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Production and mass partitioning in Peruvian carrot plants grown under artificial shading period and intensity

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ABSTRACT. Due to its long production cycle, the Peruvian carrot has been cultivated on marginal land, resulting in low yields. Intercropping is an option for planting in better areas, but there is a lack of research on crop shade tolerance. This study aimed to evaluate the effect of period and intensity of artificial shading on mass partitioning and root yield on Peruvian carrot 'Amarela de Carandaí'. The treatments were four shading intensities (18, 30 and 50% of shading with Sombrite® cover and full sun), imposed either from 30 to 120, or from 30 to 210, or from 120 to 210 days after planting (DAP), totaling 10 treatments at harvest (210 DAP), with four repetitions. Light restriction above 18% from 30–210 DAP and from 120–210 DAP reduced marketable root yield. The marketable root yield was less reduced when shading was imposed earlier (30–120 DAP) than later (120-210 DAP) on the growth cycle. Regarding light competition, Peruvian carrot should be intercropped with crops that promoted up to 50% of shading from 30-120 DAP, or up to 18% of shading from 120 to 210 or 30-120 DAP.

Keywords: *Arracacia xanthorrhiza*, arracacha, intercropping, light effect.

RESUMO. Produção e partição de massa em plantas de mandioquinha-salsa cultivadas sob intensidades e períodos de sombreamento artificial. Devido ao longo ciclo de cultivo, agricultores que dispõem de área física limitada têm cultivado a mandioquinha-salsa em áreas marginais, resultando em baixa produtividade. A consorciação de culturas é uma opção para o plantio em áreas nobres, todavia há carência de pesquisa sobre a tolerância da mandioquinha-salsa ao sombreamento. Objetivou-se avaliar o efeito de intensidades e períodos de sombreamento artificial sobre a produção e o particionamento de massa em plantas de mandioquinha-salsa 'Amarela de Carandaí'. Os tratamentos foram constituídos de três intensidades de sombreamento (18, 30 e 50%), implementados com malhas Sombrite® em três períodos (30 a 120; 30 a 210 e de 120 a 210 dias após o plantio – DAP), mais o controle a pleno sol, totalizando, respectivamente, quatro tratamentos na colheita realizada aos 120 DAP e 10 tratamentos na colheita aos 210 DAP, com quatro repetições. Intensidades de sombra acima de 18% dos 30 aos 210 ou dos 120 aos 210 DAP prejudicaram a produção de raízes comerciáveis. Todas as intensidades de sombra no período inicial (30-120 DAP) não prejudicaram a produção de raízes comerciáveis na colheita aos 210 DAP. Considerando a restrição por luz, a mandioquinha-salsa pode ser cultivada consorciada com culturas que promovam sombreamento de até 50% dos 30 aos 120 DAP ou de até 18% dos 120 aos 210 ou dos 30 aos 210 DAP.

Palavras-chave: *Arracacia xanthorrhiza*, batata-baroa, consórcio, restrição de luz.

Introduction

Peruvian carrot (*Arracacia xanthorrhiza* Bancroft) is a tuberous vegetable of long cultivation cycle that occupies the land for a period of 10 to 12 months (CASALI, 1984; GRANATE et al., 2007; SANTOS, 1997; SANTOS; CARMO, 1998). In most cases, it is cultivated by producers with limited area, who are forced to implant the culture in marginal areas, usually soils with low fertility and high inclination, thus achieving low yields (CASALI, 1984; GIL LEBLANC et al., 2008). It is estimated that the area cultivated with Peruvian carrot in Brazil is 13,000 ha, with an average productivity of 9.2 t ha^{-1} (REGHIN et al., 2001). In spite of the high perishability of tuberous or storage roots (MENOLLI et al., 2008), the high prices achieved and the rusticity of the culture have encouraged their culture, mainly in the familiar agriculture system (GRANATE et al., 2007; HEREDIA ZÁRATE et al., 2007; SANTOS, 1997; SANTOS; CARMO, 1998; TOLENTINO JUNIOR et al., 2002; VIEIRA et al., 2003), due to the great involvement of manpower, especially at harvest (SANTOS; CARMO, 1998).

