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PRODUCTIVITY UNDER SHADE AND DIFFERENT NUTRIENT SOLUTION OF HYDROPONIC WATERCRESS (*NASTURTIUM OFFICINALE* R. BR.)

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□ *Commercialization of watercress in the Sierra Norte mountain range in Oaxaca, Mexico principally relies on harvesting plants growing on riverbanks; however, semi-intensive cultivation throughout the year could be established as an alternative for the region. With this as an objective, the present study was carried out using the laminar flow of nutrients technique to evaluate four solutions of different macronutrients and four shade percentages. Treatment distribution was formulated according to a bifactorial arrangement. Four harvest periods were employed, in April, June, September, and November of 2010. Yields and vegetative growth of watercress decreased linearly with increasing shade levels. The best results were obtained with a nutrient solution using an electrical conductivity (EC) of 0.90 dS m^{-1}. Shade cloth percentages higher than 10% caused a significant decrease in total cycle production; the use of shade cloth is not recommended during seasons with low incident radiation.*

Keywords: watercress, *Nasturtium officinale*, hydroponics, recirculating nutrient solution, shade netting, photosynthetically active radiation

INTRODUCTION

Watercress (*Nasturtium officinale* R. Br.) is a perennial aquatic plant native to Europe that belongs to the Brassicaceae family (Gonçalves et al., 2009), and a crop of global economic importance, valuable both as a food product and for medicinal purposes. Its leaves and stems contain vitamins A and C, and minerals such as iron, calcium, zinc, iodine (De Chávez et al.,

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1992; Palaniswamy et al., 2003; Hedges and Lister, 2005), as well as arginine, glycine, lysine, tryptophan, and antioxidants (Palaniswamy and McAvoy, 2001; Engelen-Eigles et al., 2006). Consumption of watercress ameliorates problems such as rheumatoid arthritis, multiple sclerosis, and cancer (De Chavéz et al., 1992; Hedges and Lister, 2005; Cruz et al., 2006). It also helps maintain normal liver functions (Ebadollahi-Natanzi et al., 2010).

In the Sierra Norte mountain range in Oaxaca, Mexico, watercress is not cultivated, but rather grows wild in clean-water streams. The indigenous Zapotec inhabitants of the region harvest it both for their own consumption and for sale in the regional market. Watercress sales provide a permanent economic income to the people of this region. The Sierra Norte has a cold, temperate climate; however, in recent years, solar radiation, temperature, and water scarcity have been higher in the months from March to June. This has had negative repercussions on the growth and quality of watercress plants in the region, and even to their extinction in some areas. The price of watercress during these months triples in the regional market, and as such, it must be brought from State of Mexico, where crops are watered with poor-quality water, putting the health of consumers at risk due to possible contamination with *Fasciola hepatica* (Sena-Bernabé et al., 2010; Díaz-Fernández et al., 2011).

In its cultivated form, watercress is a plant that requires large amounts of water or moisture and low levels of solar radiation; it adapts well to temperate and cold climates (Maroto, 2002; Guiberteau, 1990); and is cultivated under different soilless culture systems (Carrasco et al., 2011).

Global radiation is an important factor in watercress cultivation. The implementation of shade cloths as a technique for controlling temperature is growing more and more prevalent in protected horticulture, as, in addition to reducing the intensity of solar radiation, they also prevent high temperatures during the dry period (Valera et al., 2001). In the other hand, some crops can be grown successfully under lightly shaded conditions and still receive enough radiant energy for maximum photosynthesis and yield (Wolff and Coltman, 1989; Ayala-Tafoya et al., 2011).

The objective of the present study was to evaluate different nutrient solutions and the use of shade cloth at different percentages in the recirculating hydroponic cultivation of watercress.

MATERIALS AND METHODS

Experimentation was carried out in the locality of La Nevería in the Municipality of Santa Catarina Lachato, Ixtlán District, in the Sierra Norte mountain range of Oaxaca State, Mexico (17°07′N, 96°14′ W) at 2700 m above sea level. The climate of the region is humid temperate, with an average temperature in the coldest month ranging between -3 and 18ºC.

