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OPTIMIZING HYDROPONIC FORAGE PRODUCTION: THE IMPACT OF WATER QUALITY ON WHEAT GROWTH AND YIELD

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ABSTRACT

This study investigates the impact of water quality on the productivity of hydroponic wheat forage. Two water sources were compared: water from a local lake and water from a fish farming center. After a six-week acclimation period, repeated experiments were conducted for 17 days each to evaluate the growth and productivity of hydroponic wheat. The results show that lake water, despite its higher mineral content, led to faster growth and greater final height of wheat plants compared to fish farming water. Dry matter yields were also significantly higher with lake water (36.6 tons/ha) compared to fish farming water (22.5 tons/ha). Analyses revealed significant differences in ash content, indicating a higher mineral accumulation in forage grown with lake water. These findings suggest that the source and quality of water play a crucial role in the productivity of hydroponic forage, offering a viable and sustainable solution for small-scale farmers, particularly in regions where traditional forage production is challenging. This technology promises to enhance the sustainability of future livestock farming systems.

Keywords: water quality, growth, productivity, wheat.

INTRODUCTION

Currently, the hydroponic forage production system is an alternative technology used to produce animal feed without using soil as a planting medium. Instead, it uses water with or without a mix of dissolved minerals (Ceci et al., 2023; Harerimana et al., 2023). The hydroponic forage production technique converts energy-rich food sources like barley or wheat grains into green fodder. This method requires less soil, water, and labor, and it enables year-round production regardless of climatic conditions. Additionally, the fresh forage produced in hydroponic systems is known for its high digestibility (Harerimana et al., 2023).

Hydroponic cultivation has been integrated into aquaculture systems to produce a valuable byproduct by recovering accumulated nutrients in the water and producing green forage (Snow et al., 2008). In these integrated systems, nutrient-rich effluents from the aquaculture facility provide moisture and nutrients for plant production (Ghaly et al., 2005).

MATERIALS AND METHODS

The Hydroponic System: This study was conducted from January to April 2023, including a 6-week acclimatization period to determine the optimal water quantity for wheat germination. After the acclimatization period, the experiments were conducted and repeated three times, each lasting 17 days. The experiments took place at the Faculty of Istom located in western France.

The wheat species cultivated was Rgt Sacramento, provided by a local farmers' cooperative.

A hydroponic system was designed and installed at Istom's experimental unit. The hydroponic unit featured a greenhouse structure with a three-tier system and manual spray irrigation to control the water amount used in each tray. Trays with an area of 600 cm² each and a reservoir height of 2 cm were used.

During the experimental phase, each treatment involved 3 trays per repetition, with a wheat density of 200 g/m². Water spraying of 200 ml per tray was performed twice daily at 8 am and 6 pm, five times a week. Each day of the experiment, the germination height was measured during the morning spray, and mold or abnormal growth was monitored. One tray from the first repetition was excluded due to abnormal germination delay.

Temperature was controlled and maintained between 19°C-20°C. No artificial lighting was used, relying on a natural light cycle of approximately 12 hours of light and 12 hours of darkness.

Once a repetition was completed (17 days), the forage was collected from the six trays, and the fresh yields of each tray were weighed. The forage was then dried in an oven to determine the dry matter content of each tray and stored until all three repetitions were completed to conduct chemical analyses simultaneously.

Treatments: Two types of water were used in these experiments: the first was sourced from a local lake near Istom's experimental unit. This water was collected once during the acclimatization period and again before starting the actual experiments. It was stored in closed, opaque containers and used daily for spraying at 200 ml per tray.

The second type of water was obtained from a fish farming center. This water was filtered and treated by the center to remove waste and food residues.

Chemical Analysis: Immediately after each series of experiments, the fresh forage was collected, and the productivity of each tray in each treatment was weighed. Each sample was then placed in an oven to obtain the dry matter within 72 hours. These samples were stored in bags until the chemical analyses were performed. The forage samples were analyzed using proximate analysis according to AOAC (AOAC, 2004).

Water quality analyses were performed before each repetition using specialized test strips for these types of analyses.
The Anova test using the R system was employed to compare means, with a significance level of 5% adopted for all results.