In situations of limited available areas, plant intercropping becomes an excellent alternative because it allows better soil exploration and an increase in production and income per unit of explored area and time unit (VANDERMEER, 1989). Due to the long cultivation cycle, the intercropping of Peruvian carrot with other plant species could be a solution for properties with area limitations, allowing its cultivation in better areas, an increment in culture yield and the diversification in production and income (HEREDIA ZÁRATE et al., 2007; TOLENTINO JÚNIOR et al., 2002; VIEIRA et al., 2003).

Some research works have been carried out on the intercropping of the Peruvian carrot and other vegetables of smaller size, such as lettuce (VIEIRA et al., 2003), lettuce and beet (TOLENTINO JÚNIOR et al., 2002) and carrot and coriander (HEREDIA ZÁRATE et al., 2007), with positive results in income for the intercropping of Peruvian carrot with lettuce (TOLENTINO JUNIOR et al., 2002; VIEIRA et al., 2003). However, although some producers cultivate Peruvian carrot in the row spacing of coffee plants (CASALI, 1984), its intercropping with coffee plants and other species of larger size lacks scientific information.

When establishing a plant intercropping system, it is very important to know the real light need or the tolerance cultures have to shading (VANDERMEER, 1989). Studies using some clones of Peruvian carrot demonstrated that the productivity of storage roots correlates directly and positively with the rate of CO_2 assimilation and the specific leaf area (JAIMEZ et al., 2008). In this context, studies on the use of artificial shading are desirable for a better evaluation of the effects of light by itself, since, without any other intercropped culture, other interferences such as competition for nutrients and water are not present.

Therefore, knowledge on the behavior of the Peruvian carrot culture as for light demand, as well as to the knowledge on the phenology of the cultures that will be associated with it, makes it easier to decide which cultures and periods would be more appropriate for intercropping implantation. Thus, the achievement of information that will help in the decisions related to the establishment of intercropping involving Peruvian carrots and other plant species has become a basic need.

The objective of the present work was to evaluate the effect of intensities and periods of artificial shading on the production and mass partitioning in the organs of the Peruvian carrot plant 'Amarela de Carandaí'.

Material and methods

The experiment was carried out in the Research Station of the Department of Plant Science, of the Universidade Federal de Viçosa, Viçosa, Minas Gerais State, from 5/15/2002 to 12/20/2002. The soil, Argissolo Vermelho Amarelo Câmbico (Ultisol), with mild topography, with approximately 1-2% of inclination, presented the following values in the chemical analysis (depth of 0-20 cm): pH in water (1:2.5) = 5.5; P = 89.3* and K = 162.0* mg dm^{-3}; Ca = 3.4**; Mg = 0.6**; Al = 0.0**; H + Al = 4.3***; SB = 4.2; CTC_t = 4.2 and CTC_T = 8.5 $cmol_c$ dm^{-3}; V = 49.0 and m = 0.0%. (*Mehlich 1 Extractor; ** KCl Extractor 1 mol L^{-1}; ***Calcium Acetate Extractor 0.5 mol L^{-1} pH 7.0). The soil was prepared with plowing and harrowing. Then, the planting furrows were made, with about 0.20 m of height, and spacing of 0.80 m.

Shoots from the clone 'Amarela de Carandaí' (BGH 5746) were used. They were achieved from the Vegetable Germplasm Bank of the Universidade Federal de Viçosa (BGH-UFV). The aerial and basal parts of the shoots were cut, maintaining 1.0 cm of the petiole, inclined cut at the base (simple bevel) and average length of 2.5 cm.

