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Fertigation in mulched fields for the Starfighter lettuce cultivar. An alternative to consider

Fertirrigación en campo acolchado en el cultivar Starfighter de lechuga. Una alternativa a tomar en cuenta

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Abstract

In order to analyze the response of the Starfighter lettuce cultivar to fertigation in mulched field, an experimental field plot was implemented. The 3 treatments were in an experimental design of completely randomized blocks (T_1 medium fertigation, T_2 high fertigation, T_3 basic fertigation, as the farmer is accustomed to), and 4 replications. The effect of transplant time was blocked. Analyses of variance and means using Tukey at 5 % were performed using the technique of repeated measures over time. Each experimental unit consisted of 40 plants planted in 4 rows at 0.20 m between plants and 1.80 m between platforms. The 20 plants in the center rows were evaluated. The response variables were: plant height, number of leaves, head diameter, percentage of leaf area, root length, plant weight and flavor. The results refer to the best response expressed by fertigation T_2, with an average of 25 leaves, a percentage of leaf area of 59.95 %, head diameter 22.59 cm and weight 184 g per plant, in relation to T_3 (control). The leaves in the 3 treatments were fresh and did not present spiciness. The use of mulching, drip irrigation and fertigation in the improvement of the production of the Starfighter cultivar was notorious, which did not have any attack of pests or diseases

Resumen

Con el objetivo de analizar la respuesta del cultivar Starfighter de lechuga a la fertirrigación en campo acolchado, fue implementada una parcela experimental en campo. Los 3 tratamientos fueron en un diseño experimental de bloques completamente aleatorios (T_1 fertirrigación media, T_2 fertirrigación alta, T_3 fertirrigación básica, como acostumbra el agricultor), y 4 repeticiones. Se bloqueó el efecto del tiempo de trasplante. Los análisis de varianza y de medias mediante Tukey al 5 % fueron realizados con la técnica de medidas repetidas en el tiempo. Cada unidad experimental estuvo constituida por 40 plantas sembradas en 4 hileras a 0.20 m entre plantas y 1.80 m entre platabandas. Se evaluaron las 20 plantas de las hileras centrales. Las variables de respuesta fueron: altura de planta, número de hojas, diámetro de la cabeza, porcentaje de área foliar, largo de raíz, peso de planta y sabor. Los resultados refieren, T_2 de fertirrigación (alta) fue la que mejor respuesta expreso, con un promedio de 25 hojas, porcentaje de área foliar de 59.95 %, diámetro de la cabeza 22.59 cm y peso 184 g por planta, en relación a T_3 (testigo). Las hojas en los 3 tratamientos fueron frescas y no presentaron picantes. Fue notorio el uso del acolchado, riego por goteo y fertirrigación en la mejora de la producción del cultivar Starfighter, que no tuvo ningún ataque de plagas ni de enfermedades.

Introduction

In today's agriculture, the efficient use of available irrigation water resources is essential to increase agricultural production, thus ensuring food and nutritional security for a constantly growing population. Water and fertilizers are two key factors that determine agricultural production; both are becoming scarce and expensive over time[1]. In the face of dwindling land resources, increasing water scarcity, rising fertilizer prices, energy crises, environmental pollution, and the rapid degradation of other natural resources, it is necessary to improve nutrient and water use efficiency for the sustainability of agriculture[2].

Lack of irrigation usually results in poor crop growth and vigor, which reduces yield and quality; while overwatering not only causes water loss, but also increases vulnerability to various diseases and contamination of surface and groundwater, due to fertilizer leach[3]. Therefore, efficient irrigation systems are needed, not only to overcome the aforementioned problems, but also to promote the sustainable use of resources[4]. The rational use of water resources such as drip irrigation is necessary to improve the yield, quality and efficiency of water use in crops, especially vegetables.

