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Research Note

Optimizing of tray arrangement for the production of hydroponic green fodder from *Avena sativa*

Otimização do arranjo de bandejas para a produção de forragem verde hidropônica a partir de Avena sativa

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ABSTRACT

Hydroponic green forage is an alternative from the point of view of nutritional supplement and it is estimated that the water savings in these systems can be significant, saving up to 90% compared to conventional irrigation methods. The objective of this research was to evaluate the arrangement of the trays in a hydroponic green forage production system with water recirculation, to determine the effect on the performance of the oat crop. The test consisted of 80 polyethylene trays; each one with an area of 0.167 m^2. In the evaluated treatments, the water flow was configured in two distinct ways. Nutrient solution (18-18-18) was applied, applying 90 grams to 150 liters of water. In Treatment A, the flow pattern alternates between levels in a zigzag pattern: at levels 4 and 2, water flows from the center to the sides, whereas at levels 3 and 1, it flows from the sides to the center, where the excess volume is collected. In Treatment B, the water flow is more uniform: at levels 4, 3, and 2, it is directed from the center to the sides, ensuring an orderly flow, while at level 1, it is channeled from the sides to the center towards the collection point. This configuration simplifies system management and facilitates efficient water drainage. To compare the treatments, the following variables were evaluated: plant height and total dry matter. The arrangement of the tray with water recirculation showed a significant effect on the dry matter yield of the oat crop. The arrangements that favored better performance and greater production of dry matter were the trays arranged facing outwards from the rack.

KEYWORDS: Efficient water use. Hydroponics. Intensive cultivation.

RESUMO

A forragem verde hidropônica é uma alternativa do ponto de vista de suplemento nutricional e estima-se que a poupança de água nestes sistemas pode ser significativa, poupando até 90% em comparação com os métodos de irrigação convencionais. O objetivo desta pesquisa foi avaliar a disposição das bandejas em sistema hidropônico de produção de forragem verde com recirculação de água, para determinar o efeito no desempenho da cultura da aveia. O teste foi composto por 80 bandejas de polietileno, cada bandeja possui área de 0,167 m^2. Foram aplicados quatro intervalos diários de irrigação, com duração de um minuto. Foi aplicada solução nutritiva (18-18-18), aplicando 90 gramas em 150 litros de água. Os tratamentos avaliados foram que o fluxo de água foi configurado de duas maneiras distintas. No Tratamento A, o padrão de fluxo alterna entre os níveis em formato ziguezague: nos níveis 4 e 2, a água flui do centro para as laterais, enquanto nos níveis 3 e 1, ela flui das laterais para o centro, onde o volume excedente é coletado. No Tratamento B, o fluxo de água é mais uniforme: nos níveis 4, 3 e 2, é direcionado do centro para as laterais, garantindo um escoamento ordenado, enquanto no nível 1, é canalizado das laterais para o centro em direção ao ponto de coleta. Essa configuração simplifica o manejo do sistema e facilita a drenagem eficiente da água. Para comparação dos tratamentos foram avaliadas as seguintes variáveis: altura de plantas e

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matéria seca total. A disposição da bandeja com recirculação de água apresentou efeito significativo na produtividade de matéria seca da cultura da aveia. Os arranjos que favoreceram melhor desempenho e maior produção de matéria seca foram as bandejas com disposição voltada para fora da rack.
PALAVRAS-CHAVE: Uso eficiente da água. Hidroponia. Cultivo intensivo.

INTRODUCTION

In Uruguay, agricultural activity and agro-industrial chains play a fundamental role in the national economy, serving as key drivers of economic growth, as measured by GDP. In 2021, livestock farming was the main employing activity in the agricultural sector, representing 44% of its activity and contributing 4.7% to GDP, followed by agriculture with 2.2% (MGAP 2023). Livestock farming, especially cattle breeding, relies heavily on natural grasslands as the main forage resource. The country maintains a strict policy of sustainable and environmentally friendly agricultural development, which positions hydroponic green fodder as an innovative alternative to explore, capable of optimizing the use of vertical space and freeing up land for other crops.

