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Scientific Article

Dynamics and period of weed control in lettuce grown in an organic system

Dinâmica e período de controle de plantas daninhas em alface cultivada no sistema orgânico

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ABSTRACT - Growing lettuce in a shaded environment in the semi-arid region has become an alternative to creating an ideal microclimate for crop development. However, this microclimate also favors weed development. Therefore, the objective of this study was to evaluate the effect of the reduction in luminosity caused using shading screens on the critical period of interference prevention (CPIP) in organic lettuce cultivation. Two experiments were carried out in randomized blocks with three replications in a split-plot design. The first experiment was conducted under full light conditions and the second in a shaded environment with a 35% reduction in light intensity. Shading altered the dynamics of weeds, with *Digitaria horizontalis* Willd and *Amaranthus spinosus* L. having the highest density in crops without cover and shaded environments, respectively. The lack of weed control reduced lettuce productivity by 66 and 90% in uncovered and shaded systems, respectively. The CPIP of lettuce in an uncovered environment occurred 11–33 and 12–28 days after transplant (DAT) considering an acceptable production reduction of 2.5 and 5%, respectively. The shaded environment decreased the CPIP of lettuce to 8–19 and 9–18 DAT for acceptable production reductions of 2.5 and 5%, respectively. Therefore, growing organic lettuce in a shaded environment allows for a shorter control period.

Keywords: *Lactuca sativa* L. Competition. Protected environment.

RESUMO - O cultivo de alface em ambiente sombreado na região semiárida tem se tornado uma alternativa para criar um microclima ideal para o desenvolvimento da cultura. No entanto, esse microclima também favorece o desenvolvimento de plantas daninhas. Sendo assim, o objetivo desse estudo foi avaliar o efeito da redução da luminosidade provocada pelo uso de tela de sombreamento sobre o período crítico de prevenção à interferência (PCPI) no cultivo orgânico da alface. Dois experimentos foram realizados em blocos ao acaso com três repetições em esquema de parcela subdivididas. O primeiro experimento foi conduzido sob condição de luminosidade plena e o segundo em ambiente sombreado com redução de 35 % da intensidade luminosa. O sombreamento alterou a dinâmica das plantas daninhas, sendo que a *Digitaria horizontalis* Willd e a *Amaranthus spinosus* L. foram as espécies com maior densidade nos cultivos sem cobertura e ambiente sombreado, respectivamente. A ausência de controle das plantas daninhas reduziu em 66 e 90 % a produtividade da alface nos sistemas descobertos e com sombreamento, respectivamente. O PCPI da alface em ambiente descoberto foi do 11º ao 33º e 12º aos 28º dias após o transplante (DAT), considerando redução da produção aceitável de 2,5 e 5 %, respectivamente. O ambiente sombreado diminuiu o PCPI da alface para o 8º ao 19º e 9º ao 18º DAT para redução da produção aceitável de 2,5 e 5 %, respectivamente. Sendo assim, o cultivo da alface orgânica sob cultivo em ambiente sombreado permite diminuir o período de controle.

Palavras-chave: *Lactuca sativa* L. Competição. Ambiente sombreado.

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INTRODUCTION

Lettuce (*Lactuca sativa* L.) is a vegetable that is widely cultivated and consumed throughout the world. The estimated area and world production are approximately 1.22 million hectares and 26.78 million tons, respectively (FAO, 2016). In addition to its economic importance, the consumption of this vegetable provides benefits to human health, as it has nutritional and medicinal properties, providing fiber, minerals, and bioactive compounds, such as folate, β-carotene, lutein, and phenols (KIM et al., 2016).

Organic plant production has increased due to increased consumer interest in foods that are free from chemical fertilizers and pesticides (ZHU et al., 2017). In addition to quality, other premises of organic agriculture, such as the preservation of rural areas and more sustainable planting methods, aim to preserve natural resources and popularize environmental conservation (REGINALDO et al., 2021).

Among the challenges surrounding organic farming, the restriction on the use of chemical products for phytosanitary control makes it difficult to manage some insects and fungi. Another biotic factor that reduces productivity in organic crops is competition with weeds (FREITAS et al., 2021). Without the possibility of chemical control methods, it is necessary to determine the options for integrated weed management.

One way to reduce the number of weedings needed to avoid losses due to competition between weeds is to integrate other control methods (LINS et al., 2021). Practices that favor rapid crop growth to the detriment of weeds increase control success. The higher crop growth speed promotes canopy closure, reducing light intensity between crop lines and limiting weed growth (FREITAS SOUZA et al., 2021).