TABLE 1 Evaluated nutrient solutions (mmol L^{-1}) and averages of their physiochemical parameters during cultivation of watercress in a recirculating hydroponic system

Nutrient solution	NO_3^-	$H_2PO_4^-$	SO_4^{2-}	NH_4^+	Ca^{2+}	Mg^{2+}	K^+	pH	EC (dS m^{-1})
A	12.50	2.00	1.75	1.25	5.00	1.80	5.00	6.36	1.20
B	8.50	1.35	1.18	0.85	3.40	1.20	3.40	6.23	0.90
C	6.50	1.00	0.90	0.65	2.50	0.90	2.50	6.74	0.59
D	0.23	0.00	0.46	0.00	4.71	2.17	0.01	7.01	0.71

Wooden beds, 8 m x 30 cm with a depth of 15 cm, were used. The containers were placed on 1 m high wooden posts at a 2% slope; the interior of the containers was covered with black polypropylene, with a thickness of 125 micrometers. River gravel, 0.5 cm in diameter, was placed at the bottom of each trough to support the watercress plants.

Four nutrient solutions and four levels of shade were evaluated. The nutrient solutions were based on different concentrations of macronutrients (Table 1); the control was water from the locality. Commercial fertilizers were used in the preparation of the solutions, based on Sonneveld and Straver (1994). For the shade variable, black polyethyline shade cloth at 10%, 50%, and 70% solar transmissivity was used, in addition to a control (no shade cloth). The relevant shade cloth was attached to the wooden structure for each experimental unit, according to randomization within the containers. The experimental area covered by each cloth was 2.0 m long, and covered the width of the trough. Photosynthetically active radiation (μmol m^{-2} s^{-1}) was measured monthly with a quantum sensor LI-191SA (LI-COR, Inc., Lincoln, Nebraska, USA) placed in a shade-free area one meter above ground level. The sensor was connected to a Data Logger LI-1400 (LI-COR, Inc.) that stored averages every 15 minutes, from 09:00 to 16:00. A second linear quantum sensor LI-191SA (LI-COR, Inc.) connected to the same data logger measured photosynthetically active radiation, alternating between the different treatments, from 12:00 to 14:00 (Ayala-Tafoya et al., 2011), because the shade cloth was parallel to the containers when the sun was at its zenith. Eight readings were taken per treatment; average values, as well as standard deviation, were calculated.

A bifactorial treatment design was utilized, with three nutrient solutions plus unfertilized, local water as a control, and three shade percentages, plus the non-shaded control; 16 treatments were generated. The nutrient solution was applied to the containers; each bed was randomly distributed, independent of the three shade percentages and the control. Two containers were installed for each treatment, 3 m apart; the distance between experimental units was 1.5 m. All units were oriented along the north-south axis.

Intermittent recirculation of the nutrient solution was implemented according to Urrestarazu and García (2000); it consisted of the use of buried tanks with submergible electropumps (one per containers). Electric conductivity (EC) and pH were measured every time a nutrient solution was prepared and introduced into the system; this was carried out with a Hanna H199 1300 potentiometer (Hanna Instruments Co. Ltd., Woonsocket, RI, USA).

Cuttings measuring 2 to 3 cm in height, taken from watercress plants from a stream in the locality, were planted in February of 2010 with a planting frame of 10 × 20 cm. A uniformity cut at 2.5 cm in height was applied one month after planting for subsequent evaluation.

Harvesting was performed in April, June, September, and November of the same year, when the majority of the plants had reached 20 cm in height. Samples were taken from each experimental parcel, defined as a quadrant with an average of 75 plants. Ten plants were selected randomly from each quadrant; measurements were taken for plant height (from the base to the highest foliage), and stem diameter (at the cut). Fresh weight and dry weight were quantified per plant; for the latter measurement, plants were dried in an oven at 70°C for 72 hours.

Statistical analysis was carried out according to Steel and Torrie (1985) and Restrepo (2007). According to the statistical analysis, there was no interaction between factors, and the effects of the shade factor were nested within the nutrient solution factor. Range separation of means was carried out according to the linear model suggested by Steel and Torrie (1985) and Martínez (1996).

Statistical analysis of the shade and nutrient solution factors was performed separately in each harvesting period (April, June, September, and November). When significant differences were obtained between factor levels, Tukey's range test was applied ($P \leq 0.05$). All analysis was performed by SAS statistical program (SAS Institute, Cary, NC, USA).

RESULTS AND DISCUSSION

In 2010, an average annual temperature of 18ºC and an average annual precipitation of 786.7 mm were recorded in La Nevería in the Municipality of Santa Catarina Lachatao, Ixtlán de Juárez, Oaxaca, Mexico (Figure 1). Smith (2007) mentions that watercress reaches its highest yield when diurnal temperatures range between 20°C and 25°C, and nocturnal temperatures fall between 15°C and 20°C, although it may grow successfully even at 28°C. In the present study, the best harvests were obtained in the harvest periods of June and September (Table 2), with maximum temperatures coinciding with the range mentioned by Smith (2007) (23°C to 25°C). Minimum temperatures did not fall in this range, as they averaged 12°C. Production was lower when the maximum temperature exceeded 25°C, and the minimum fell to 10°C, production was lower.