Hydroponic technology is presented as a sustainable and efficient alternative to conventional fodder production methods, particularly in arid and semi-arid areas (BOUADILA *et al.* 2022). This system produces HGF in controlled environments, such as greenhouses, using an aqueous medium instead of soil. Among the most commonly used seeds are oats, barley, corn, wheat, and sorghum (CELI-SABANDO & TORRES-AVELLAN 2023). According to VELÁSQUEZ *et al.* (2023), HGF is a live fodder with high digestibility and nutritional quality, ideal for feeding different species of livestock.

The HGF production process involves placing the seeds in polycarbonate trays without a substrate, where they germinate by applying water and nutrient solutions. To maximise space and create optimal conditions for seedling development, shelving and shading nets are used (NÚÑEZ-TORRES & GUERRERO-LÓPEZ 2021). The forage is harvested as 'forage bread,' which can be fed directly to the animals or stored for later use. This method ensures a balanced diet that includes proteins, energy, vitamins and minerals from leaves, roots and seed remains (BIRGI *et al.* 2018).

The main advantages of HGF include lower water use, efficient use of space, faster production cycles and improved nutritional quality (MORALES *et al.* 2020). Water is used efficiently and can be recycled (GIRMA & GEBREMARIAM 2018), while irrigation with nutrient solutions increases biomass yield and reduces cutting times (NÚÑEZ-TORRES & GUERRERO-LÓPEZ 2021). Furthermore, HGF is free of weeds, pests, and contaminants (JORDAN *et al.* 2018).

Hydroponic systems, by recirculating water and directing it directly to the roots, minimize losses through evapotranspiration, runoff and infiltration, producing higher dry matter yields while using less water. For example, producing 1 kg of HGF requires only 2–3 liters of water, achieving a dry matter content of 12-18%, depending on the forage species. This makes HGF a highly efficient and sustainable solution.

Hydroponic green fodder (HGF) production requires precise management of environmental conditions to ensure both efficiency and sustainability. Factors such as temperature, drainage, and tray arrangement play crucial roles in preventing problems and optimizing yield. As the minimum germination temperature increases, ensuring adequate drainage in trays is essential to avoid excess moisture and the appearance of fungal diseases that can compromise production (MARTINEZ *et al.* 2024). Tray arrangement directly influences drainage, air circulation, and water distribution, key factors to maintain an optimal microclimate and efficient irrigation.

Exploring different configurations helps identify strategies to optimize crop germination and growth, reduce management losses, and improve system sustainability. In this context, the present study analyzes how tray arrangement in a HGF production system with water recirculation impacts oat (*Avena sativa*) crop yield.

MATERIAL AND METHODS

The study was carried out in the greenhouse of the South-Central Regional Institute of the Technological University of Uruguay, in the town of Durazno. The greenhouse has the following dimensions: length 20 m, width 10 m (area of 200 m^2). The region is characterized by a humid subtropical climate, classified as (Cfa), according to the Köppen climate classification system. The annual average values of the parameters average temperature and relative humidity are 17 °C and 75%, respectively. The climogram of the internal meteorological conditions in the greenhouse during the test period is shown in Figure 1. The averages of the maximum, average, minimum temperature; RH; Evaporation and instantaneous solar radiation were: 31.9 °C, 10.2 °C, 18.4 °C, 68.2%, 1.8 mm/day and 411 W m^{-2}, respectively. The temperature fluctuations were: maximum (14.3 to 49.1 °C), average (9.3 to 28 °C), minimum (1.3 to 18.6 °C); Relative humidity (48.7 to 91.1%), solar radiation (32 and 849 W m^{-2}) and maximum evaporation 3.6 mm/day.