Cultural management can reduce the critical period for preventing interference (CPIP) in several crops. For example, localized nitrogen fertilization in cotton plants favored rapid crop growth in relation to weeds, reducing the CPIP, and consequently the number of weedings necessary to ensure a 95% productivity (TURSUN et al., 2015).

The use of shaded environments, with screens that block the passage of a portion of the solar radiation, has become increasingly common among leafy vegetable producers in Brazil. This technology allows producers to better manage environmental variables such as light, temperature, and evapotranspiration, providing an ideal environment for maximum crop development and increasing its competitive capacity (PEREIRA et al., 2011; DARYANTO; WANG; JACINTHE, 2017). Excessive solar radiation and high temperatures directly interfere with lettuce crop development. These conditions cause a reduction in the cycle, decreased production, changes in leaf texture, and induction of tasseling. These characteristics make the product unviable for commercialization (DIAMANTE et al., 2013; RICARDO et al., 2014).

Despite the short cycle, lettuce is short and does not provide any shade capable of making cultural control effective in the initial periods. However, management systems that reduce light intensity, such as the use of a shaded environment, in lettuce crops can have some level of cultural control since these conditions benefit crop development (COSTA JÚNIOR et al., 2019). Thus, we hypothesized that the use of a shaded environment in lettuce crops in an organic system could reduce CPIP and alter weed dynamics. Therefore, the objective of the work was to evaluate the effect of a shaded environment on CPIP and on the dynamics of weeds in organic lettuce crops.

MATERIAL AND METHODS

Field studies were carried out on an organic farm in the municipality of Governador Dix-Sept Rosado, state of Rio Grande do Norte, located at 5°18’48”S latitude and 37° 26’34”W longitude, from 05/06/2017 to 06/17/2017. The approximate altitude is 20 m, and the climate, according to Thornthwaite, is classified as DdAa’ (CARMO FILHO; ESPÍNOLA SOBRINHO; MAIA NETO, 1991). The areas used in this study had been in production in the organic system for more than eight years, and all cultural treatments were carried out in accordance with the production practices adopted by the property. The average meteorological data collected during the period in which the experiments were carried out are shown in Figure 1.

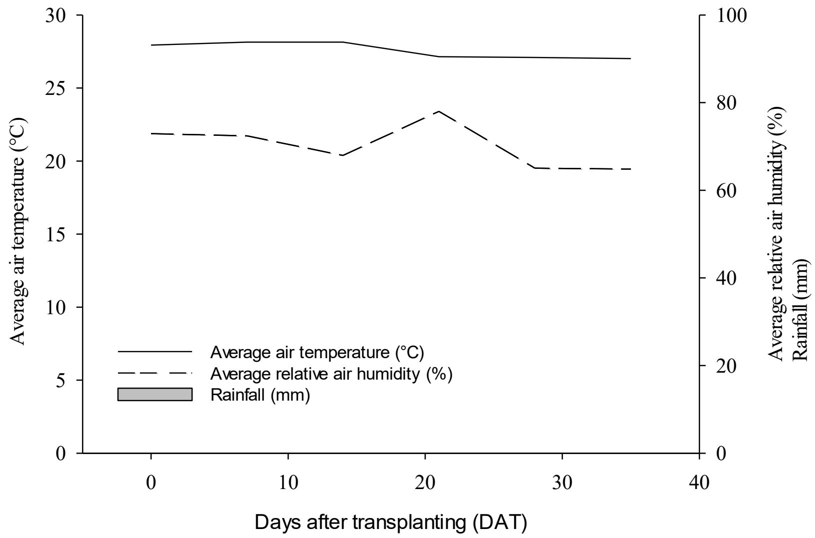

Figure 1. Average air temperature (ºC), average relative air humidity (%), and rainfall (mm) from 05/06/2017 to 06/17/2017. Source: INMET Automatic Meteorological Station, and rain gauge installed on the agricultural property.

The soil in the experimental area has a clayey loam texture, and its chemical composition is shown in Table 1. The beds were prepared using a rotary hoe, leveled, and fertilized with humus at a dose of 5 kg m^{-2}.