In drip irrigation, water is delivered drop by drop near the root zone continuously or at frequent intervals. The regulated supply of water via drippers not only provides conditions conducive to root flowering, but also ensures optimal nutrient acquisition and ultimately better shoot growth[5]. Drip irrigation helps to reduce overexploitation of water resources that are otherwise overused by inefficient surface irrigation methods[6]. In addition, untimely nutrient application after an inappropriate application method leads to severe nutrient losses through leaching and fixation with low use efficiency[7]. The use of fertilizers is also optimized with drip irrigation and is called fertigation[8]. Drip fertigation optimizes nutrient use by applying them at critical stages, resulting in better absorption and higher efficiency of use, thus ensuring greater water and nutrient savings, as well as higher crop yield and quality[9,10]. Fertigation by drip irrigation also reduces energy consumption, improves disease and pest control, labor cost, and is feasible in all types of terrain[9].

Plastic mulching technology, widely used since the 1950s, has revolutionized modern agriculture by improving the microenvironment of crops. Thanks to its thermal insulation and moisture retention properties, it raises the floor temperature by 3 to 5° C and reduces water evaporation by up to 50 %. In addition, it acts as a physical barrier that decreases weed germination by more than 60 %, limits soil-borne diseases and optimizes the use of light and heat by 20 %. These effects translate into an increase in crop yields of between 15 and 25 %, significantly improving commercial productivity[11,12].

On the other hand, it is known that the world production of lettuce is estimated at 26,866,557 t per year with an average yield of 21.89 t ha[13]. Data from the Food and Agriculture Organization of the United Nations indicate that the main producer of this species is Spain, as it exports to more than 53 countries, exceeding 900,000 tons per year[13].

In Ecuador, it is one of the main vegetables for fresh consumption, it is grown from 2800 meters above sea

level in the center of the country; its popularity increased progressively, as it is a product with a pleasant, nutritional, medicinal flavor and low caloric content. Lettuce is produced at any time of the year and like the rest of the vegetables, it is a supplier of vitamins, minerals and salts, essential for the body. The awareness that exists to maintain health has increased the consumption of fruits and vegetables, which includes the different types of lettuce[14-16]. Lettuce is grown mainly in the Sierra with about 1145 ha, and an average yield of 7928 kg ha^{-1}. The main provinces producing this crop are Cotopaxi (481 ha), Tungurahua (325 ha) and Carchi (96 ha)[17].

For all the above, the objective of this research was to analyze the response of the Starfighter lettuce cultivar to fertigation in mulched field, in the area of Puerto la Boca, Manabí.

Materials and methods

Geographical location. The research was carried out in a greenhouse owned by Mr. Miguel Correa, in the Puerto La Boca Campus, in the Puerto Cayo Parish, in the Jipijapa Canton, located at 1°18'20" South latitude and 80°45'42" West longitude, at an altitude of 53 meters above sea level. The average temperature is 24.8° C/year and the average rainfall is 298 mm/year, with rainfall concentrated in the month of February and the driest month in August[18].

Table 1 Doses of macronutrients required for lettuce fertigation by growth stages, corresponding to T_1

Nutrients	Dosage (ppm)	Dosage (mL L^{-1})	Fertilizer	g 100 L^{-1}
First stage: 15-20 days after transplant				
Nitrogen	120	.12		
Phosphorus (P_2O_5)	120	.12	Monopotassium phosphate	3.75
Potassium (K_2O)	120	.12	Potassium nitrate	55.33
Calcium (CaC)	60	.06	Calcium nitrate	61.20
Magnesium (MgO)	30	.03	Magnesium Sulfate	10.89
Sulfur	168	.168	Potassium Sulfate	61.00
Iron	5	.05	Iron chelate (10 % iron):	5.00
Second stage: 25-30 days after transplantation				
Conductivity from 1.5 to 1.8 mS				
Nitrogen	120	.12		
Phosphorus (P_2O_5)	120	.12	Monopotassium phosphate	3.75
Potassium (K_2O)	150	.12	Potassium nitrate	69.17
Calcium (CaC)	80	.08	Calcium nitrate	81.60
Magnesium (MgO)	40	.04	Magnesium Sulfate	14.52
Sulfur	168	.168	Potassium Sulfate	61.00
Iron	5	.05	Iron chelate (10 % iron):	5.00

The experiment was carried out between the months of September and October 2022.

