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Effects of hydrogel and nitrogen fertilization on the production of arugula in successive crops

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Appropriate management techniques, such as fertilization programs and the use of technology in the production process, have been employed to meet the demand for vegetables year-round. Because vegetables require a considerable amount of water for their development, hydrogels can guarantee the supply of water in regions with water deficits. The aim of this study was to evaluate the use of hydrogel and nitrogen fertilizer on the development and productivity of arugula cv. Cultivada in two successive crops. The experiment was conducted at the State University of Mato Grosso do Sul (Universidade Estadual de Mato Grosso do Sul – UEMS), Aquidauana University Unit, in the state of Mato Grosso do Sul, Brazil, from April to July 2011. The experimental design consisted of randomized blocks with a 2×5×2 factorial scheme, with and without application of hydrogel (polymer), five different doses of nitrogen (0, 60, 120, 180 and 240 kg ha^{-1}) and two successive crops of arugula, with four replications. The gel was applied to the first crop, and the residual effect on the second crop was evaluated. The results show that the hydrogel had no effect on the fresh and dry mass of arugula, regardless of the cultivation period. The use of the N fertilizer significantly affects the development of arugula, as evidenced by a linear increase in the shoot dry mass, number of leaves and leaf area. The application of N influenced the components of production and productivity of arugula.

Key words: *Eruca sativa* Miller, brassica, hydrogel, nitrogen.

INTRODUCTION

The arugula is a herbaceous leafy vegetable belonging to the family Brassicaceae, a large family with more than three thousand species. Its name comes from the Italian "ruccola", and its center of origin is the Mediterranean region in southern Europe and western Asia. The crop has a short growth cycle of between 30 and 40 days and prefers mild temperatures for vegetative development, but it has been cultivated in various regions throughout

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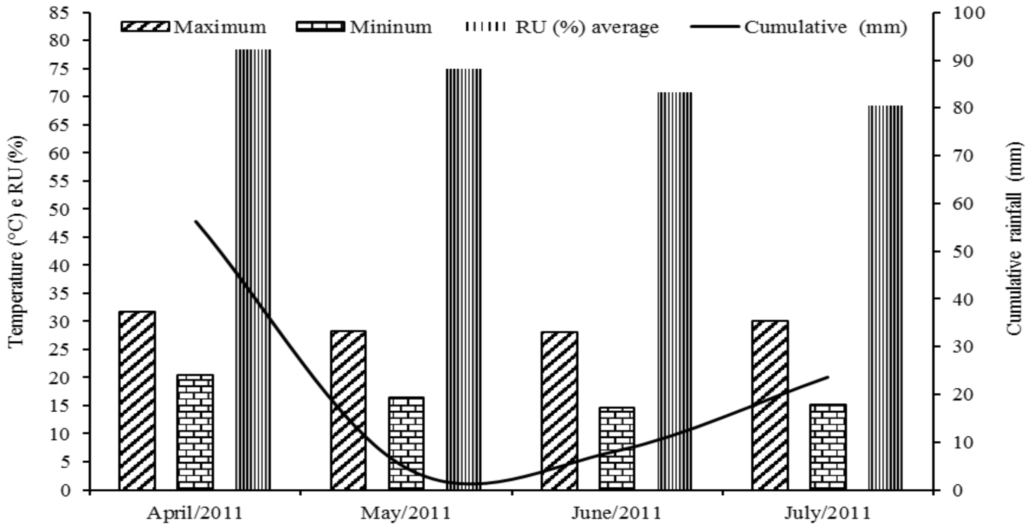

Figure 1. Values of temperature (°C), mean relative air humidity-HR (%) and cumulative rainfall (mm) during the experimental period. Source: Station INMET (2011).

the year (Camargo, 1992; Filgueira, 2012). Arugula has great value for human nutrition and health, being one of the most nutritious vegetables; its leaves are rich in vitamins A and C and in minerals, especially potassium, calcium, iron and sulfur (Trani and Passos, 1998), in addition to being an excellent appetite stimulant as well as conferring anti-inflammatory and detoxifying effects to the body (Linhares et al., 2007).