To obtain the seedlings, curly lettuce seeds (cv. ‘Elba’) were used. The seeds were planted in polystyrene trays filled with humus and manufactured on the rural property, placing approximately five seeds in each cell. The trays were stored in a greenhouse for 21 days. Thinning was carried out 9 days after planting (DAP), maintaining 1 seedling per cell. At 21 DAP, the seedlings were transplanted to the beds following a spacing of 0.30 × 0.30 m.

Table 1. Soil characterization regarding chemical attributes.

pH	P	K	Ca^{2+}	Mg^{2+}	SB	CEC	V	OM	N
H_2O	------- mg dm^{-3} -------		--------------------- cmol$_c$ dm^{-3} ---------------------				%	-------- g dm^{-3} -------	
8.0	47.23	1706.13	15.46	8.65	33.00	33.00	100	38.06	2.24

* pH: Hydrogen potential; P: Phosphorus; K: Potassium; Ca^{2+}: Calcium; Mg^{2+}: Magnesium; SB: Sum of Bases; CEC: Cation Exchange Capacity; V: Base Saturation; OM: Organic Matter; N: Nitrogen.

Two experiments were developed in a randomized block design with three replications. One was conducted under full light conditions and the other in a shaded environment, with a 35% reduction in light. The screen used was of the Monofilament Nylon type (Sombrite®) with UV ray blocks and was fixed to metal rods at a height of 2.5 m. The treatments were arranged in a split-plot scheme, with coexistence or control of weeds as plots, and the coexistence/control period of 0, 7, 14, 21, 28, and 35 days after transplant (DAT) as subplots. The experimental unit evaluated measured 1.73 m² and contained 26 plants. The useful area was composed of the central rows, totaling 15 plants.

The irrigation system used was a micro-sprinkler, with micro-sprinklers with a flow rate of 36 L h^{-1}, spaced 3 m apart, with two 30-min irrigation shifts totaling 14 mm, according to the management adopted by the producer. The subplots were weeded manually.

To determine solar irradiation and air temperature inside and outside the shaded environment, an infrared gas analyzer (IRGA, portable model LI-6400, LI-COR Biosciences®) was used. Data collection was performed between 9 am and 11 am following the manufacturer's instructions, with three measurements in each environment.

At the end of each coexistence period, the weeds present in the subplots were collected in sample areas of 0.25 m^2 and were counted and classified by species to determine the density and dry matter.

To determine the dry matter, the classified samples were placed in paper bags and dried in a forced circulation oven at 65°C until they reached a constant weight.

Lettuce plants were harvested, counted, and weighed at 35 DAT to measure production and estimate productivity. The average productivity data (kg ha^{-1}) of the treatments at different levels of control and coexistence with weeds were converted to relative productivity. The data were subjected to regression analysis using Equation 1:

$$y = \frac{A + (B - A)}{1 + \left(\frac{X}{C}\right)^{-D}} \quad (1)$$

where y represents relative productivity; X is the days after emergence; A, B, C, and D are parameters of the logistic equation, where A and B correspond to the minimum and maximum values; C is inflection point of 50% between the minimum and maximum values, and D is the slope of the curve at the inflection point (KNEZEVIC; DATTA, 2015). Losses of 2.5, 5.0, and 10% were established to determine the CPIP of the cultivars.

For regression analysis at 5% (0.05) and the construction of graphs of weed dry matter and periods of interference, SigmaPlot 12.0® software was used.

RESULTS AND DISCUSSION

The weed species that occurred in the area were: *Aeschynomene rudis* Benth (Angiquinho), *Alternanthera tenella* Colla (Apaga-fogo), *Amaranthus spinosus* L. (Caruru), *Amaranthus hybridus* L. (Caruru-roxo), *Cleome spinosa* Jacq. (Mussambê), *Commelina benghalensis* Linn. (Trapoeraba), *Cynodon dactylon* L. (Grama-seda), *Cyperus rotundus* L. (Tiririca), *Digitaria horizontalis* Willd (Capim-colchão), *Eleusine indica* (L.) Gaertn. (Capim-pé-de-galinha), *Ipomoea triloba* L. (Corda-de-viola), *Macroptilium lathyroides* L. (Feijão-de-rola), *Physalis angulata* L. (Juá-de-capote), *Phyllanthus niruri* L. (Quebra-pedra), *Portulaca oleracea* L. (Beldroega), *Senna obtusifolia* L. (Mata-pasto), *Sida cordifolia* Linn. (Malva-sida), *Sida rhombifolia* L. (Guanxuma), and *Trianthema portulacastrum* L. (Bredo).

