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Growth analysis of lettuce under different substrate compositions

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Abstract: The objective of this work was to evaluate lettuce growth in greenhouse under different types of substrates. The experiment was conducted in a greenhouse, under randomized block design, with six treatments and three replicates. The compositions of the substrates were: T1= 100% organic compound; T2= 75% organic compound plus 25% substrate Plantmax®; T3= 50% organic compound plus 50% substrate Plantmax®; T4= 25% organic compound plus 75% substrate Plantmax®; T5= 100% substrate Plantmax®; T6= vermiculite. The number of leaves, dry mass, leaf area index, culture growth rate, relative growth rate, net assimilation rate, specific foliar area, foliar area ratio and foliar weight ratio were evaluated. Higher growth of lettuce plants are produced by mixture of organic compound and substrate Plantmax®. The isolated use of vermiculite does not give good results for the growth of lettuce plants, but is an alternative for mixing with other substrates.

1. Introduction

Lettuce (*Lactuca sativa* L.) is one of the most consumed vegetables in the world (Gomes *et al*., 2008), due to its taste, nutritional quality and low price (Teodoro *et al*., 2016). Its adaptability to different climatic conditions that allows successive crops during the year, low cost of production and safe marketing, makes it a crop preferred by small producers, adding economic and social value to its cultivation (Medeiros *et al*., 2007).

Lettuce is responsive to organic fertilization, varying according to the cultivar and source of nutrients used (Teodoro *et al*., 2016). Thus, the use of substrates must ensure that lettuce presents characteristics appropriate to plant growth, with adequate physical and chemical compositions (Lima *et al*., 2006). It should be well structured and with good texture, adequate pH, good fertility and pathogen free (Araújo *et al*., 2013).

The different substrates compositions have an effect on the biomass production of the plants, since they are able to comply with the species' requirements (Afonso *et al*., 2012). There is a trend toward using organic compounds because they provide nutrients and contribute to good development of the root system (Lima *et al*., 2006). A lettuce crop has high production potential with organic fertilizers (Santos *et al*., 2001). The organic compounds, resulting from composting, vermicomposting or other sources, have good aeration, structure, water retention capacity, ability to regulate the temperature of the substrate, and are sources of several nutrients that may be readily available (Trindade *et al*., 2001). Organic compounds are also stabilized products, rich in nutrients and derived from vegetable and animal waste (Souza and Alcântara, 2008).

Moreover, the use of organic substrates reduces cultivation time and consumption of chemical inputs (Medeiros *et al*., 2015), modifying the microbial populations that improve substrate quality and plant production. These microorganisms decompose the residues, releasing nutrients and substances that stimulate plant growth (Medeiros *et al*., 2015).

Growth analysis is still the most accessible and accurate way to evaluate plant growth and the contribution of physiological processes to plant behavior. It allows differentiating the behavior of the same cultivar under different cultivation conditions (Benincasa, 2003).

Due to the influence of factors on plant production and the importance of knowing the growth and development of the plants, the objective of this work was to evaluate lettuce growth in a greenhouse under different types of substrates.

2. Materials and Methods

Location of experiment, plant material and cultivation

The experiment was conducted in a greenhouse located on the experimental area of the Federal University of Santa Maria, Campus of Frederico Westphalen, RS, Brazil, with geographic location 27° 23’ S, 53° 25’ O and altitude of 490 m. According to Köppen’s classification, the climate of the region is humid Cfa-temperate with hot summer, with maximum air temperatures in warmer months over 22°C (Alvares *et al*., 2013). The average temperature inside the greenhouse were 22±3 °C during the day and 18±3°C in the night.

The lettuce seedlings, cultivar *Pira Verde*, were transplanted to the wooden benches on 3 days in October 2013, arranged in spacing of 20 cm between plants and 30 cm between rows. The plants were cultivated for 49 days until November 21, when all had reached the harvest point. A 150-micron double-sided canvas was placed on the substrate to reduce water loss through soil evaporation. Before transplantation, small holes were opened to introduce the seedlings into the substrates. The irrigation method used was drip irrigation, allowing a distribution of the same volume of water for all plants.

Water was supplied depending on environmental conditions, taking into consideration temperature, relative humidity, and other factors. Along with water, nutrients were supplied through nutrient irrigation. The nutrients were chosen according the recommendations of Furlani (2009), obtaining electrical conductivity around 1.2 µS cm^{-2}, by use of hidrogoodfert, calcinit and chelated iron, which have soluble nutrients in water. Hidrogoodfert is composed of the macronutrients nitrogen, phosphorus, potassium, magnesium, sulfur and the micronutrients boron, copper, molybdenum and zinc. Calcinit is composed of calcium nitrate. The solution was replaced according to the evaporation and absorption of the plants.