Because vegetables require a considerable amount of water for their development, the hydro-retention gel can guarantee the supply of water to plants in regions with water deficits. During the formation of the gel, the polymer absorbs water and increases in volume in up to 200%, improving the availability of water by reducing loss through evaporation and subsequently gradually releasing the water to nearby plants. The addition of hydrogels to the soil increases soil water retention, reduces the leaching of nutrients and improves aeration and the cation exchange capacity (Azevedo et al., 2002). Vale et al. (2006), Oliveira et al. (2004) report that hydrogels can be used to stimulate the growth of trees in greenhouses and in reforestation of degraded areas, also minimizing the possible effects of dry spells during the implementation phase of the crop.

According to Sita et al. (2005), the studies on the interaction among hydrogels, substrates and fertilizers are few and inconclusive, and further studies on the subject are required. The same authors reported that the polymer adversely affects the absorption of nutrients and biomass production but contributes substantially to increase K in substrates consisting of soil with organic compost, soil with tobacco waste compost or soil alone. They also observed inverse relationships between polymer doses and biomass and between polymer application and the uptake of K, Ca and Mg, independent of the substrate and of the source of nitrogen and potassium fertilizers used.

Because arugula is a leafy vegetable, nitrogen fertilization is important (Purquerio et al., 2007). Recommendations for application of N in arugula are in the range of 40 kg N ha^{-1} at sowing and 90-150 kg N ha^{-1} as topdressing (Trani and Raij, 1996). Nitrogen has structural functions in plants, as a constituent of amino acids, proteins, nitrogenous bases, many enzymes and energy transfer components, such as chlorophyll, ADP and ATP, and it also plays a role in the processes of ion absorption, photosynthesis, respiration, cell division and cell differentiation (Malavolta et al., 1997).

This study aimed to evaluate the use of the hydrogel and various doses of nitrogen on the development and productivity of arugula cv. Cultivada in two successive crops.

MATERIALS AND METHODS

The experiment was carried out at the State University of Mato Grosso do Sul (Universidade Estadual de Mato Grosso do Sul - UEMS), in the experimental area of the Aquidauana University Unit in the state of Mato Grosso do Sul, Brazil, at geographic coordinates 20º 20' South, 55º 48' West and at a mean elevation of 174 m. The experiment was performed from April to July 2011. The climate in the region belongs to the Aw category in the Köppen classification, defined as a sub-humid warm tropical climate; the average annual rainfall is 1200 mm, and there is a rainy season in the summer and a dry season in the winter.

Maximum temperatures can exceed 40ºC in the summer, and minimum temperatures can approach 5ºC in the winter. The climate data for the period of this experiment are shown in Figure 1. The soil of the experimental area is classified as an Oxisol (very clayed), and deep (Embrapa, 2006). Analysis of the soil in the experimental area showed the following chemical composition: pH ($CaCl_2$) = 5.5; H + Al = 21 $mmol_c\ dm^{-3}$; Ca = 62 $mmol_c\ dm^{-3}$; Mg = 22 $mmol_c\ dm^{-3}$;

Table 1. Mean values of shoot fresh mass (SFM), shoot dry mass (SDM), root fresh mass (RFM) and root dry mass (RDM) of arugula on functions of the application of the hydrogel on successive crops.

Treatments	SFM (g)		SDM (g)	
	1º crops	2º crops	1º crops	2º crops
with gel	81.94^{aA}	76.93^{aA}	6.14^{aA}	5.17^{aA}
Without gel	74.30^{aA}	76.43^{aA}	5.40^{aA}	5.55^{aA}
CV (%)	25.43	32.08	28.24	29.31
Treatments	**RFM(g)**		**RDM(g)**	
	1ºcrops	**2ºcrops**	**1ºcrops**	**2ºcrops**
with gel	2.47b^{A}	5.38^{aA}	0.41b^{A}	0.62^{aA}
Without gel	2.24b^{A}	5.36^{aA}	0.35b^{A}	0.64^{aA}
CV (%)	25.21	19.64	33.27	19.87

Means followed by the same lowercase letter in the same row and the same uppercase letter in the same column, for each factor studied, do not differ by the Tukey test at 5% probability.

