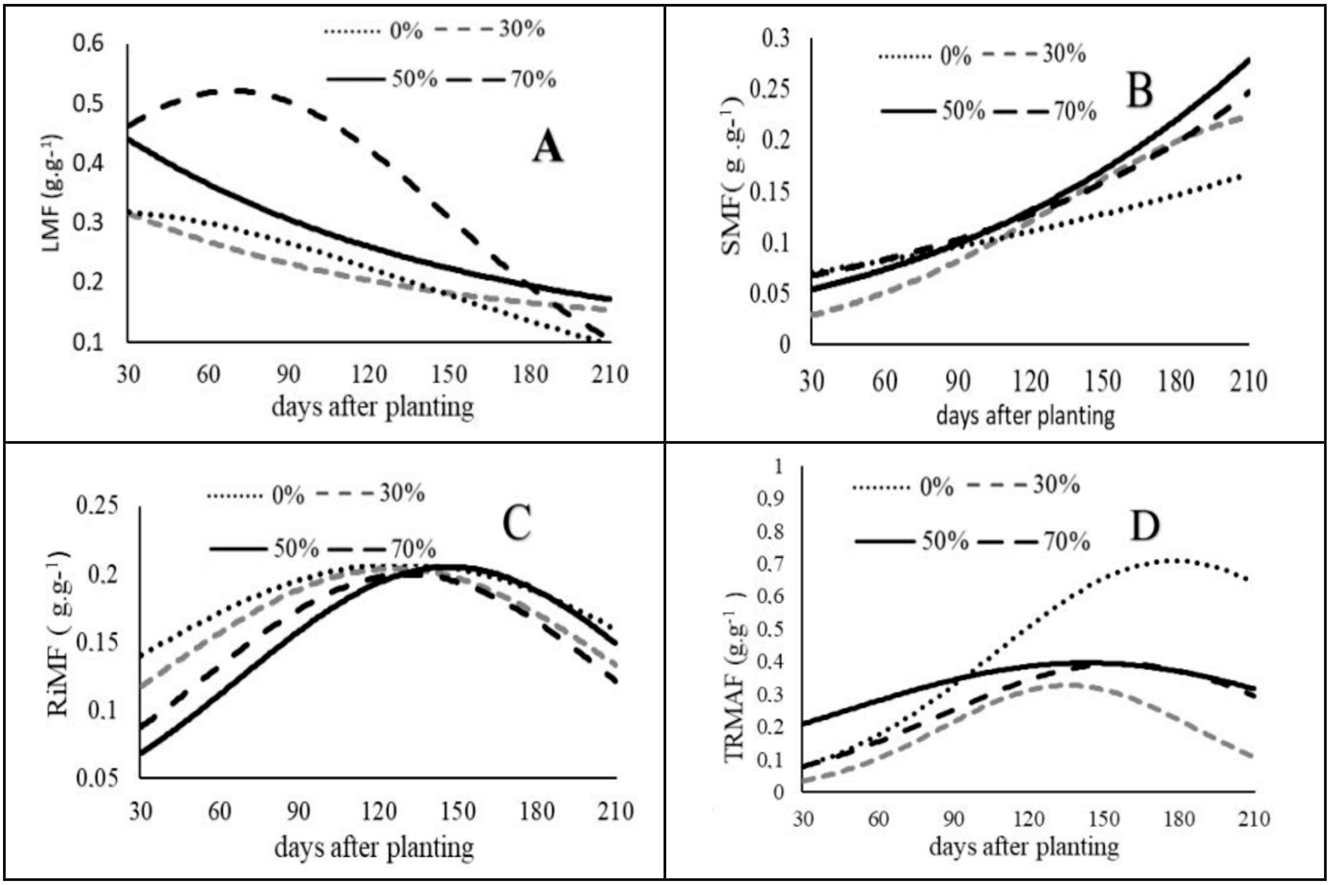

Figure 3. Leaf mass fraction (LMF), stem mass fraction (SMF), rhizophores dry mass fraction (RiMF) and tuberous roots mass fraction (TRMAF), along the yacon ontogeny in the four shading levels (0%, 30%, 50% and 70%). Alegre, UFES, 2015.