Experimental design and treatments

The experiment was conducted on wooden benches inside the greenhouse, with a randomized block design, with six treatments and three replications per treatment. Each replication have had 40 plants. The compositions of the substrates were T1= 100% organic compound; T2= 75% organic compound plus 25% substrate Plantmax®; T3= 50% organic compound plus 50% substrate Plantmax®; T4= 25% organic compound plus 75% substrate Plantmax®; T5= 100% substrate Plantmax®; and T6= vermiculite. The organic substrates were obtained by Mechanized and Automated Composting Unit (UMAC), a project of the company LPC-Ambiental Technology, located in the municipality of Concórdia-SC. This residue is generated by mixing pig slurry with compost shavings and storing it in retention rails.

The commercial substrate Plantmax® has excellent physical properties and high water retention capacity. This substrate is composed mainly of pine bark and vermiculite, and presents chemical properties constituted of macronutrients and micronutrients. Vermiculite was used for application of nutrients by means of irrigation, since it is a non-nutritive substrate with high water retention capacity.

Evaluations and analysis

The evaluations of the plants were conducted every week, when 3 plants of each treatment were sampled by the destructive method, from the transplant to the beginning of the stem elongation for posterior emission of the floral tassel. The evaluations were made by counting the number of leaves and separating the morphological parts of the plant, which was put into the drying oven at 60°C until it reached constant weight for determination of the dry mass. The analyzed variables were number of leaves (NL), dry mass (DM) and leaf area index (LAI). The number of leaves was determined by counting all the leaves of the plants, and dry mass was obtained by measuring the mass of the aerial part of the plant. Leaf area (LA) was determined by the disc method, in which 10 discs were removed from the leaves, obtaining its dry mass, and estimating the leaf area of the plant through the equation:

$$LA = \frac{\text{disc number x nozzle number x total leaf dry mass}}{\text{dry mass of the discs}}$$

From the leaf area, the leaf area index was calculated by the following equation:

$$LAI = \frac{LA}{SA}$$

where SA is the area of soil occupied by a plant.

In addition, culture growth rate (CGR), relative growth rate (RGR), net assimilation rate (NAR), specific foliar area (SFA), foliar area ratio (FAR) and foliar weight ratio (FWR) were calculated according to the methodology presented by Barbero *et al*. (2013).

The CGR was determined by:

$$CGR = \frac{DM}{SA \text{ x} \Delta t}$$

where Δt is the time interval of the evaluations. This variable is an indicator of productivity, since it represents the increase of dry matter in a time interval, considering the area of soil occupied by the plant.

The equation to obtain the RGR is:

$$RGR = \frac{\log \Delta DMA}{\Delta t}$$

where log ΔDM is the logarithm of the increment of DM, so RGR is an increment of productivity of dry mass in a time interval.

NAR was calculated as:

$$NAR = \frac{CGR}{LAI}$$

This variable indicates the rate of increase in dry matter per unit of time and per unit of leaf area. According to Benincasa (2003), NAR demonstrates the photosynthetic efficiency of the leaves.

FAR is the ratio between leaf area and dry mass and expresses the foliar area useful for photosynthesis; it is the measure of the size of the assimilating apparatus. It is obtained by:

$$FAR = \frac{LA}{DM}$$

FWR relates to how much of the dry matter accumulated by the plant is composed by leaves, which, besides being the organ responsible for photosynthesis, is the organ of commercial interest. It is given by:

$$FWR = \frac{\text{DM leaves}}{\text{DM plant}}$$

SFA were determined by the equation:

$$SFA = \frac{LA}{\text{DM leaves}}$$

This variable indicates the accumulation of photoassimilates in the leaves or the translocation to the other organs, that is, differences in leaf thickening (Taiz and Zeiger, 2013).

The data were submitted to analysis of variance and comparison of means by the Tukey's test, with a 5% probability of error.

The meteorological data, like air temperature and global solar radiation, were collected at the mobile weather station installed inside the greenhouse.

3. Results and Discussion

Weather conditions

During the experiment, minimum and maximum average temperatures were 15-27±3°C, respectively. These values are in agreement with the values considered optimal for the culture between 15-24°C (Knott, 1962) and 15-20°C (Santana *et al*., 2009).