P (resin) = 68 mg dm^{-3}; K = 7.0 mmol$_c$ dm^{-3}; organic matter = 52 g dm^{-3}; CEC = 112 mmol$_c$ dm^{-3}; %V = 81; Cu (DTPA) = 8.0 mg dm^{-3}, Fe (DTPA) = 75.0 mg dm^{-3}, Mn (DTPA) = 20.6 mg dm^{-3}, Zn (DTPA) = 0.9 mg dm^{-3} and B (hot water) = 0.32 mg dm^{-3}. The soil texture presents 56, 29 and 15% of clay, silt and sand, respectively. The soil porosity is 49% to field capacity and permanent wilting point of 32.3 and 24.8% respectively.

A randomized block design was used for the experiment, in a 2×5×2 factorial scheme, with and without application of the Forth Gel® hydrogel (4.0 g of product m^{-2}), five doses of N (0, 60, 120, 180 and 240 kg ha^{-1}) and two successive crops of arugula, with four replications. The gel was applied to the first crop (C1), and the residual effect on the second crop (C2) was evaluated. The gel is hidroretentor consisting of potassium polyacrylate copolymer, physical characteristics of white crystals of different particle sizes for each specific application condition and can absorb an average of 200 to 400 times its mass, increasing its volume until 100 times.

The arugula cv. Cultivada was planted in four beds of 12×0.8×0.2 m, corresponding to length, width and height. The parcels consisted of four rows of 1.0 m in length spaced 0.15 m apart. The useful area consisted of the two central rows of each parcel. The base fertilization was performed 20 days before planting on the total area, using 200 kg ha^{-1} in the proportions 4-20-20 (N, K, P). The gel was applied by mixing 25 g of the polymer in a portion of soil taken from each parcel to a depth of 0.08 m, and the mixture was then returned and homogenized in the corresponding parcel. Sowing was performed manually in furrows of 0.01 m deep on May 11, 2011 for the first crop and on June 17, 2011 for the second crop. The thinning was performed 9 and 11 days after sowing (DAS) for the first and second crops, respectively, leaving the plants spaced 0.05 m apart.

For the nitrogen fertilization, urea was used as the source because 45% of its nitrogen is accessible. The doses were divided and applied over the soil between crop rows at a distance of approximately 0.05 m from the plant at 7, 14 and 21 days after emergence (DAE), respectively. To avoid competition for water and nutrients, the control of invasive plants was performed manually when needed, and pest control was performed by applying insecticides recommended for the crop. Water was supplied by a conventional sprinkler irrigation system on alternating days with the hydrogel supplying the water in the interim.

Plants were harvested 30 days after sowing in the first crop and 42 days after sowing in the second crop. At harvest, evaluations were performed on the height of plants chosen randomly within the useful area of the plot, the number of leaves per plant, and the fresh and dry mass of roots and shoots. To determine the fresh and dry mass, the plants were placed in paper bags and dried in a forced air oven at 65ºC until they reached constant weight (weighed on a digital precision scale); the leaf area was measured with the help of the IMAGE software TOOL®, and the productivity was calculated per hectare.

Data were subjected to analysis of variance (ANOVA), means were compared by the Tukey test at 5% probability for the effect of the application of the hydrogel, and regression analysis was used for the effect of the nitrogen doses. For the difference between crops, a joint analysis was performed. Statistical analyses were processed using the statistical analysis program Sanest.

RESULTS AND DISCUSSION

Based on the results there was no significant interaction effect between hidroretentor gel application (polymer) and nitrogen doses in the culture of the rocket, for any of the parameters. The analysis of the effect of the hydrogel in each arugula cultivation period demonstrated that the mean values of shoot fresh mass (SFM), shoot dry mass (SDM), root fresh mass (RFM) and root dry mass (RDM) did not differ significantly between the presence and absence of gel application (Table 1). These results may be explained by the rainfall (Figure 1) that most likely provided a similar water supply for the plants, especially in the final periods of each cycle, when there is an increase in mass accumulation.

According to Grangeiro et al. (2011), leafy vegetables have an initial slow phase of dry mass accumulation that increases at the end of the growth cycle. Although the amount of water available for the plants is increased with the use of the hydrogel, its time of availability is also important for the plants and is determined by the rate of evaporation from the soil (Akhter et al., 2004); thus, the results obtained in this study may be explained by observing the mean maximum temperatures during the experimental period (Figure 1).