Cultivation in a shaded environment altered the amount of accumulated dry matter and the weed species density (Figures 2A and 2B, Table 2). The dominant species in the system without cover were *Amaranthus spinosus* L., *Eleusine indica* L. Gaertn., *Commelina benghalensis* Linn., *Trianthema portulacastrum* L., and *Digitaria horizontalis* Willd., which had the greatest accumulation of dry matter and density. In the shaded environment, the presence of a smaller number of species was observed. *Amaranthus spinosus* L. had the greatest accumulation of dry matter and density, and *Alternanthera tenella* Colla and *Commelina benghalensis* Linn. were dominant.

Analyzing the occurrence of species in the environments studied, we found that, in the environment without coverage, plants with C4 photosynthetic metabolism (four species) were predominant, and the lowest incidence was found in plants with C3 metabolism (one species). Plants with C4 metabolism are not saturated by light, accumulating a greater amount of dry matter compared to C3 plants and becoming more competitive in environments with full light (TAIZ; ZEIGER, 2013). In conditions of reduced light, C3 species tended to be more competitive in relation to C4 plants. This effect was observed in the shaded environment because we did not verify the incidence of *Digitaria horizotalis* Willd and *Eleusine indica* L. Gaertn, a classic C4 species (MWENDWA et al., 2018).

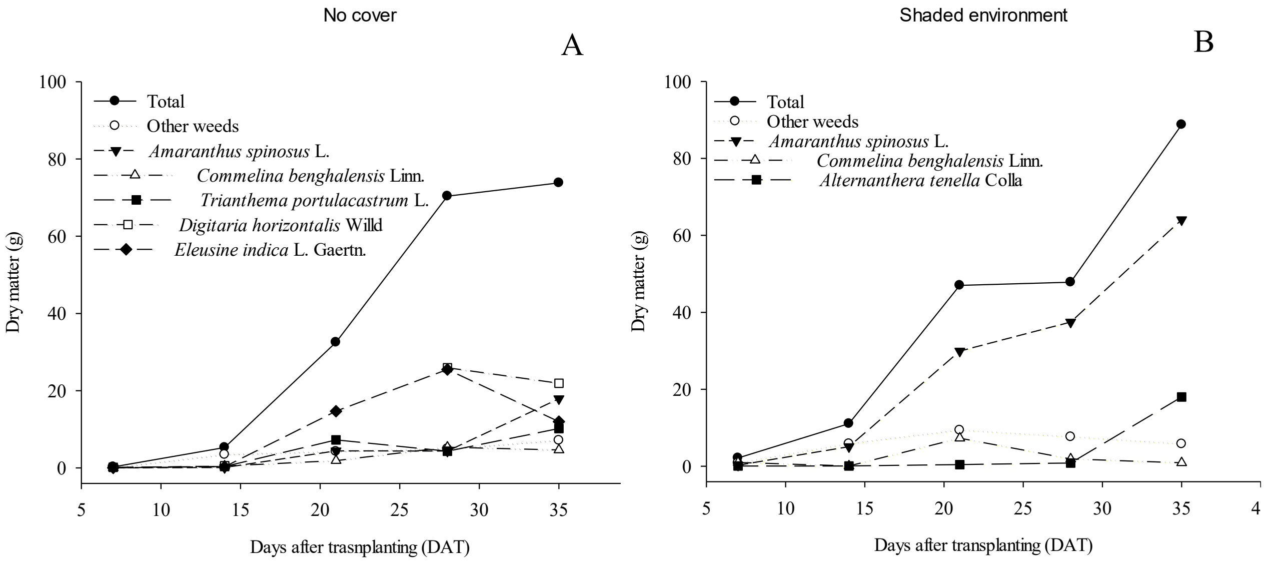

Figure 2. Dry matter of dominant weeds as a function of days after transplanting in organic lettuce cultivation without cover (A) and in a shaded environment (B).

Table 2. Average density of dominant weeds in the last collection of the experimental area.