The global solar radiation presented variations between 653 and 1.090 kJ m^{-2}. These values are considered adequate for the growth of the culture. A reduction of solar radiation at the beginning of the crop cycle can be observed, but it did not have any influence, since the plants were in establishment period and had little leaf area (Fig. 1).

Thus, air temperature and incident solar radiation were the main environmental factors that affected lettuce growth, development and yield.

Growth variables

During the growth and development of the plants, small burns were observed in the border of the new leaves. These were symptoms of calcium deficiency, because it is a little mobile element in the plant and then wasn't available to the plants. However, by harvest, the plants had recovered with no apparent symptoms.

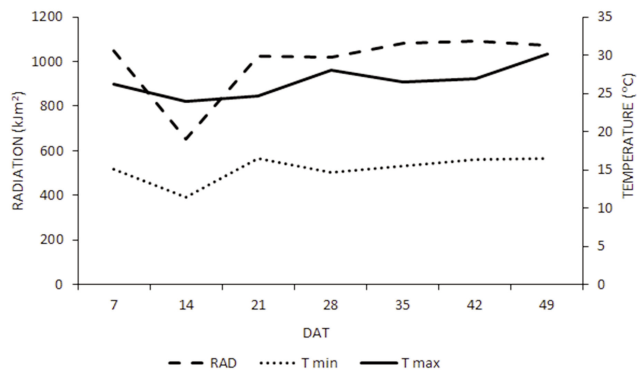

Fig. 1 - Solar global radiation (kJ m^{-2}), maximum temperature and minimum temperature (°C) during the lettuce crop cycle. Frederico Westphalen, RS, Brazil, 2013.

The leaves are the main component of interest of lettuce. Thus, it is important that the plant produces the maximum number of leaves, dry matter and leaf area for good production. Figure 2 shows that the number of lettuce leaves increased during the crop cycle for the different substrate compositions. Therefore, it can be observed that the T1 treatment (100% organic compound) showed a smaller number of leaves at 28 days after transplantation. However, at 35 days after transplant, the treatment composed of 100% substrate Plantmax® (T5) was less effective than the others, with approximately 12 leaves. At the end of the cycle of the culture, the substrate with the lowest number of leaves was vermiculite, with approximately 20 leaves, but that did not differ statistically from the others. This demonstrates that the combination of different substrates such as organic compost and commercial substrate present better conditions for the development of plants than when used alone.

The results obtained show that the analyzed growth variables presented different behaviors in relationship to the types of substrates used in the lettuce crop. A decline was also observed on the growth variables toward the end of the crop cycle (Fig. 3), which is considered normal because they are relational to growth of this culture.

Figure 3A shows the dry mass accumulated by the plants during the cycle. Slow initial growth due to the small size of the plants and small leaf area makes a lower nutrient absorption and a low solar radiation,

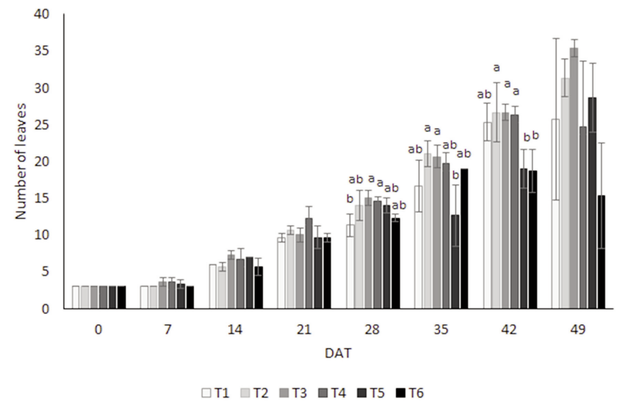

Fig. 2 - Number of leaves of lettuce growth under different substrates. Frederico Westphalen, RS, Brazil, 2013.

causing little growth of these plants. From 21 days after transplant, an increase in the DM for all the substrates was observed, with emphasis on mixtures of substrates. The substrate composed of 50% organic compound plus 50% substrate Plantmax® (T3), was outstanding for presenting higher values in most of the crop cycle, reaching maximum increment at 49 days after the transplant, with approximately 26 g. The worst results were obtained with vermiculite, reaching approximately 11 g (Fig. 3A).

The leaf area index presented a similar behavior to DM, with the most accentuated and perceptible increase at 21 days after transplant, when the plant presented an increase in dry matter (Fig. 3B). LAI falls at certain points in the crop cycle may be related to the abscission of older leaves. LAI is important for studying crop growth, development and productivity. The leaf area will depend in addition to the number and size of the leaves of the plant and the period in which the leaves remain on the plant (Monteiro *et al.*, 2005). This demonstrates that the increase of leaf area provides greater interception and absorption of the available solar radiation, and, consequently, higher photo assimilates production, which results in higher growth and dry matter of the plants. The best results for these variables were obtained by substrate mixtures.