After the cuts were healed, the shoots were planted on the furrows, with a distance of 0.40 m between them, with enough depth to cover about 2.0 cm of the apex. No fertilization procedures were used because the fertility levels were fit for the culture. At 60 days after planting (DAP) one single cover nitrogen fertilization was performed, with ammonium sulfate, in the dose of 40 kg ha^{-1} of N, according to recommendations of Santos and Carmo (1998). Manual weeding and irrigation by infiltration were performed, when necessary. Pulverizations with pesticides were not necessary.

The treatments presented three shading intensities (18, 30 and 50%), implemented in three periods (30 to 120; 30 to 210 and 120 to 210 days after planting - DAP), and the control (control under full sun during all the cycle) (Table 1). The intensities of the shading were achieved with the use of Sombrite® covers, starting with 30 DAP when the plants were producing the second leaf, except for the control and shading of 120 to 210 DAP. Following this treatment, the covers were changed 120 DAP. Therefore, in the evaluation performed 120 DAP, there was a total of four treatments, while in the evaluation performed 210 DAP, there were 10 treatments (Table 1).

Table 1. Treatments of artificial shading intensities and periods used during the cultivation of the Peruvian carrot 'Amarela de Carandai'. UFV, Viçosa, Minas Gerais State, 2002.

Treatment	Intensity	Period (Days)		
		0-30	30-120	120-210
1 (control)	SUN	SUN	SUN	SUN
2	18%	SUN	18%	18%
3	30%	SUN	30%	30%
4	50%	SUN	50%	50%
5	18%	SUN	18%	SUN
6	30%	SUN	30%	SUN
7	50%	SUN	50%	SUN
8	18%	SUN	SUN	18%
9	30%	SUN	SUN	30%
10	50%	SUN	SUN	50%

A randomized experimental design was used, with four replications. The experimental unit presented eight rows with 2.8 m of length, each one with seven plants, totaling 56 plants and an area of 17.92 m². The four central lines were considered useful, while the 0.80 m in the extremities were excluded. The Sombrite® covers were stretched about 0.50 m above the canopy of the plants, and were fixed by extensors in the lateral areas. During cultivation, the covers were lifted as plants grew.

Two harvests were carried out at 120 and 210 DAP; for each evaluation, six plants per plot were harvested, corresponding to two rows inside the useful area of each plot. The plants were separated into blade (limb), petiole, shoot, crown, absorbent roots and storage roots. All the roots with a diameter larger than 1.0 mm were considered storage roots; among them, those with a diameter larger or equal to 15.0 mm in the thicker portion were considered marketable. The dry matter (DM) of each organ was obtained after drying with forced air ventilation at 60 ± 5°C, until the constant mass was achieved. The DM ratio of the aerial part (blade + petiole + shoot + crown)/subterranean part (storage roots + absorbent roots) and the harvest index (HI = DM of marketable roots / plant total DM) were calculated.

The data achieved in the evaluations carried out on 120 and 210 DAP were separately submitted to the variance analysis. The averages of the treatments were compared to the average of the control treatment (full sun) using the Dunnett test at 5% probability. The descriptive analysis was carried out through the percentage proportion of DM in each plant organ in the treatments.

Results and discussion

In the evaluation carried out at 120 DAP, the accumulation of DM in the plant organs, except for the petiole and absorbent roots, was significantly lower in plants under shading than under full sun (Table 2). These results demonstrate that the shading in the initial period of cultivation (30 at 120 DAP) influenced the growth of the plants, since they accumulated less DM in their organs and in the whole plant; additionally, although non-significant in number, plants under higher intensities of shading presented, proportionally, a higher DM accumulation in the aerial part (DMAP/DMSP ratio), evidencing that there was a higher investment in the aerial structures, in search for light capture, a typical response of sun plants to light restriction (LARCHER, 2000). These results are in accordance with those found by Jaimez et al. (2008), who achieved a linear and positive relation between the specific leaf area and CO_2 assimilation rate and the production of storage roots, while working with five cultivars of Peruvian carrot in two locations with different altitudes in Venezuela.