Study factors. The research was single-factorial, the study factor was the application of 2 fertigation strategies and a control (T_1 medium fertigation, T_2 high fertigation, T_3 basic fertigation, as the farmer does) in the lettuce Starfighter cultivar.

Treatments. The sources and treatments applied were 3 doses of fertilizers (Tables 1, 2).

Table 2 Doses of macronutrients required for lettuce fertigation by growth stages, corresponding to T_2

First stage: 15-20 days after transplant				
2.0 mS conductivity				
Nitrogen	140	.14		
Phosphorus (P_2O_5)	120	.12	Monopotassium phosphate	55.20
Potassium (K_2O)	200	.12	Potassium nitrate	6.25
Calcium (CaC)	120	.12	Calcium nitrate	55.33
Magnesium (MgO)	60	.06	Magnesium Sulfate	61.20
Sulfur	168	.168	Potassium Sulfate	61.00
Iron	5	.05	Iron chelate (10 % iron):	5.00
Second stage: 25-30 days after transplantation				
Conductivity from 2.5 to 2.8 mS				
Nitrogen	140	.14		
Phosphorus (P_2O_5)	120	.12	Monopotassium phosphate	55.20
Potassium (K_2O)	270	.27	Potassium nitrate	8.44
Calcium (CaC)	140	.14	Calcium nitrate	64.56
Magnesium (MgO)	70	.07	Magnesium Sulfate	71.40
Sulfur	168	.168	Potassium Sulfate	61.00
Iron	5	.05	Iron chelate (10 % iron):	5.00

The T_3 treatment (basic fertilization, as the farmer does).

Experimental design. The experimental plot was implemented in an experimental design of completely randomized blocks (DBCA) with 4 replications and 3 treatments[19]. The transplant time effect was blocked. The analysis of variance was performed with the model of repeated measures over time[19]. Each experimental unit (UE) had 40 plants planted in 4 rows at 0.20 m between plants and 1.80 m between platforms. Each platform per treatment had 40 plants, and 160 plants for the 4 repetitions. The central lines were evaluated, which corresponded to 20 plants of each treatment by repetition.

To prepare 1000 L of nutrient solution 1 (S_1) for lettuce, the recommended formulas for pepper[20] were used, in which it is suggested to make the applications by stages of development of the crop Table 1.

Statistical analysis. In morphological and agronomic assessments, once the data satisfied the assumptions of normality and homogeneity, analyses of variance were performed to test hypotheses about fixed effects, as well as comparisons of means of treatments using Tukey's test ($P<0.05$).

Analysis of variance also estimated the variance components for random effects. The analyses were performed using the infoStat software[21].

Response variables. i) Floor height (cm) (ADP). During the trial, periodic measurements were made every 15 days, starting 15 days after transplanting (ddt) until harvest, ADP was measured from the base to the top of the head with a tape measure[22]. ii) Number of leaves (NDH). The total per floor was counted[23]. iii) Head diameter (cm) (DDC). Every 15 days from head formation to harvest day with a caliper or caliper[24]. iv) Percentage of leaf area (PAF). It was evaluated every 15 days using the Canopy Cover Free application from the Play Store[23]. v) Root length (cm) (LDR). It was evaluated with a tape measure[23]. vi) Plant weight (g) (PDP). Once the harvest was done, when the head of the lettuce was compact, each one was weighed with its roots using a gram scale[24].

Management of the investigation. The experimental plot was implemented in the field in an area of 134 m^2. The floors were distributed at 0.20 m between plants and 0.8 m between rows. Each UE was com-

posed of 40 plants, transplanted into the field in a DBCA. The soil was removed using a rototiller, then crumbled to obtain finer particles for the development of seedlings on the platforms. Biocompost was applied to the soil at a rate of 75 kg per row of 33 m long. The ground was measured with the help of a winch, for the formation of the platforms of 0.80 m wide by 33 m long and a height of 0.15 m, finally, the leveling of the platforms was carried out.