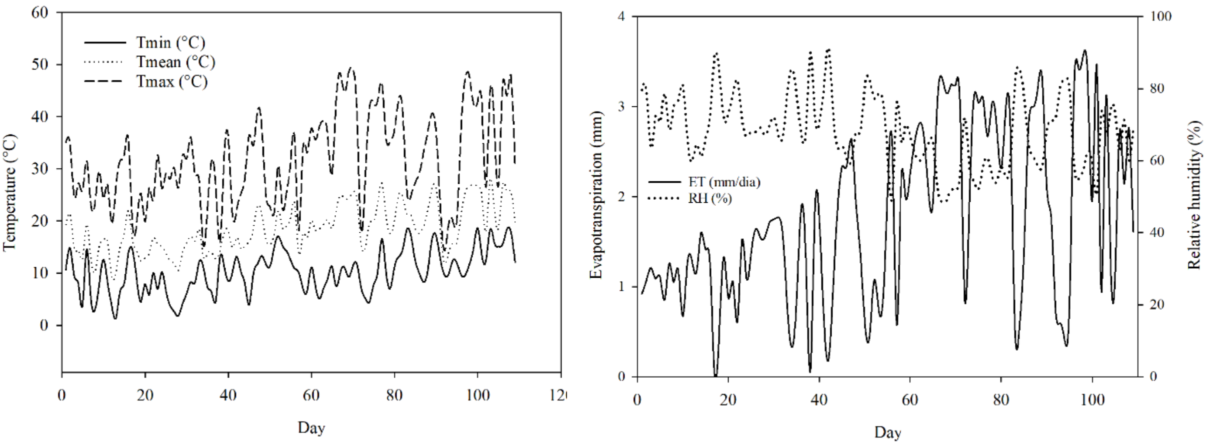

Figure 1. Climogram of internal climatic conditions in the greenhouse during the hydroponic green forage trial in the cultivation of oats (*Avena sativa*). from August 1 to November 17.

The test consisted of 80 polyethylene trays, each tray having an area of 0.167 m^2 (0.585 x 0.285 m). The sowing density was 0.713 kg/tray of dry seed, equivalent to 4.27 kg m^{-2}. The rack used for the production of green forage was a metal structure, with the following dimensions: length 1.5, width 1.08 m and height 1.8 m. The separation between levels was 0.3 m, the first level was separated from the ground surface by 0.5 m. This rack was made up of 4 levels, considering the first and the last as edges, evaluating the two middle levels. Ten trays were evaluated per level, five on each side, totaling 20 trays for each treatment. The percentage of inclination was 10%. The arrangement of trays on the racks for each treatment is shown in Figure 2.