Since CGR represents the increment of dry matter per unit of soil area occupied over a given period of time, the pattern of the graph was very similar to that for dry matter. At 49 days after transplant, the substrate, composed of 50% organic compound plus 50% substrate Plantmax®, was higher than the others, differing statistically just from vermiculite (T6). At this point, T3 reached approximately 60 g m^{-2} day^{-1} (Fig. 3C). According to Beckmann-Cavalcante *et al.* (2009), growth rate of the crop is mainly determined

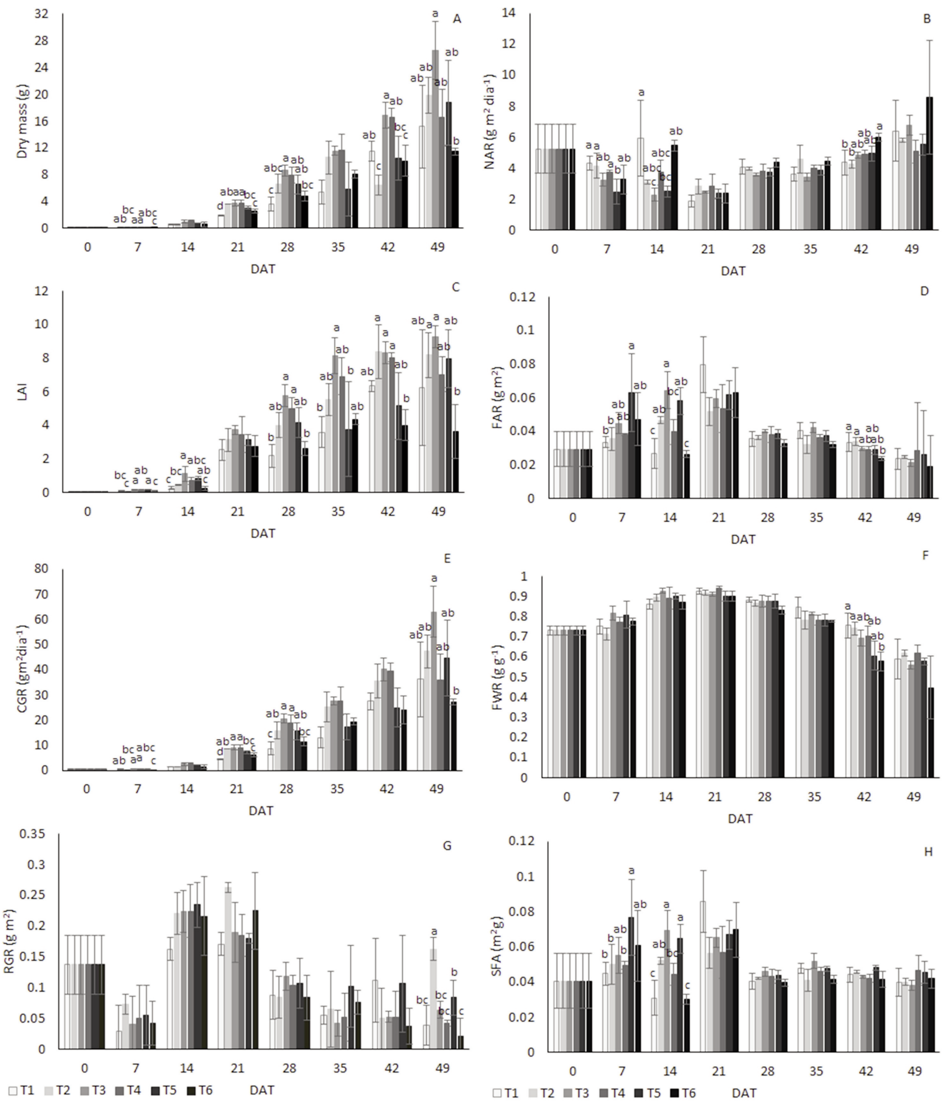

Fig. 3 - Dry mass (A), Leaf area index (B), Culture growth rate (C), Relative growth rate (D), Net assimilation rate (E), Foliar area ratio (F), Foliar weight ratio (G) Specific foliar area (H) for lettuce culture growth under different substrates. Frederico Westphalen - RS, UFSM , 2013. Lowercase letters differ by Tukey means test at 5% error probability.

by the air temperature. Thus, from 21 day after transplant (DAT), CGR also increased as a function of changes in air temperature.