For sowing in germination trays, the substrate was prepared with biocompost, guava leaf and local soil, in a 2:1:1 ratio. 10 kg of humus and a bag (10 g) of commercial mycorrhiza purchased at the Agropecuaria Del Valle in Jipijapa were put in to prevent the attack of pathogens that cause *damping off*. Once the substrate was prepared, the holes were filled with it, taking care to moisten it. The seeds of the cultivar were then sown in these trays. The trays were watered 2 times a day to maintain humidity.

The final transplant in the field was carried out in rows, for which holes were made with a depth of 0.15 m at a distance between plants of 0.20 m and 0.80 m between rows, then one plant per hole was transplanted. A coat of worm humus (50 g) was added to the transplant to encourage root development. The platforms were covered with a white plastic mulch on the side and black on the other side, in order to keep the temperature stable in the soil, control weeds, conserve moisture and prevent the loss of nutrients by leaching and evaporation.

To control mildew caused by the oomycete *Bremia lactucae* and other leaf spots, Metalaxyl + Mancozeb (Ridomil) (2.5 g L^{-1}) alternated with Chlorothalonil (2.5 mL L^{-1}), *Trichoderma* (3 mL L^{-1}) and *Bacillus subtilis* (3 mL L^{-1}) was applied from the eighth day after transplantation[25].

Pest control was carried out according to the monitoring and application of the damage threshold for the control of insect pests such as whitefly (*Bemisia tabaci*), bold (*Prodiplosis longifila*) and aphids (*Myzus persicae*), the application of Thiamethoxam (0.25 mL L^{-1}) was used, alternating with abamectin (2.25 mL L^{-1}), Confidor (0.60 g L^{-1}) and Neem (4 mL L^{-1}).), starting at 10 ddt[26].

The plots were irrigated with drip irrigation and the frequency was 2 to 3 times a day, for 1 hour, depending on the temperature. The harvest was carried out from 40 days ddt.

Results

Analysis of normality and homogeneity of variances. It was observed with the Shapiro-Wilks test ($P<0.05$), that there were no significant differences for ADP and NDH, for the LDR, PDP and flavor variables. For DDC and FAP, there were no significant differences ($P<0.01$).

The homogeneity of variances by the Levene test, ADP, NDH, DDC, PAF, LDR, PDP and taste were not significant ($P<0.01$).

The analyses of normality and homogeneity of variances suggested the continuity of the analyses of variance and the comparison of means of the treatments.

Analysis of morpho-agronomic and yield variables. The ANVA for cultivars and dates were highly significant ($P<0.01$) (Table 3), for ADP, NDH, DDC, and PAF, the percentages of coefficients of variation (CV) were between 4 and 10 %. There were also highly significant differences ($P<0.01$) for the Treat-

ment * Date interaction, so these effects are not independent.

Table 3 Analysis of variance for leaf count, leaf area percentage, leaf area index, head diameter and plant height

FV	gl	Medium squares			
		ADP (cm)	NDH	DDC (cm)	PAF
Rep	3	12.82*	22.83**	1.79ns	28.81**
Treatment	2	723.29**	1418.01**	542.82**	2171.99**
Date	2	3987.79**	11817.23**	2567.80**	22268.65**
Treatment*Date	4	24.44**	54.00**	31.26**	102.34**
Error	708	4.00	5.10	2.95	4.16
total	719				
Rep		10.35	9.68	8.23	3.55

*: Significant to P<0.05, **: Highly significant to P<0.01, ns not significant, ADP plant height, NDH number of leaves, DDC head diameter, PAF percentage of leaf area, Trat fertigation.

Table 4 Analysis of variance for number of leaves, percentage of leaf area, leaf area index, head diameter and plant height

FV	gl	Medium squares		
		LDR (cm)	PDP (g)	Sabor
Rep	3	12.10**	3039.57**	.08ns
Treatment	2	83.79**	38640.70**	.18ns
Error	6	1.84	267.56	.15
Total	11			
CV		27.34	9.82	7.99

*: Significant at P<0.05, ** highly significant at P<0.01, ns not significant, LDR root length, PDP plant weight, treated fertigation.

.