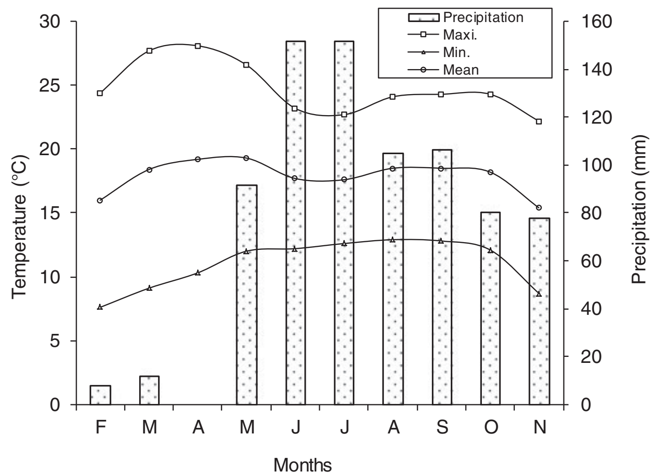

FIGURE 1 Distribution of temperature and precipitation during 2008 in La Nevería, Santa Catarina Lachatao Municipality, Ixtlán de Juárez, Oaxaca, Mexico.

Smith (2007) indicates that 10°C is the minimum temperature required to maintain a commercial system; in this regard, the results of the present study corroborate his statement, as the lowest temperatures from May to October were higher than 10°C (Figure 1). There is some evidence that

TABLE 2 Effects of the nutrient solutions on different growth parameter and yield in watercress plants in a recirculating hydroponic system during four harvesting periods

Nutrient solution	April	June	September	November	Total
			Plant height (cm)		
A	14.8 b	42.1 a	25.0 b	21.6 a	25.9 a
B	25.9 a	28.6 b	27.5 a	14.4 b	24.1 b
C	14.3 b	30.7 b	26.4 abc	7.4 c	19.7 c
D	3.8 c	—	6.9d	—	5.4 d
			Stem diameter (cm)		
A	0.40 a	0.80 a	0.70 a	0.60 a	0.63 a
B	0.40 a	0.90 a	0.50 a	0.55 a	0.58 a
C	0.30 a	0.45 b	0.70 a	0.35 b	0.45 b
D	0.20 b	—	0.39 b	—	0.30 c
			Fresh weight (g plant^{-1})		
A	1.13 a	6.29 a	2.89 c	2.62 a	12.93 a
B	1.43 a	6.13 a	4.37 a	1.64 b	13.57 a
C	1.23 a	3.66 b	3.54 b	0.72 c	9.15 b
D	0.18 b	—	0.87 d	—	1.05 c
			Dry weight (g plant^{-1})		
A	0.08 a	0.22 b	0.13 c	0.14 a	0.57 b
B	0.09 a	0.32 a	0.22 a	0.10 b	0.73 a
C	0.10 a	0.08 c	0.16 b	0.05 c	0.39 c
D	0.03 b	—	0.04 d	—	0.07 d

Different letters indicate significant differences at 95% according to Tukey's test. — indicates no value.

watercress cultivated in diurnal temperatures between 10°C and 25°C accumulates higher levels of the anticarcinogenic agents 2 -phen(yl)ethyl-Isothiocyanate (PEITC) and gluconasturtiin (Palaniswamy et al., 1997; Engelen-Eigles et al., 2006). This would further justify intensive hydroponic cultivation of watercress, as temperatures primarily fall into this range in the region of study. Furthermore, such cultivation would yield a clean product with no risk of *Fasciola hepatica*, in contrast with watercress obtained through traditional harvesting on the banks of streams (Sena-Bernabé et al., 2010; Díaz-Fernández et al., 2011).