Table 2. Dry matter (g plant^{-1}) of blade, petiole, shoot, crown, storage roots (RR), marketable (MR) and absorbent (AR), total of the plant, dry matter of aerial part / subterranean part ratio (AP/SP) and harvest index (HI = DM of marketable roots / plant total DM) observed at 120 and 210 days after planting, in Peruvian carrot plants cultivated under intensities (levels) and periods (days) of artificial shading. UFV, Viçosa, Minas Gerais State, 2002.

Artificial shading		Aerial part			Roots				Plant	Ratio AP/	HI
Level (%)	Period (DAP)	Blade	Petiole	Shoot	Crown	RR	MR	AR	whole	SP	
					Evaluation 120 days after plantation						
Sun (Control)	-	162.4	66.7	38.2	17.0	24.3	-	3.4	312.0	10.3	-
18		64.9 *	33.5 ns	10.7 *	8.2 *	10.6 *	-	3.6 ns	131.5 *	8.3 ns	-
30	30-120	103.7 *	62.8 ns	13.3 *	10.9 *	10.1 *	-	3.3 ns	204.1*	14.2 ns	-
50		98.9 *	60.2 ns	15.0 *	10.4 *	7.9 *	-	3.3 ns	195.7 *	16.5 ns	-
					Evaluation 210 days after plantation						
Sun (Control)	-	197.7	746.0	344.0	76.0	255.7	233.35	8.8	1628.2	5.7	0.14
18	30-210	256.2 ns	748.7 ns	588.0 ns	81.0 ns	255.0 ns	230.5 ns	5.4 ns	1934.3 ns	6.4 ns	0.12
30		263.2 ns	550.7 ns	532.0 ns	47.0 ns	170.6 ns	109.6 ns	11.4 ns	1574.9 ns	7.7 ns	0.07*
50		299.0 ns	533.9 ns	362.0 ns	47.0 ns	50.4 *	28.3 *	10.2 ns	1302.5 ns	20.5 *	0.02*
18		236.7 ns	543.7 ns	455.0 ns	79.0 ns	320.0 ns	308.3 ns	10.0 ns	1644.4 ns	4.0 ns	0.18
30	30-120	328.7 ns	618.5 ns	568.0 ns	76.0 ns	256.8 ns	205.3 ns	11.5 ns	1859.5 ns	5.9 ns	0.11
50		237.7 ns	626.5 ns	524.0 ns	92.0 ns	353.4 ns	272.3 ns	15.3 ns	1848.9 ns	4.2 ns	0.15
18		249.2 ns	545.2 ns	458.0 ns	80.0 ns	296.2 ns	265.0 ns	7.8 ns	1636.4 ns	4.4 ns	0.16
30	120-210	235.2 ns	631.0 ns	436.0 ns	54.0 ns	136.8 *	98.2 ns	9.4 ns	1502.4 ns	9.3 ns	0.07*
50		204.4 ns	561.0 ns	335.0 ns	45.0 ns	58.7 *	42.4 *	8.8 ns	1212.9 ns	17.0*	0.03*

*; ns: in each evaluation, significant and non-significant, respectively, at the level of 5%, in relation to the control (full sun), by the Dunnett test.

However, the results found in the evaluation at 210 DAP were different from those achieved in the evaluation at 120 DAP, for the same shading period (30-120), in which no difference for the dry matter of the organs was detected between the treatments of shading and the control (Table 2). It demonstrates that, although the young plants (120 DAP) present growth restriction for several organs due to shading, when exposed to full light (sun) during the three following months, these plants recovered that decrease, accumulating, at 210 DAP, dry matter in similar quantities to those plants that developed under full sun during the whole cycle. Such recovery is also evidenced by the total plant dry matter and the balance of the DMAP/DMSP ratio, as well as by the harvest index, which, inclusively, presented a numeric value higher than that of the control for the treatment of 18% of light restriction.