According to Woodhouse and Johnson (1991), the

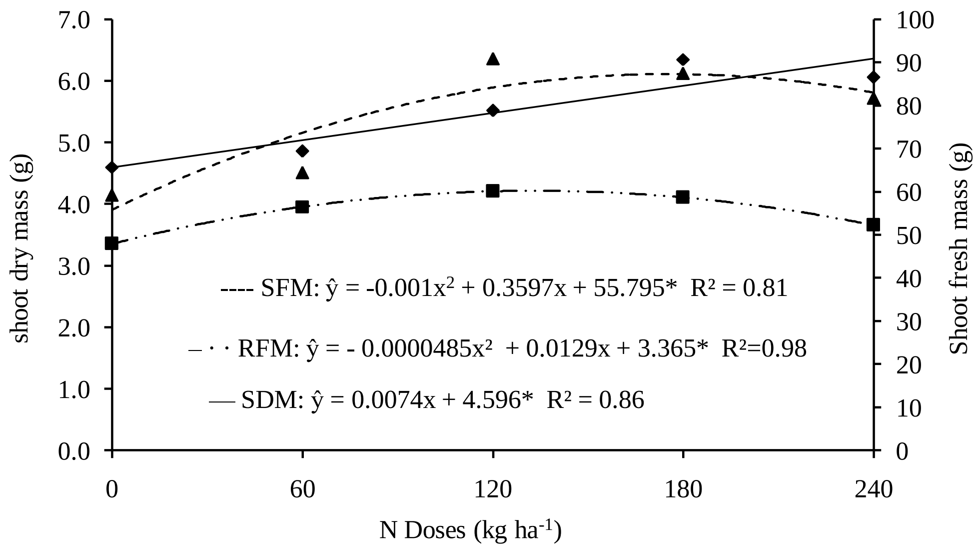

Figure 2. Shoot fresh mass (SFM), shoot dry mass (SDM) and root fresh mass (RFM) as functions of the nitrogen doses in successive crops of arugula. *Significant at $p<0.05$.

efficiency of water use is not only a measure of how much water is needed to produce one unit of dry mass but is essential for the evaluation of the performance of a polymer in a soil-plant growth system because it includes the evapotranspiration by the plant and evaporation of the soil-polymer mixture.

The results of this study differ from those of Sayed et al. (1991), who evaluated the effect of a hydrogel in the cultivation of various vegetables and found an increase in the fresh and dry mass of plants with the incorporation of the polymer, compared to cultivation without the polymer.

Only RFM and RDM differed significantly between the cultivation periods (Table 1); for both parameters, greater root biomasses were obtained when evaluating the residual effect of the hydrogel in the second crop (C2). The arugula grown in soil that received the hydrogel had greater SFM and SDM values in the first crop (C1) than in the second crop, but the difference was not significant.

The nitrogen dosage had a significant effect on SDM, SFM, and RFM, independent of hydrogel application, and an increase in N produced a linear increase in SDM. These results differed from those observed by Purquerio et al. (2007), in which the SDM data for arugula were described by a quadratic polynomial equation.

Regarding fresh mass, there was a quadratic fit of the data to quadratic polynomial regressions with maximum values estimated at 179.8 and 132.9 kg N ha^{-1} for the SFM and RFM, respectively (Figure 2). Ratke et al. (2011), working with N fertilization in the cultivation of arugula, found that the SFM increased quadratically with a maximum value of 600 kg ha^{-1}, which is greater than that obtained in the present study.

When assessing the number of leaves in C1, the plants that were treated with the hydrogel had a greater number of leaves than the plants grown without the polymer, but no difference was observed in C2 (Table 2). The addition of hydropolymers in the soil favors the availability of water, reduces nutrient loss by leaching, improves soil aeration, and thereby accelerates the shoot development of plants (Peterson, 2009). Marques and Bastos (2010) tested various doses of hydrogel in the cultivation of chili and observed that, even with daily irrigation, increasing doses of hydrogel produced a positive linear increase in the number of leaves.