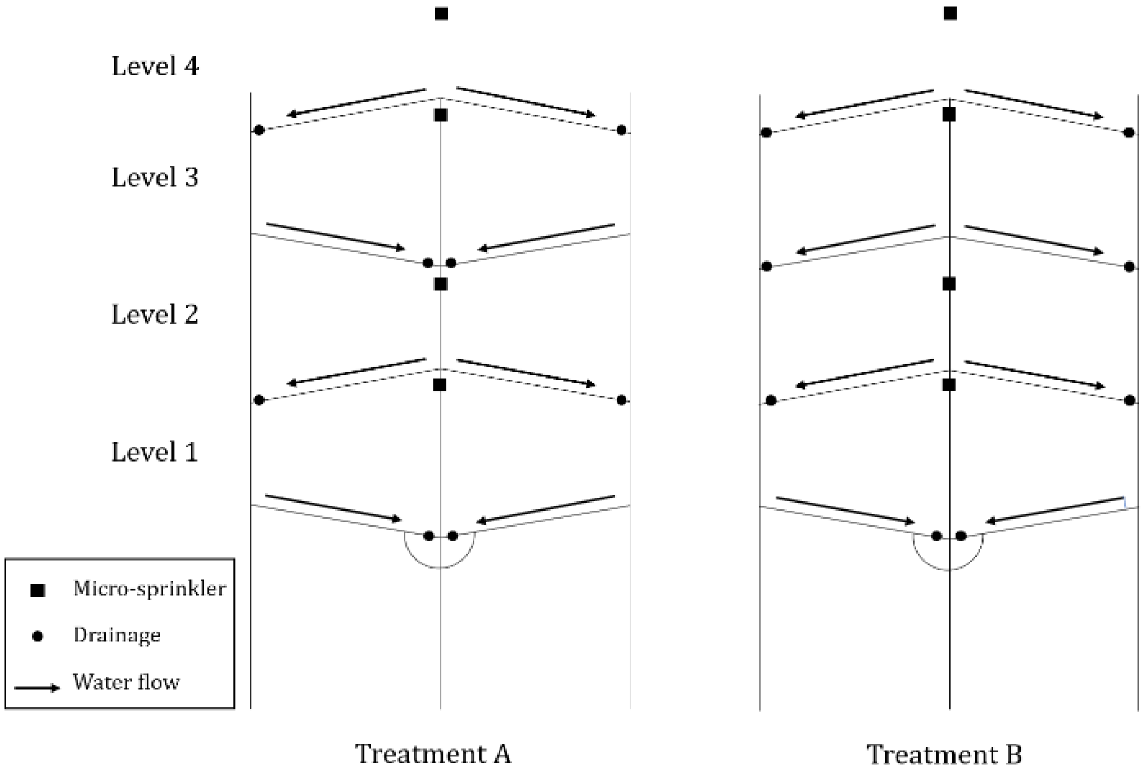

Figure 2. Arrangement of trays on the racks for the production of hydroponic green forage in the cultivation of oats (*Avena sativa*).

In Treatment A, the water flow pattern alternates between levels, forming a zigzag pattern. At Level 4, water is directed from the center to the sides, while at Level 3, it flows from the sides to the center. In Level 2, water is again directed from the center to the sides, and finally, in Level 1, it is directed from the sides to the center, where the excess volume is collected. This alternation allows the water to stay in contact with the tray surface for a longer duration, thoroughly moistening the forage, although it may increase the risk of moisture buildup if not properly controlled. In contrast, Treatment B exhibits a more uniform and consistent flow pattern across the upper levels. In Levels 4, 3, and 2, water flow is directed from the center to the sides, allowing for faster and more efficient drainage. However, in Level 1, water flows from the sides to the center, serving as the final collection level, where it directs water to the outlet pipe. This design simplifies system management by eliminating the need for multiple drainage pipes, promoting orderly water evacuation, and reducing water contact time with the trays.

The production process began by hydrating the seed, using 270 L tanks, where the seed remained submerged in water for 24 hours with an interval of 1 hour without water (FAO 2002). After 24 hours of the hydration process, the seeds were transferred to the trays with the respective established sowing density. At this stage the seed weight gain ratio was approximately 60% (±2). After placing the trays in the racks, they were covered by a shade mesh to prevent the entry of light for a period of 120 hours, to promote germination. Four daily irrigation intervals were applied (every 2 hours), lasting one minute each, using flat micro sprinklers of 30 L/h, with a coverage diameter of 0.9 m. The nutrient solution used was (18-18-18), applying 90 grams in 150 liters of water, replenishing it every two days. In the nutrient solution, the electrical conductivity parameters are monitored with a conductivity meter and pH with a ph meter (HANNA). The nutrient solution was generally kept constant with a pH between (5.5-6.5), as well as an electrical conductivity of 1500-2000 dS/cm and a water temperature of 9-11°C.

The following variables were evaluated: yield (green matter), plant height (PH), a millimeter ruler was used, where it was measured from the base of the plant to its apex; Dry matter (DM), initially, a partial drying was carried out to prepare the sample and be able to grind it, the samples were dried using a forced circulation oven at 60°C (between 24 and 72 hours) or until weight constant, and the partial dry matter content (PDM) was obtained. Subsequently, the PDM sample is ground and the residual dry matter (RDM) content is determined in a forced circulation oven at 100-105°C for 24 hours. Finally, to obtain the total dry matter content (DM), the RDM is corrected by the PDM.

The experimental design was completely randomized, each tray is an experimental unit. All variables were tested for normality, multiple comparison of means was performed using the Tukey method with a 5% probability level. Data processing was carried out with SAS® Version 24 statistical software.

RESULTS AND DISCUSSIONS

The average yield of green matter (GM), the percentage of total dry matter (DM) and the plant height (PH), according to the arrangement of the tray for the production of hydroponic green fodder (HGF) for oat cultivation, are shown in Figure 3. The harvest was carried out after 14 days, when the crop reached a height of 15 cm (±2 cm). According to the statistical analysis, significant differences in the dry matter variable (DM) ($p < 0.05$) were found between treatments A and B.