RESULTS AND DISCUSSION

The results of the water quality analysis reveal a difference in the quality of water collected from the local lake and the fish farming center (Table 1). Contrary to expectations, the fish farming water was found to be purer than the local lake water. Total water hardness is an indicator of water mineralization by divalent alkaline earth cations, which can precipitate as calcareous deposits. It is determined solely by calcium and magnesium ions. Water is classified according to its hardness as follows:Very soft: hardness less than 7; Soft: 7 < hardness < 15 ; Moderately hard: 15 < hardness < 30 ; Hard: 30-40 ; Very hard: more than 40

Table1. Average values of water parameters measured before each repetition

Water parameters	Lac Water	Fish Farming Water
Total water hardness (mg/L)	25 ± 3^{a}	0^{b}
Carbonate Hardness KH (mg/L)	80 ± 9^{a}	60 ± 3^{b}
Nitrate(NO3-)(mg/L)	25 ± 4^{a}	10 ± 0.5^{b}
Chlore (mg/L)	0	0
pH	8±0.3	6,8±0.1

The means in each row that are followed by different letters are significantly different with a 5% probability.

As shown by the analysis results in the table above, the lake water is considered moderately hard and falls within the upper range (25 mg/L), while the fish farming water, after filtration, is classified as very soft, containing no traces of magnesium or calcium.
The carbonate hardness (KH) of the water corresponds to the amount of carbonates present in the medium, indicating its capacity to stabilize the pH. Our results show that the carbonate hardness in lake water is 33% higher than in fish farming water (80±9 vs. 60±3, $P<0.05$).
Water analysis reveals that both types of water contain nitrates (NO_3^-), with a significant difference between the two samples. Nitrate (NO_3^-) is an ion produced during the nitrogen cycle in water, often responsible for pollution. Its natural concentration in waters, in the absence of fertilization, ranges from 5 to 15 mg/L. The nitrate concentration in lake water is two and a half times higher than in fish farming water, 25±4 vs. 10±0.5 mg/L for lake and fish farming water, respectively ($P<0.05$).

Effect of Water Quality on Hydroponic Barley Growth

Figure 1 shows the daily growth of hydroponic barley sprayed with two types of water, from the first day until harvest after 17 days.

From the first to the twelfth day, no difference was observed in the growth of barley between the two treatments. However, starting from day 13, the growth rate began to differ depending on the water used. Barley grown with lake water outperformed barley grown with fish farming water. The three-leaf stage began on day 14 for the lake water treatment and on day 15 for the fish farming water treatment. From day 15 to day 17, the growth rate differences between the two treatments became significant.

The average height of the three trays of barley on day 15 was 123 mm for fish farming water versus 135 mm for lake water. By the final day (day 17), the barley height reached 165 mm for lake water and 141 mm for fish farming water.

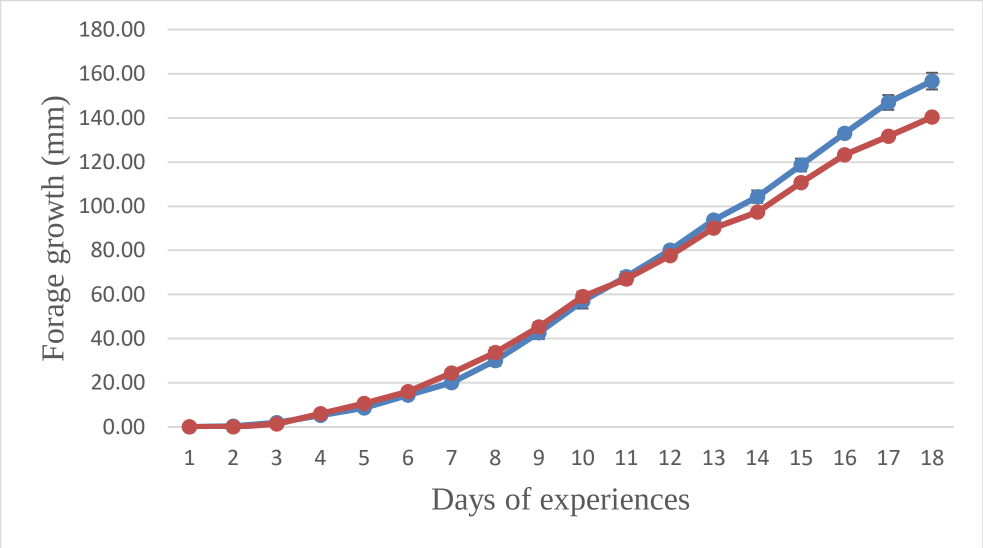

Figure1: shows the average daily growth of barley depending on the type of treatment, with SD for each day

The * shows a significant difference at level 5%

Fresh and Dry Matter Yields: The results shown in Table 2 present the average yield of fresh forage collected immediately after each experiment, as well as the average dry matter yield according to the type of treatment. These results indicate that the type of water impacts the amount of forage produced. Although the fresh forage yield produced with lake water was higher than that produced with fish farming water (100.16 T/Ha vs. 98.5 T/Ha for lake water and fish farming hydroponic forage, respectively), this difference is not significant (P=0.6).