Effects of the Nutrient Solutions

The nutrient solutions A, B, and C had a significant effect ($P \leq 0.05$) on all growth variables in watercress plants for each of the four harvesting periods in comparison with the control (D) (Table 3). In April, the greatest value for plant height (25.9 cm) was obtained with nutrient solution B. No differences were found for stem diameter, fresh weight, and dry weight between solutions A, B, and C, although they did differ from the results obtained with the control solution (D). It is worth mentioning that during the month of April, no rain occurred, and the minimum and maximum average temperatures were 10°C and 28°C, respectively (Figure 1). In June, with intense rains and an average monthly minimum and maximum temperature of 12°C and 23°C, respectively (Figure 1), the greatest watercress plant height (42.1 cm) was obtained with solution A. Although no significant differences were found between the other variables, the highest average values were found in June for all evaluated variables with respect to the other

TABLE 3 Average monthly photosynthetically active radiation recorded from 12:00 to 14:00 under different levels of shade cloth placed over the watercress crop

	Shade cloth			
	0%	10%	50%	70%
January	1018.5 ± 45.1	929.1 ± 38.4	573.1 ± 60.4	268.9 ± 55.8
February	1087.0 ± 71.0	991.6 ± 65.6	637.4 ± 76.6	287.0 ± 87.0
March	1193.9 ± 86.8	1089.1 ± 90.9	706.8 ± 120.7	315.2 ± 112.2
April	1003.2 ± 68.4	915.1 ± 98.2	663.4 ± 56.4	264.8 ± 70.2
May	1088.6 ± 32.9	993.0 ± 65.2	585.0 ± 91.4	287.4 ± 99.1
June	990.1 ± 58.4	903.2 ± 53.4	529.7 ± 47.3	107.3 ± 54.5
July	257.5 ± 48.3	234.9 ± 24.5	137.8 ± 51.5	106.7 ± 41.6
August	301.8 ± 100.0	275.3 ± 81.8	286.0 ± 14.7	79.7 ± 43.9
September	84.2 ± 61.8	259.2 ± 31.4	152.0 ± 21.6	65.0 ± 18.8
October	1171.8 ± 118.5	968.9 ± 117.6	538.2 ± 134.3	209.4 ± 117.1
November	1108.6 ± 42.6	1011.3 ± 32.1	578.1 ± 63.9	292.7 ± 65.0
December	1029.7 ± 33.2	939.3 ± 31.6	528.3 ± 72.9	271.8 ± 68.0

Means and standard deviation of eight readings per treatment.

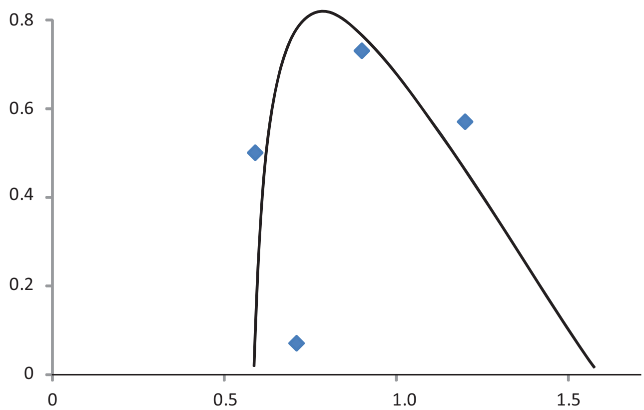

FIGURE 2 Mean yield (dry weight, g plant^{-1}) versus EC (dS m^{-1}) of nutrient solution of watercress crop, model according to Sonneveld et al. (2005).

three harvesting periods. Width and size of stems and leaves are highly important in achieving maximum market value for the product. Urrestarazu and García (2000) indicate that in closed systems, a high concentration of elements in the nutrient solution can seriously affect certain plant organs, often increasing stem thickness and decreasing plant height. In September, as pluvial precipitation decreased and environmental temperature increased slightly (18°C), solution B yielded the greatest values for all studied variables; this also occurred in April. This confirms that watercress is highly sensitive to salinity, so a closed correlation to salinity model reported in relation to EC model of nutrient solution by Sonneveld et al. (2005) was used (Figure 2).

In November, with the lowest levels of pluvial precipitation and temperatures (9°C to 23°C), in general, the highest values for all evaluated variables were obtained with solution A in comparison with other treatments. The control nutrient solution (local water) consistently yielded the worst results. In general, considering the total crop cycle values, these tendencies did not vary in any of the four harvesting periods.

There is a slight difference (approximately 20%) between EC (0.71 dS m^{-1}) of the control treatment D and the EC of solution B (0.90 dS m^{-1}), but this difference in salinity led to an almost 90% decrease in the growth and production parameters. This significant difference is due to an imbalance in macronutrient equilibrium. Similar results were found by Urrestarazu et al. (2013) in aromatic plants; although EC in their trial was equal, macronutrients were imbalanced, producing a clear reduction in yield. The relationship between nutrient solution EC and production parameters in the present study fits the theoretical model proposed by Sonneveld et al. (2005).