The harmful effect of the restriction of light on the growth of Peruvian carrot plants depends on the stage in which the plant is submitted to the stress and the level of restriction of light applied. So, levels of light restriction of up to 50% applied in the initial stage (30-120 DAP), and of up to 18% during the whole cycle (30-210 days) or in the final stage (120-210 days) were not harmful to the culture in terms of production of marketable root mass and harvest index. However, levels of light restriction above 18% during the whole cycle (30-210 days) or in the final stage (120-210 days) were harmful to the formation of marketable roots, causing a lower harvest index (Table 2).

Although the dry matter of the whole plant at 210 DAP for all the treatments of intensities and periods of shading was not different from the results for the control (Table 2), accumulation rate of the DM in its parts (partitioning) varied among the treatments (Figure 1). Plants submitted to the shading intensity of 30% and, mainly, of 50% during the whole cycle (30-210) or in the final period (120-210 DAP), proportionally allocated a higher percentage of mass for the aerial part (especially blade) than for the subterranean part, mainly the storage roots. Consequently, in these periods and intensities of shading, the DMAP/DMSP ratio was higher and the harvest index was lower (Table 2).

Therefore, plants under a higher restriction during the whole cycle (30-210 DAP) or in the final period (120-210 DAP) produced photo assimilates in amounts only enough for their maintenance and the investment in aerial parts, providing a restricted quantity of assimilates to be allocated for the storage roots. This harmful effect was proportional to the intensity of the restriction of light (Table 2, Figure 1). Thus, it could be used an intercropping with other species that provides for the Peruvian carrot culture shading intensities of up to 18% during the whole cycle (30-210) or in the final period (120-210), or up to 50% in the initial period (30-120 DAP), because it would less harmful to the production of marketable storage roots.

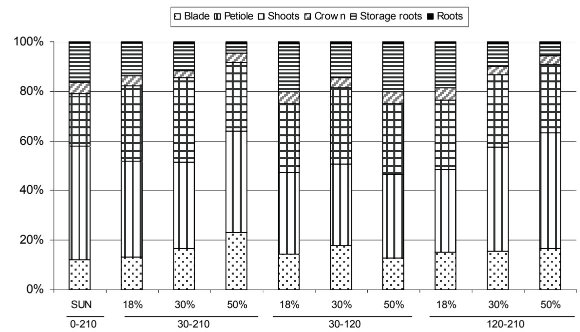

Figure 1. Partitioning of dry matter (in percentage) among the organs of the Peruvian carrot 'Amarela de Carandaí' plants cultivated under intensities and periods of artificial shading, 210 days after planting. UFV, Viçosa, Minas Gerais State, 2002.

Although LER (Land Equivalent Ratio) was higher than 1.0, a productivity decrease was observed for Peruvian carrot during the intercropping of Peruvian carrot with other vegetables of smaller size, such as lettuce (VIEIRA et al., 2003), lettuce and beet (TOLENTINO JÚNIOR et al., 2002) and carrot and coriander (HEREDIA ZÁRATE et al., 2007), but the results were positive for income for the intercropping of Peruvian carrot with lettuce (TOLENTINO JÚNIOR et al., 2002; VIEIRA et al., 2003). In cases like this, besides competition from other growth factors other than light (water, nutrients etc.) among plants of different cultures, there may have been a restriction of light for the Peruvian carrot plants in the initial stage of growth, since this species presents a slow initial growth when compared to other vegetables. Therefore, the harmful effect of the restriction of light, besides the level of restriction, depends on the stage in which the plant is submitted to the light restriction stress.

The plants in the treatments under restriction of light invested, proportionally, more mass in the aerial part (mainly blade and petiole), which suggests a morpho-adaptive response of the plant to the light environment. However, perhaps Peruvian carrot plants do not present more refined adaptive physiological mechanisms as to the restriction of available radiation, such as the diminishing of the respiratory standard and the light compensation point, usually observed in plants under shading, since in these treatments with higher restriction of light there was probably a restriction of assimilates for the storage roots. The low productivity of storage roots in some Peruvian carrot cultivars in Venezuela was also ascribed to the restriction of assimilates due to the rainy season, according to Jaimez et al. (2008).