Table 5 Analysis of means of response variables

Treatment	ADP	NDH	DDC	PFA	LDR	PDP (g)	Sabor
2	**21.31 a**	**25.63 a**	**22.59 a**	**59.95 a**	**5.93 a**	**184.26 a**	4.88 a
1	18.54 b	23.59 b	20.08 b	58.14 b	5.08 b	173.33 b	4.80 a
3	18.11 c	20.79 c	19.90 b	54.08 c	3.89 c	141.93 c	4.79 a
DSH	.43	.48	.37	.44	.50	6.07	.14

Stockings with a common letter are not significantly different (P<0.05). ADP plant height, NDH number of leaves, DDC head diameter, PAF percentage of leaf area, LDR root length, PDP plant weight, 1: high fertigation, 2: medium fertigation, 3: basic fertigation (as the farmer does).

Table 6 Analysis of means using Tukey at P<0.05 probability for dates

Date	ADP (cm)	NDH	DDC (cm)	PAF
Date 3	**23.49 a**	**30.12 a**	**24.15 a**	**66.91 a**
Date 2	19.13 b	23.78 b	20.83 b	57.62 b
Date 1	15.34 c	16.10 c	17.60 c	47.65 c
DSH	.43	.48	.37	.44

Stockings with a common letter are not significantly different (P<0.05). ADP plant height, NDH number of leaves, DDC head diameter, PAF percentage of leaf area.
Date 1: 01/01/2023, Date 2: 10/01/2023, Date 3: 18/01/2023.

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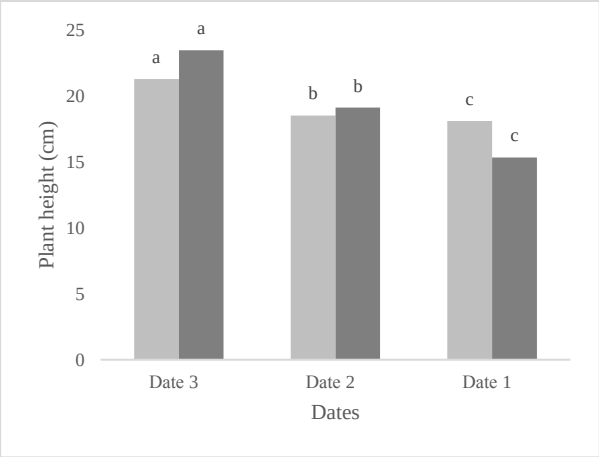
The ANVA of the effects of the treatments for the LDR, PDP, and taste variables, which had QOL between 8 and 27 %, there were no highly significant differences (P<0.01) (Table 4).

The comparison of means using the Tukey test (P<0.05) (Table 5) indicated that the T_2 treatment was outstanding for ADP, NDH, DDC and PFA, compared to the T_3 (control).

T_2 was outstanding in LDR, PDP and taste compared to the other 2 treatments (Table 4). In Table 6, the comparison of means using the Tukey test ($P<0.05$), date 3 was the most outstanding for the ADP, NDH, DDC and PAF.

Figure 1 Interaction between floor height and evaluation dates



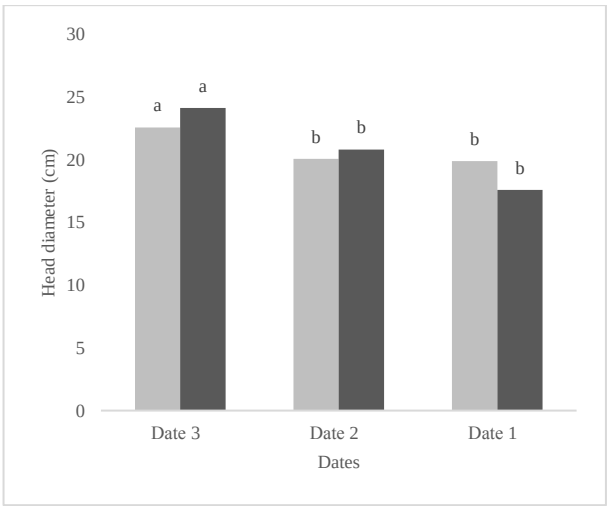
It was notorious to observe that there was interaction between the variables evaluated (Figure 1), a significant interaction is observed between the ADP and the date of evaluation, indicating that the ADP depends on the evaluation time, also, it was observed for the DDC, it depends on the evaluation time.