Regarding the cultivation periods, the C1 plants had more leaves than the C2 plants, regardless of the presence of the hydrogel. For the leaf area, only in the second crop was a difference observed when using the hydrogel: plants that received gel treatment had greater leaf area (Table 2). Taiz and Zeiger (2009) explain that leaf expansion is driven by turgidity. When the water content of the plant decreases, the cells contract and loosen the turgor pressure against the cell walls. With a low leaf area, there is less transpiration, and the limited water supply in the soil is conserved for a longer period of time. Thus, the decrease in leaf area can be a defense mechanism against drought. Carvalho et al. (2013) observed that in passion fruit plants, the thickness of the leaves is reduced in seedlings grown without the hydropolymer and that the same effect was observed on specific leaf area, which relates the leaf surface to the weight of the leaf, representing the leaf thickness.

As observed in Table 2, there was no difference in plant height in either crop regarding treatments with and without the hydrogel. In contrast, the plants were significantly taller in C1 than in C2, either with or without application of the gel. Costa et al. (2011) and Dantas and Torres (2010) obtained plants with maximum heights of

Table 2. Mean values of the number of leaves, leaf area, height and productivity of the arugula as functions of the application of the hydrogel in successive crops.

Treatments	Leaf of number		Leaf area (cm²)	
	1º crops	2º crops	1º crops	2º crops
With gel	9.87 bA	12.93aA	295.01^{aA}	277.65^{aA}
Without gel	8.60 bB	13.68aA	246.67^{aA}	230.41^{aB}
CV (%)	14.93	15.43	22.33	14.83
Treatments	**Height (cm)**		**Productivity (kg ha^{-1})**	
	1º crops	**1º crops**	**1º crops**	**2º crops**
with gel	20.06 aA	13.93^{bA}	12682^{aA}	10392^{bA}
Without gel	19.53 aA	13.88^{bA}	12191^{aA}	11055^{aA}
CV (%)	9,54	15.62	18.89	19.72

Means followed by the same lowercase letter in the same row and the same uppercase letter in the same column, for each factor studied, do not differ by the Tukey test at 5% probability.

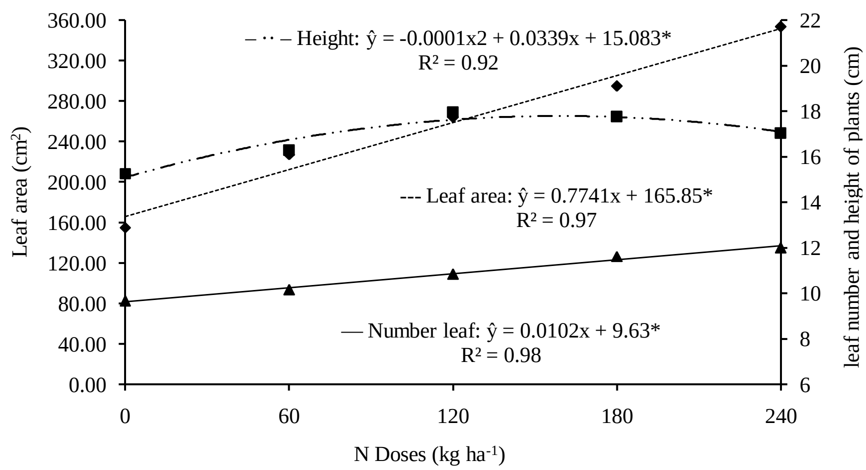

Figure 3. Leaf area, leaf number and height of arugula plants as functions of the N doses in successive crops. *Significant at $p<0.05$.

27.5 and 21.75 cm at 37 and 36 days after sowing, respectively.

There was no correlation between gel application and plant height as a function of the increasing doses of N (Table 2). Thus, N fertilization can be used without damage to the development and size of arugula. According to Peterson (2009), hydropolymers also have the ability to promote plant growth when nutrients are incorporated into the soil, by releasing the nutrients to the plants when needed. However, in certain situations, the addition of nutrients has shown little effect on plant performance, especially when higher levels of fertilizers and salts are present.