The results show that treatment A achieved a production of 72.77 kg m^{-2} of GM, while for treatment B, the average production was 71.25 kg m^{-2}. On the other hand, in terms of dry matter, there was a difference of 3.88% in favor of treatment B, with a general average of 13.31% for treatment A and 17.19% for treatment B. The greatest differences in performance were obtained in levels 1 and 2, while level 3 showed similar performances between both treatments. The main differences in performance were in biomass production between both treatments, but these hydroponic green forage production systems as a nutritional supplement require obtaining a higher dry matter content. This concentration of higher dry matter content could have been generated due to the shade or less solar radiation that the tray arrangements in treatment A have, which influences greater plant growth, as indicated by the results of plant height (19 cm on average).

Plants in shady conditions often grow taller to seek solar radiation, a phenomenon known as positive phototropism, and this effect could influence obtaining a lower dry matter content and a lower concentration of nutrients. Another factor that can influence biomass production is that in treatment A, the drained and circulating water is greater, receiving drainage from the upper levels, compared to treatment B, where the recirculation of water through the levels is less. Only level 1 in treatment B receives all the drainage from the higher levels. In general, we could also mention that this difference in performance is due to the arrangement of the tray, it can be caused by the incidence of solar radiation, aeration and drainage of the trays, in addition to the incidence and/or uniformity of the application of the irrigation sheet of the micro-sprinklers. This arrangement can be favorably influenced in the accumulation of dry matter in the production of hydroponic green forage in oats. The results in dry matter content are consistent with those reported by ALBERT *et al.* (2016), who indicated an oat yield in hydroponic green forage with a DM content of 16.12% for 10 days of harvest and 13.75 % for 12 days of harvest. On the other hand, RAMOS *et al.* (2021) highlight a yield of 19.80% of dry matter with fertigation. According to MORALES *et al.* (2020) they obtained yields of 13.2% with the use of fertilizer. According to CONDOY *et al.* (2023) they indicate yields of 16.6% of DM.