The highest rates of RGR were observed at 14 and 21 days after transplant (Fig. 3D). Substrate with 75% organic compound plus 25% substrate Plantmax® (T2) reached maximum RGR-approximately 0.25 g m^{-2}. This may be because the plants were in a phase of high photosynthetic rate due to the elevation of LAI and high growth. This same treatment has achieved the highest RGR at 49 DAT, statistically differing from the others. At 28 days after transplant, the growth rate tended to decrease. According to Zuffo *et al*. (2016), this is mainly due to the shading between the plants and the increase in the respiratory rate. This shows that with shading and high respiration of the plants, the growth promotes a reduction of the RGR of the crop.

The photosynthetic efficiency of the leaves presented variations along the cycle and is represented by NAR. This rate tends to be higher at the beginning of the development of the crop due to lower self-shading (Gondim *et al*., 2008). However, in this study the NAR values increased at the end of the cycle because NAR depends on available leaf area, leaf distribution, leaf angle, and translocation and assimilation partition (Pedó *et al*., 2010; Aumonde *et al*., 2011). Some statistical differences were observed between the treatments on 7, 14 and 42 DAT (Fig. 3E).

The highest rates of FAR were obtained at 7, 14 and 21 DAT (Fig. 3F). After this period, the ratio steadily decreased for all treatments, corroborating the results of Pedó *et al*. (2013) for pepper. However, these authors obtained results in the higher FAR, providing a greater area useful for photosynthesis, which produced higher rates of NAR. As for Caron *et al.* (2007), the decrease indicates that at this stage, most of the photosynthesized material is accumulated in the aerial biomass of the lettuce to increase available solar radiation. This shows that the decrease may be due to self-shading and leaf fall resulting from the age of plants, or to energy demand for the development of other organs, such as flowers. Statistical differences were found only at 7, 14 and 42 DAT.

Foliar weight ratio remained similar between the treatments, with values ranging from 0.7 to 0.9 g g^{-1} during a large part of the crop cycle, with decreases at 42 and 49 DAT (Fig. 3G). This may be due to the appearance of preferential metabolic sinks by the formation of the reproductive organs. T1 and T2 were superior and differed statistically to T6 at 42 DAT.

Specific foliar area reached differences between the treatments at 7 and 14 DAT. At 7 DAT, the major SFA were obtained by T5, which was statistically equal to T3 and T6 treatments. At 14 DAT, the higher SFA was observed by T2, T3 and T5. At 21 DAT, the values were similar to those obtained at 7 and 14 days. In the rest of the cycle, SFA remained around 0.04 m^2 g^{-1}. After the development of the plants, there were an increase in leaf area and dry mass of the leaves, causing decreases in SFA (Benincasa, 2003).

Table 1 shows the means of fresh mass at 42 and 49 DAT. The values show that substrates mixtures obtained the better results. Although they had not shown a significant difference from the others at 49 DAT - with the exception of vermiculite - there were differences that could bring greater profits. However, from the values observed at 42 DAT, it can be concluded that the treatments with mixtures of substrates were superior to the others. In addition, the use of mixtures such as T2 (75% organic compound plus 25% substrate Plantmax®) and T4 (25% organic compound plus 75% substrate Plantmax®) anticipate the harvest, because the fresh mass was higher at 42 DAT compared to 49 DAT.

It is important to emphasize that vermiculite was used like a control treatment, since it is a inert substrate used in hydroponics cultivation or mixed with soil; it led to worse results for all variables evaluated and reduced the growth of plants cultivated under this substrate.

Table 1- Lettuce fresh mass at different substrates mixtures

Treatment	Fresh mass (g)	
	42 DAT	49 DAT
100% Organic compounds	153.20 b	160.67 ab
75% Organic compounds + 25% Plantmax ®	220.03 a	198.40 a
50% Organic compounds + 50% Plantmax ®	199.03 a	270.00 a
25% Organic compounds + 75% Plantmax ®	199.70 a	163.43 ab
100% substrate Plantmax ®	110.40 bc	161.43 ab
Vermiculite	73.07 c	71.17 b

DAT = Day after transplant.

4. Conclusions

Higher growth of lettuce plants are produced by mixture of organic compound and substrate Plantmax®. The isolated use of vermiculite does not give good results for the growth of lettuce plants, but is an alternative for mixing with other substrates.

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