Discussion

The Starfighter cultivar from the company Rik Zwaan Rijk Zwaan[27]. It is an open green plant, with great vigour and yield, recommended for winter crops and especially for processing. This cultivar was used, because it was outstanding in previous research carried out[23] however, there was no known fertigation strategy to improve its productivity.

The ADP was 23.49 cm at 25-30 ddt, which was outstanding, in relation to Ríos Mesa et al.[28], who reported ADP of 25.8 cm on average. López Carhuatanta[29], applying calcium phosphonate and boron to lettuce plants of the Greak Lakes 659 cultivar obtained 25.40 cm of AP at harvest.

Figure 2 Interaction between head diameter and evaluation dates



The NDH at harvest was 25.63 on average at 25-30 ddt, which was excellent, in relation to Rojas Hidalgo[30], who applied calcium phosphonate, from the Greak Lakes 659 cultivar, was 16.4 leaves on average. López Carhuatanta[29], obtained 22.1 leaves at harvest.

The DDC at 25-30 ddt was 22.59 cm, Pechu Santisteban[31], determined that the DDC in 88 in Romaine lettuce were 8.50 to 18.00 cm on average. Ríos Mesa et al.[28], applying chemical fertilization, determined a DDC of 10.80 to 15.20 cm at harvest. All these results, there was a better response to the fertigation performed.

Chacha Barba & Chávez López[32] conducted research to evaluate the morpho-physiological and productive behavior of 2 lettuce cultivars, in a hydroponic cultivation system, in the nutritious and conventional field film technique. This experiment was developed at the Center for Research, Graduate Studies and Amazonian Conservation (CIPCA). The cultivars

studied were Cherokee RZ (81 - 36) and Starfighter RZ (81 - 85). The results were that the Starfighter cultivar had 11 leaves, 724 cm^2 of leaf area and 8272 kg ha^{-1} of yield. In our study, 25.63 leaves, 59.95 % leaf area and 11500 kg ha^{-1}, when a high dose of fertigation was applied.

It should be mentioned that the average annual temperature in Puerto la Boca is 24° C, which indicates that species in general must adapt to high temperatures. The Starfighter cultivar according to Rijk Zwaan[27], has a wide range of adaptation, this was notorious, being sown in summer the cultivar had a behavior suitable for fresh consumption.

The benefit of the use of mulching, drip irrigation and fertigation in the production of the Starfighter cultivar was notorious, which did not have any pest or disease attacks, and the quality of the leaves were fresh and without a spicy taste, which was observed in a previous study[23].

In summary, the results of this study suggest that modifications of the soil microenvironment, in part, moisture and nutrients, played diverse roles due to management practice such as plastic mulching associated with fertigation, and influenced various cellular processes, while the resulting soil nutrient supply had greater control over its composition. and there is still a lack of studies in the area on these effects and give signs of the benefits of this alternative, which contributes to increasing yields.

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Conflicts of interest

The authors declare that this research was carried out at the State University of the South of Manabí (Jipijapa Canton) and does not present conflicts of interest.

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Ethical considerations

The approval of the research by the Directorate of Research and Graduate Studies, the Ethics Committee, and the Research Committee of the Agricultural Career of the State University of Southern Manabí (UNESUM), (Jipijapa Canton), followed the guidelines established by these instances.

Limitations in the research

The authors point out that there were no limitations in the present research work.

Authors' contribution

Julio Gabriel-Ortega, planning of the experiment, statistical analysis, systematization, syntax, grammar and interpretation of the information. *María Fernanda Pineda Vásquez*, data collection, systematization and interpretation of information. *Gema Burgos*

López, transcription, systematization and revision of the document. *Jessica Morán Móran*, syntax, spelling, and revision of the document.

Access to data

The data and information of this research are present in the article.

Consent for publication

The authors, after reviewing the document, are considered approved for publication.

Use of Artificial Intelligence

We assume that the entire document was written based on ethical and professional criteria, and AI was not used to make the images or text.

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