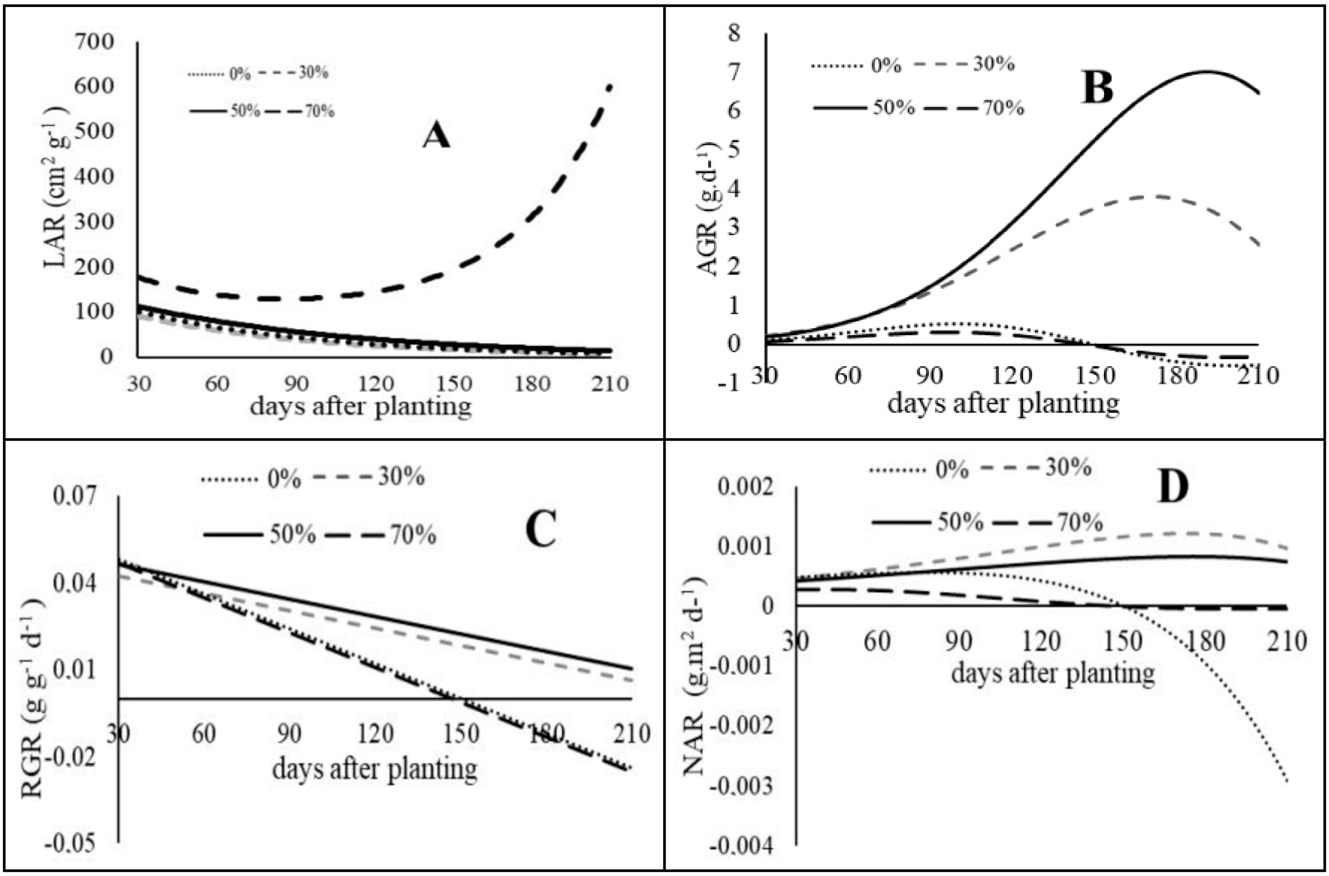

Figure 4. Leaf area ratio (LAR), absolute growth rate (AGR), relative growth rate (RGR) and net assimilation rate (NAR), along the yacon ontogeny in the four shading levels (0%, 30%, 50% and 70%). Alegre, UFES, 2015.

2B) is a response to the condition of light restriction that led the plants to produce thinner leaves with larger limbs, for better light interception. But that did not reflect in photosynthetic gains, demonstrating that the restriction of the light is harmful to the plant (Milla *et al*., 2008). Similar behavior was observed by Oliveira *et al*. (2011) with the culture of taro.

Plants grown in full sun (0%) can maintain the NAR almost constant until 90 DAP, when it starts decreasing up to 150 DAP, when the NAR assumed negative values, showing that from that moment on, the photosynthetic activity became less than the respiratory. However, in these plants the decrease is related to the leaf area loss (Figure 2B) and consequently will promote less mass accumulation in these plants.

However, plants grown under 50 and 30% shade show NAR, slightly increasing throughout the plant cycle (Figure 4D), indicating that there is carbon assimilation throughout the ontogeny (the photosynthetic activity is greater than the respiratory activity), which corroborates with the assertion that these two conditions create a favorable microclimate for yacon growth. Therefore, we can observe greater accumulations of total biomass in the plants (Figure 2A).

These results show that moderate shading levels, such as 30 to 50%, favor the activity of RuBPCase and ATPase in yacon, maintaining the photosynthesis activity of the leaves, thus having the highest NARs (Wang *et al.*, 2014). This response of yacon to moderate shading levels may be related to its environment of origin (Andes), which has high altitudes, and there is a cloudiness during most of the year (Seminário *et al.*, 2003), which could lead the plant to have a certain capacity to grow under smaller amount of incident radiation.

Yacon plants growing under moderate shading levels (30 to 50%) showed better growth rates, higher accumulations of total biomass, with investment in the tuberous roots fraction, which directly reflects gains in agronomic yields.

The results indicate that yacon culture has potential to be associated with other crops, which promote a moderate shading.

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