Effects of the Shade Cloth

Table 4 shows the reduction in radiation due to the implementation of shade cloths in the central hours of the day. This decreased radiation occurred as a function of the degree of shade that each cloth provided, coinciding approximately with the percentage of shade that is commercially indicated by the manufacturer.

The use of shade cloth had a significant effect ($P < 0.05$) on all growth variables (Table 4). The 10% shade treatment yielded the best results in the June harvest in terms of dry weight and plant height. In September, the plants covered at 10% by the shade cloth yielded the greatest production, whereas the plants under the cloths at 50% and 70% in general produced the worst results. Plants covered with shade cloth at 70% consistently presented lower values in all evaluated variables, for all four harvesting periods. Production in the November harvest, as well as in the total crop cycle, was most successful with the no shade cloth treatment.

Irradiance below 900 μmol m^{-2} s^{-1}. In the dry season resulted in a loss of production. Smith (2007) reports that watercress plants can tolerate a wide range of light conditions, from partial shade to full sun; and a clear correlation between luminosity and production. This may explain why the non-shaded treatment in November (and in the total cycle) displayed superior production. A significant correlation was found in the present study

TABLE 4 Effects of the shade cloth variable on watercress growth during four harvesting periods.

Percent shade (%)	April	June	September	November	Total
			Plant height (cm)		
0	9.51 c	29.86 a	20.35 b	15.21 a	18.73 a
10	15.09 a	26.27 b	23.12 a	13.01 b	19.37 b
50	14.99 a	24.27 c	21.37*ab*	8.55 c	17.29 c
70	13.31 b	20.47 d	20.92 b	6.61 d	15.33 d
			Stem diameter (cm)		
0	0.40 a	0.80 a	0.70 a	0.60 a	0.68 a
10	0.40 a	0.90 a	0.50 a	0.55 a	0.63 b
50	0.30 a	0.45 b	0.70 a	0.35 b	0.60 b
70	0.20 b	—	0.39 b	—	0.30 c
			Fresh weight (g plant^{-1})		
0	1.13 a	6.29 a	2.89 c	2.62 a	11.24 a
10	1.43 a	6.13 a	4.37 a	1.64 b	10.32 b
50	1.23 a	3.66 b	3.54 b	0.72 c	7.83 c
70	0.18 b	—	0.87 d	—	1.05 d
			Dry weight (g plant^{-1})		
0	0.08 a	0.22 b	0.13 c	0.14 a	0.50 a
10	0.09 a	0.32 a	0.22 a	0.10 b	0.51 a
50	0.10 a	0.08 c	0.16 b	0.05 c	0.37 b
70	0.03 b	—	0.04 d	—	0.07 c

Different letters indicate significant differences at 95% according to Turkey's test. — indicates not valuable

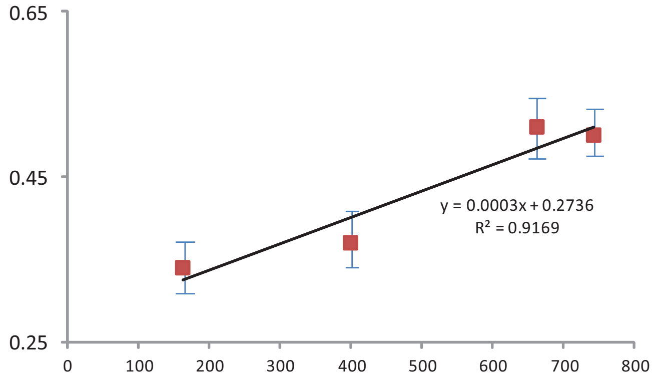

FIGURE 3 Mean yield (dry weight, g plant^{-1}) versus incident photosynthetically active radiation (μmol m^{-2} s^{-1}) during watercress crop cycle.

between received radiation and production (Figure 3). As such, shade cloth has not been clearly shown to be beneficial in these radiation and cultivation conditions.

CONCLUSION

With climatology similar to that of the Sierra Norte mountains of Oaxaca, Mexico, hydroponic cultivation and production of watercress under an intensive recirculating system, utilizing a balanced nutrient solution at EC of 0.9 dS m^{-1}, is feasible. During the hot, dry months, it is advisable to cover the crop with shade cloth at 10%; but during rainy months, it is recommended not to use shade cloth.

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