Treatment	Weed	Photosynthetic system	Density (plants m^{-2})
No cover	*Digitaria horizontalis* Willd	C4	100
	Trianthema portulacastrum L.	C4	68
	Amaranthus spinosus L.	C4	60
	Eleusine indica L. Gaertn.	C4	32
	Commelina benghalensis Linn.	C3	12
	Other weeds	-	60
Shaded environment	*Amaranthus spinosus* L.	C4	180
	Commelina benghalensis Linn.	C3	8
	Alternanthera tenella Colla	C3-C4	4
	Other weeds	-	72

In the shaded environment, we identified the presence of C3, C4, and C3–C4 intermediate metabolism species. The species that best adapted to the environment was *Amaranthus spinosus* L. (Amaranthaceae), with the greatest accumulation of total dry matter (64.07 g) and density (180 plants m^{-2}), even though it is classified as a C4 species. Despite being the species with the lowest density, *Alternanthera tenella* Colla (Amaranthaceae) was the species with the second highest dry matter accumulation (Figure 2B, Table 2).

Studies have reported that some species belonging to the Amaranthaceae family, such as *Alternanthera tenella* Colla, have a transitional photosynthetic mechanism between C3 and C4, as they have a CO_2 compensation point and photosynthetic rate as a function of light intensity and intermediate between C3 species and C4 grasses (RAJENDRUDU; PRASAD; DAS, 1986; SÁNCHEZ-DEL PINO; MOTLEY; BORSCH, 2012). In addition, belonging to the same botanical family as *Alternanthera tenella* Colla and *Amaranthus spinosus* L., it has morphophysiological characteristics that favor light capture, such as the arrangement and inclination of the leaves and the height of the plant, making it more competitive compared to other species, favoring its predominance in the area (TSUTSUMI et al., 2017). Therefore, the lower light intensity in the covered environment favored better adaptation of *Amaranthus spinosus* L. and *Alternanthera tenella* Colla, which dominated this agrosystem.

The relative yield data followed a logistic trend with four parameters, and the proposed model was adequate since it presented a high r^2 value (Table 3). The absence of weed control reduced productivity by 65.66 and 90.12% in crops grown in full light and shaded environments, respectively (Figure 3). When transplanted, lettuce seedlings need time to adapt to the new environment and establish themselves in the area. Due to the microclimate generated by the reduction in light, it is likely that the use of the shading screen facilitated the germination of the seed bank and weed establishment, mainly *Amaranthus spinosus* L., which was the dominant species and was aggressive. These events were responsible for the drastic reduction in lettuce productivity in the plots where there was no control.

The shaded environment caused a positive effect on the crop, reducing the CPIP from 22.2 to 11.0, from 16.4 to 9.0, and from 9.2 to 6.6 DAT, considering a productivity reduction of 2.5, 5.0, and 10.0%, respectively. The reduction in light intensity promoted a similar effect in the period before interference, where it was reduced from 10.5 to 7.9, from 11.5 to 8.6, and from 12.7 to 9.7 DAT, considering a productivity reduction of 2.5, 5.0, and 10.0%, respectively (Figure 3, Table 4). The reduction in the period prior to interference is attributed to the microclimate created by the shaded environment, leaving the soil moist for a longer period of time, and to the soil rich in organic matter, providing perfect environmental conditions for the germination of the seed bank and growth of weeds (PEREIRA et al., 2011; DARYANTO; WANG; JACINTHE, 2017).