The plants submitted to the highest level of light restriction during the whole cycle presented, proportionally, a great mass of aerial part (blade and petiole), but small production of storage roots (Figure 1 and Table 2). Therefore, a great leaf area is not enough, but it must be exposed to a level of radiation that allows to a higher liquid photosynthesis, according to observations by Jaimez et al. (2008) in Peruvian carrot cultivars in Venezuela, which demonstrates the significance of the leaf area and its efficiency in CO_2 assimilation.

The accumulation of dry matter in storage roots of the Peruvian carrot plant starts around the sixth month after planting (CÂMARA; CASALI, 1985); but, although already presenting marketable roots, they exhibit little mass until the seventh month (CÂMARA et al., 1985). In this work, although storage roots have already been observed at 120 DAP, their mass values were very low, below the commercial standard. Nevertheless, they presented a great increase of dry matter during the three following months, except for the treatments with restriction above 18% at 30-210 DAP and 120-210 DAP (Table 2), which proves that there had been restriction of assimilates for the storage roots in these treatments.

Although the culture was conducted until 210 DAP, it was evident that the negative effect of the light restriction on the production of storage roots is higher when implemented at 120 DAP, in comparison to the previous period (30 - 120 DAP). Somehow, these results are in accordance with Câmara and Casali (1985), who observed, in plants cultivated under full sun, that the restriction of the leaf area of these plants in the seventh month did not affect the following production of storage roots. However, since the plants had been cultivated under full sun, without light restriction, they could have stored reserves in the crown, as, in accordance with Gil Leblanc et al. (2008), the crown may play multiple roles, among which, it may work as a temporary drain, under certain circumstances.

Considering the population of 31,250 plants ha^{-1} and the accumulation of dry matter in the marketable roots of 0.233 kg plant^{-1} of the plants under full sun, the estimated production of marketable roots, in the seventh month was 7.3 t ha^{-1} of dry matter; in the treatments that received the shading of 50% at 30-210 DAP and 120-210 DAP, these were only 0.88 and 1.31 t ha^{-1}, respectively. Câmara et al. (1985) obtained marketable root production of 4.44 t ha^{-1}, in the eighth month, for the cultivation under full sun. Therefore, the production under full sun at 210 DAP was very satisfactory.

The production of roots of Peruvian carrot cultivars in two locations in Venezuela was higher where the Photon Flux Density from 8:30 to 10:30 a.m. was about 30% lower (JAIMEZ et al., 2008). Therefore, although being a sun plant, Peruvian carrot seems to benefit from the partial reduction of incident radiation as for the production of tuberous roots, maybe because it is a C_3 species, which means that it is subject to photorespiration when it is under high irradiance.

Therefore, in accordance with the results achieved, the shading at the level of up to 50% could be used in the initial stage of cultivation, which corresponds to up to 120 DAP, without the decrease of the production of marketable roots; similarly, shading of up to 18% during the whole cycle (30-210 DAP) or from the beginning of the formation of storage roots could also be used. Nevertheless, during the whole cycle or starting at 120 DAP, shading above 18% would not be recommended because it causes the decrease of the production of marketable storage roots. So, during the implementation of the intercropping system of Peruvian carrot with other larger species, the associated culture should not promote light restriction to the Peruvian carrot culture above 18% during the whole cycle or after 120 DAP.

Conclusion

Intensities of shading above 18% during the whole cultivation cycle (30-210 days after plantation - DAP) or starting from the beginning of the formation of tuberous roots (after 120 DAP) were harmful to the production of marketable storage roots of Peruvian carrot.

The production of marketable storage roots was not affected when light restriction occurred in the initial stage (30-120 DAP), regardless of shading intensity.

Considering only the light effect, the intercropping of the Peruvian carrot must be used with plant species that promote shading of the culture without exceeding the maximum intensity of 50% in the initial stage of cultivation (30-120 DAP) or up to 18% during the whole cycle (30-210 DAP) or in the final period (after 120 DAP), without causing significant reductions in the production of the marketable storage roots.

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