The mean productivity values showed no significant variation between treatments with and without the hydrogel in the two successive crops (Table 2). In the treatment with application of hydrogel, there was higher productivity in C1, whereas without hydrogel application, the productivity levels of the two crops were similar. Regarding productivity, a significant relationship was observed between N doses and the cultivation periods of arugula cv. Cultivada. During the C2 period, there was a climatic change (the mean minimum temperature was 14.7ºC) that caused a delay in germination and a consequent delay in the harvest, resulting in lower values of the variables analyzed.

An example of a difference in productivity achieved during different cultivation periods for the arugula crop was reported by Purquerio et al. (2007), who found that in the summer, high rainfall during the crop cycle and its concentration in short periods of time was detrimental to plants cultivated in the field and, in addition to lower productivity, lower plant quality was also observed. Regarding the N doses, there was a linear increase in both the number of leaves and the leaf area in response to increasing N, and the data were fitted with a positive linear regression (Figure 3). These results differ from those obtained by Purquerio et al. (2007) working with N

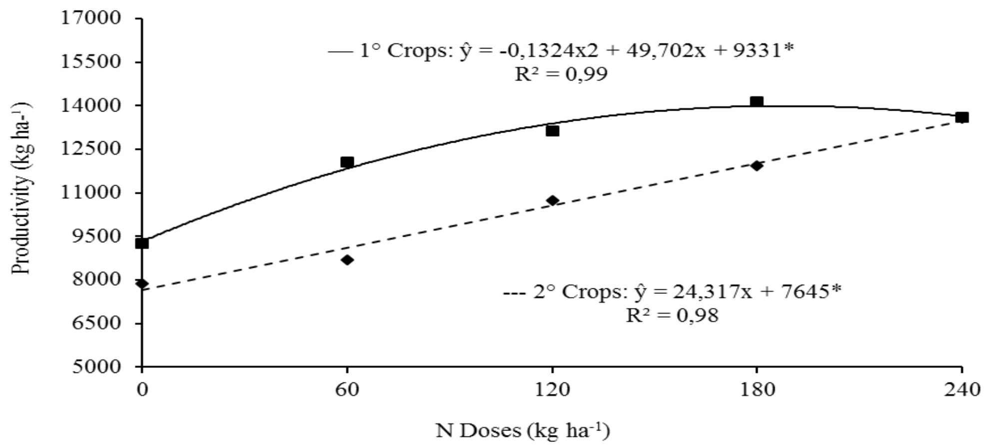

Figure 4. Arugula productivity as a function of N doses in two successive crops. *Significant at $p<0.05$.

doses on large-leaf arugula, who found that the leaf area values fit a quadratic regression. According to the same authors, there is no standardization for the cultivation of arugula that allows the classification of the leaf area and the mean values of the plant height obtained, which in their analysis were essentially satisfactory. Both wholesalers and consumers prefer packs with large leaves, but it depends on the population of each region.

Figure 3 shows a significant effect of N dose on plant height, but only in the first crop, and the data fit a quadratic polynomial equation, with a maximum value estimated for the dose of 169 kg N ha^{-1}. These results corroborate those of Oliveira et al. (2010), who evaluated two crops and observed differences in plant height and shoot dry mass between the first and second arugula cycles, with the highest mean height in the first crop and the highest SDM in the second.

Regarding productivity, the increasing N doses caused significant variations in the data, which fit a quadratic polynomial equation, with the maximum value estimated at 188 kg N ha^{-1} for the first crop, whereas in the second crop, there was an N dose increase (Figure 4). The estimated dose of N that provided the highest productivity in this study is above the 120 kg ha^{-1} recommended by Trani and Raij (1996) for the cultivation of arugula. These results are consistent with those obtained by Steiner et al. (2011), who observed an increase in the production of rocket with application of nitrogen. However, the results obtained diverge from those reported by Purquerio et al. (2007), who obtained an increase in the productivity of arugula cv. Folha Larga (Large Leaf) up to the estimated dose of 240 kg ha^{-1}.

Conclusions

(1) The results show that the hydrogel had no effect on the fresh and dry mass of arugula, regardless of the cultivation period.

(2) The use of the N fertilizer significantly affects the development of arugula, as evidenced by a linear increase in the shoot dry mass, number of leaves and leaf area.

(3) The application of N influenced the components of production and productivity of arugula.

Conflict of Interest

The authors have not declared any conflict of interest.

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