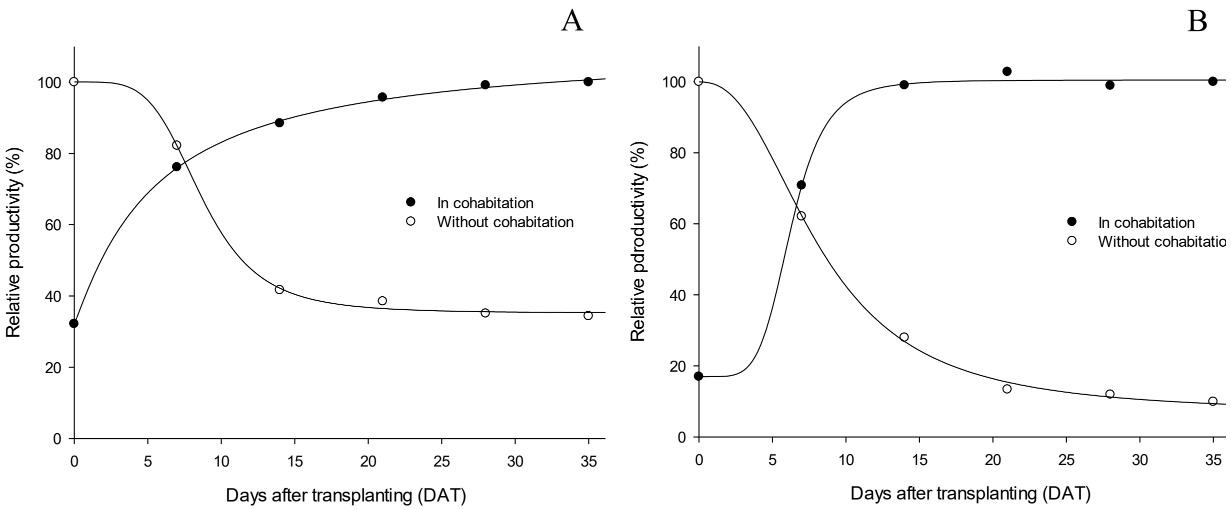

Figure 3. Relative productivity of organic lettuce as a function of days after transplanting at different levels of coexistence grown in full light (A) and in a shaded environment (B).

The shaded environment favored the development of lettuce crops due to the microclimate formed. Shading reduced the temperature by 2°C; consequently, the vapor pressure deficit (VPD) in this environment was lower compared to the system without cover. Under conditions of lower VPD, lettuce plants have a greater capacity for stomatal opening, favoring carbon accumulation (MARTÍNEZ-VILALTA et al., 2014; SINCLAIR et al., 2017). Another fact to consider is that the lower light incidence in the soil in the covered environment reduced the soil moisture loss through evaporation. Under these favorable conditions, lettuce plants are able to close their canopy faster than when grown under full light conditions, further limiting the amount of light reaching the soil, reducing the germination of the weed seed bank, and decreasing the period needed for weed control (CPIP) (PEREIRA et al., 2011; DARYANTO; WANG; JACINTHE, 2017).

Table 3. Regression parameter estimates by treatment for the four-parameter log-logistic model characterizing the influence of weed interference duration on relative yield for organic lettuce crops.

Treatment	Curve	Regression parameters				
		A	B	C	D	r²
No coverage	Without cohabitation	16.67	100.5	13.09	8.91	0.99
	In cohabitation	8.32	104.1	14.9	-4.1	0.99
Shaded environment	Without cohabitation	-367.82	107.87	2.12	1.39	0.99
	In cohabitation	35.52	100.16	15.83	-7.71	0.99

Light limitations altered the dynamics of weeds in the area. Plants, such as *Digitaria horizotalis* Willd and *Eleusine indica* L. Gaertn., which had rapid initial growth in the full sun environment, were not detected in the covered system (Figures 2A and 2B). The dominant species in this system was *Amaranthus spinosus* L., which has slow initial growth despite having C4 photosynthetic metabolism. As weeding was carried out, lettuce was able to grow and close the canopy in the rows and between crop rows, restricting the light incidence necessary for the growth of *Amaranthus spinosus* L. This effect was not observed in the system without a screen cover. In these areas, plants with a higher initial growth rate, such as *Digitaria horizotalis* Willd and *Eleusine indica* L. Gaertn., grew and accumulated dry matter even after the first weedings. Therefore, in the uncovered system, it is necessary to carry out control for a longer period compared to the shaded environment.

Table 4. Period prior to interference (PPI) and critical period of interference prevention (CPIP) for weed control in organic lettuce crops, in an uncovered environment and in a shaded environment, according to the acceptable reduction in productivity.

Management system	Reduced productivity (%)	Interference periods (Days)	
		PPI	CPIP
No cover	2.5	10.5	22.2
	5.0	11.5	16.4
	10.0	12.7	9.2
Shaded environment	2.5	7.9	11.0
	5.0	8.6	9.0
	10.0	9.7	6.6

The results of this work reveal that shading caused by the shaded environment modified the dynamics and period of weed control. Considering a 5.0% reduction in productivity, the period in which the crop must be kept free of weeds is from day 11 to day 28, totaling 17 days of management in the uncovered environment and from day 8 to day 18, totaling 10 days of weed management in the shaded environment. The shaded environment reduced the control period by 7 days, requiring two weedings, the first on day 7 and the second on day 14, while in the uncovered environment approximately three weedings were necessary, the first on day 10, the second on day 18, and the third on day 26.

CONCLUSIONS

Growing organic lettuce in a shaded environment, with a 35% reduction in light, alters the dynamics of weed species and reduces the control period, favoring crop development and productivity.