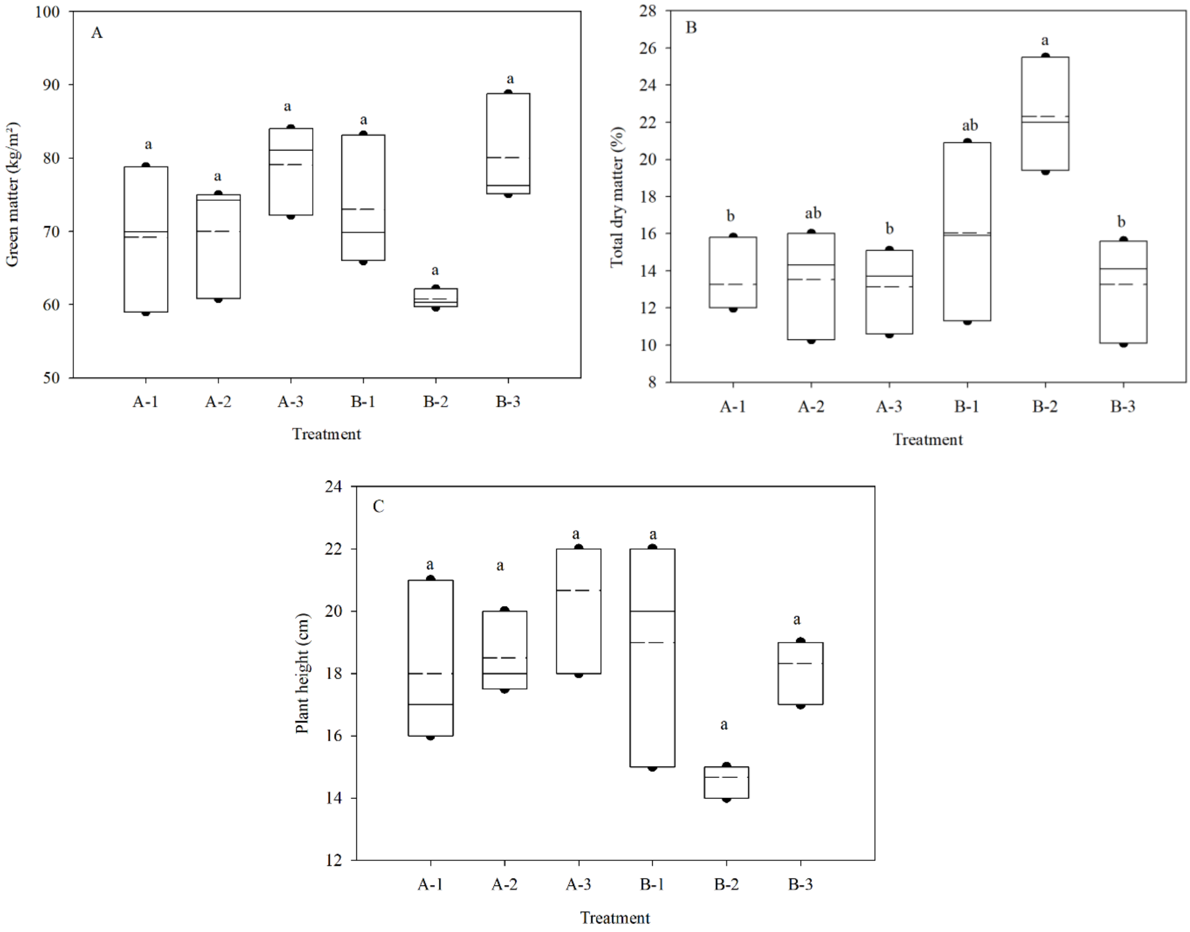

Figure 3. Green matter (A), total dry matter (B) and plant height (C), according to the tray arrangement (level 1, 2 and 3) and treatment (A and B), in the production of green forage hydroponic in the cultivation of oats (*Avena sativa*). Different letters indicate significant differences for the Tukey test ($p<0.05$).

The plant height variable, according to the statistical analysis, did not show significant differences ($p<0.05$) between both treatments. According to MEJÍA-CASTILLO & NÚÑEZ (2019), the yield in the cultivation of hydroponic green forage can be influenced by the days of harvest, genotype, type of fertilization, amount of nitrogen applied, the salinity concentration of the water and environmental variables. In addition to these variables, it could be mentioned that the arrangement of the trays could be a factor to consider in hydroponic green forage production systems. By partially replacing concentrated feed with HGF, it is possible to reduce production costs. The factors that influence biomass production are related to agronomic management, basically seed density, harvest time and type of fertilization; as well as the genotype or forage species used. Due to its high protein content, HGF can be used as a nutritional supplement for different livestock species, significantly improving milk production and composition, weight gain, feed consumption and nutrient digestibility (CISNEROS-SAGUILÁN *et al.* 2023). Therefore, this technology represents a viable and economical alternative to counteract the shortage of fresh and nutritious food (CISNEROS-SAGUILÁN *et al.* 2023).

According to the results obtained, the relationship between water consumption with recirculation in the production of hydroponic green forage in oat cultivation was 1 kg/DM, for every 18 liters of water. These results are within the range mentioned by FAO (2002) where they indicate that a total of 15 to 20 liters of water is consumed per kilogram of dry matter obtained. The production of HGF is a viable and sustainable alternative, with a high protein content for dietary supplementation, and also promotes the efficient use of water and the sustainable development and circular economy of production systems.

CONCLUSION

The arrangement and inclination of the trays in a hydroponic green fodder production system with water recirculation had a significant effect on the dry matter yield of oat (*Avena sativa*). Trays arranged facing outwards from the rack were identified as the most suitable configuration, as they optimize factors such as drainage, aeration, and uniform water distribution, contributing to improved crop performance.

NOTES

AUTHOR CONTRIBUTIONS

Conceptualization, methodology, supervision, writing – original draft, and writing – review & editing: Rodríguez-Padrón, R. A.; Validation, data curation, and supporting activities: Carrossio Escudero, A. A.; Formal analysis, investigation, and writing – review & editing: Mautone Rodríguez, W. A.; Project administration and funding acquisition: Rodríguez-Padrón, R. A. All authors have read and agreed to the published version of the manuscript.

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INSTITUTIONAL REVIEW BOARD STATEMENT

Not applicable for studies not involving humans or animals.

INFORMED CONSENT STATEMENT

Not applicable because this study did not involve humans.

DATA AVAILABILITY STATEMENT

The data can be made available under request.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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