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REFERÊNCIAS

CARMO FILHO, F.; ESPÍNOLA SOBRINHO, J.; MAIA NETO, J. M. **Dados climatológicos de Mossoró: um município do semi-árido nordestino**. Mossoró, RN: ESAM, 1991. 121 p. (Coleção Mossoroense, 30).

COSTA JÚNIOR, C. O. et al. Shading on Yield and Quality of Lettuce Cultivars in Semiarid Conditions. **Journal of Agricultural Science**, 11: 162-171, 2019.

DARYANTO, S.; WANG, L.; JACINTHE, P. A. Impacts of no-tillage management on nitrate loss from corn, soybean and wheat cultivation: A meta-analysis. **Scientific Reports**, 7: 12117, 2017.

DIAMANTE, M. S. et al. Production and resistance to bolting of loose-leaf lettuce grown in different environments. **Ciência Agronômica**, 44: 133-140, 2013.

FAO – Food and Agriculture Organization of the United Nations 2016. **Production quantities of Lettuce**. Available at: <http://www.fao.org/faostat/en/#data/QC>. Access on: Jan. 26, 2018.

FREITAS, M. A. M. et al. Water deficit on growth and physiological indicators of *Bidens pilosa* L. and *Bidens subalternans* DC. **Revista Caatinga**, 34: 388-397, 2021.

FREITAS SOUZA, M. et al. Can irrigation systems alter the critical period for weed control in onion cropping? **Crop Protection**, 147: 105457, 2021.

KIM, M. J. et al. Nutritional value, bioactive compounds, and health benefits of lettuce (*Lactuca sativa* L.). **Journal of Food Composition and Analysis**, 49: 19-34, 2016.

KNEZEVIC, S. Z.; DATTA, A. The Critical Period for Weed Control: Revisiting Data Analysis. **Weed Science**, 63: 188-202, 2015.

LINS, H. A. et al. Economic evaluation and effectiveness of herbicides applied in pre-emergency in the sesame. **Revista Caatinga**, 34: 621-630, 2021.

MARTÍNEZ-VILALTA, J. et al. A new look at water transport regulation in plants. **New Phytologist**, 204: 105-115, 2014.

MWENDWA, J. M. et al. The weed suppressive ability of selected Australian grain crops; case studies from the Riverina region in New South Wales. **Crop Protection**, 103: 9-19, 2018.

PEREIRA, F. et al. Growth, assimilate partition and yield of melon charenthais under different shading screens. **Horticultura Brasileira**, 29: 91-97, 2011.

RAJENDRUDU, G.; PRASAD, J. S. R.; DAS, V. S. R. C3-C4 Intermediate Species in Alternanthera (Amaranthaceae) Leaf Anatomy, CO_2 Compensation Point, Net CO_2 Exchange, and Activities of Photosynthetic Enzymes. **Plant Physiology**, 80: 409, 1986.

REGINALDO, L. T. R. T. et al. Weed interference in carrot yield in two localized irrigation systems. **Revista Caatinga**, 34: 119-131, 2021.

RICARDO, A. D. S. et al. Telas de sombreamento no desempenho de cultivares de alface. **Nucleus**, 11: 433-442, 2014.

SÁNCHEZ-DEL PINO, I.; MOTLEY, T. J.; BORSCH, T. Molecular phylogenetics of Alternanthera (Gomphrenoideae, Amaranthaceae): resolving a complex taxonomic history caused by different interpretations of morphological characters in a lineage with C4 and C3–C4 intermediate species. **Botanical Journal of the Linnean Society**, 169: 493 -517, 2012.

SINCLAIR, T. R. et al. Limited-transpiration response to high vapor pressure deficit in crop species. **Plant Science**, 260: 109-118, 2017.

TAIZ, L.; ZEIGER, E. **Fisiologia e desenvolvimento vegetal**. 5. ed. Porto Alegre, RS: Artmed, 2013. 954 p.

TSUTSUMI, N. et al. Variations in structural, biochemical, and physiological traits of photosynthesis and resource use efficiency in Amaranthus species (NAD-ME-type C4). **Plant Production Science**, 20: 300-312, 2017.

TURSUN, N. et al. Nitrogen application influenced the critical period for weed control in cotton. **Crop Protection**, 74: 85-91, 2015.

ZHU, B. et al. Does organically produced lettuce harbor higher abundance of antibiotic resistance genes than conventionally produced? **Environment International**, 98:152-159, 2017.