Table2: The means of forage yield in fresh and dry materials by tray ± SD

Hydroponic fodder yield	Wheat fish farming water	Wheat lake water
Average fresh material per tray (g)	591 ± 10^{a}	601 ± 9^{a}
Average dry matter per tray (g)	135 ± 14^{a}	220 ± 23^{b}

The means in each row that are followed by different letters are significantly different with a 5% probability.

In contrast, the dry matter from fresh forage dried in an oven at 70°C for 72 hours showed a significant difference. As shown in Table 2, the dry matter yield from forage treated with lake water reached 36.6 tonnes per hectare, while the dry matter yield from fish farming water was 22.5 tonnes per hectare.

Ash analysis revealed significant differences between the forage samples based on the type of water used. Our results indicate that the ash content in lake water forage samples was 34.7% DM (347±78 g/kg DM) compared to only 27.38% DM (273±42 g/kg DM) in fish farming water samples.

The analyses of organic matter (carbohydrates, lipids, nitrogenous materials) are still ongoing

The aim of this experiment was to understand the effect of the water source on the productivity of hydroponic forage. Initially, it was hypothesized that fish farming water, rich in waste and nitrogenous substances, would accelerate the growth process and increase productivity (Snow et al., 2008; Ceci et al., 2023). Some cereals (wheat, barley, and oats) grown hydroponically have significantly reduced the pollutant load in wastewater and aquaculture water. However, during the two-week acclimatization experiments, it was found that the fish farming water was treated, filtered, and very low in organic matter. Consequently, we compared the effects of fish farming water with water sourced from a local lake.

Within 24 hours of starting the experiment, the seeds in all trays began to absorb water and swell. After 2 days, the radicle and plumule emerged from the seed coat and were visible in most seeds. During the germination period, the crops in all trays grew rapidly and uniformly regardless of the water type used, appearing healthy with a green color, and no signs of mold or rot. Until the thirteenth day, no growth differences were observed between the two treatments. The three-leaf stage began on day 14 for the lake water treatment and on day 15 for the fish farming water treatment. From day 15 to day 17, the growth rate differences between the two treatments became significant.

The average height of the barley trays on day 15 was 123 mm for fish farming water versus 135 mm for lake water. On the final day (D17), the barley height reached 165 mm for lake water and 141 mm for fish farming water.

Several studies have demonstrated the ability of cereals grown hydroponically to reduce mineral content (Clarkson and Lane et al., 1991) and nutrient content (Kamal and Ghaly, 2002) in wastewater. According to numerous references, the mineral and waste content of the water affects the growth rate of hydroponic forage crops. According to Snow et al. (2008), growth rates and forage height vary depending on the species, with wheat reaching 19 cm versus 25 cm for barley at 21 days of hydroponic culture under the same treatment. Al-Karaki and Al-Hashimi 2012 found that plant height varies within the species, with heights of 18.7, 20.3, and 22.7 cm for three wheat varieties (ACSAD 176, Rum, and Local, respectively) during a 10-day hydroponic production cycle. However, Clarkson and Lane et al. (1991)

achieved 20 cm in 10 days using aquaculture water from Cyprinus carpio and Oncorhynchus mykiss, and up to 25 cm with Tilapia aquaculture water (Kamal and Ghaly, 2002). These references suggest that factors leading to differences in growth rates and plant heights are varied and complex, potentially due to differences in plant species or even plant variety. It appears that water content and source play a significant role in growth rates. This hypothesis is supported by the significant increase in ash content (minerals) in the forage extract from lake water (34.7% vs. 27.3%), indicating mineral accumulation in the resulting feed.

The hydroponic system reduces nitrite presence in water using cereals. Ghaly et al. (2005) reported a decrease in NO_3^- from 76.7% to 75.1% using oats and from 68.8% to 64.8% using barley. In our study, the higher nitrate content in lake water compared to aquaculture water could have contributed to the rapid forage growth.

Fresh forage yields were 100.16 T/Ha vs. 98.5 T/Ha for lake water and fish farming hydroponic forage, respectively, with dry matter yields of 36.6 tonnes per hectare for lake water and 22.5 tonnes per hectare for fish farming water. Al-Karaki and Al-Hashimi (2012) found yields of 113 tonnes per hectare with 22.9 tonnes/ha of dry matter. However, other studies have reported lower yields, with Snow et al. (2000) obtaining 64.59 tonnes/ha of fresh matter and Saidi and Abo Omar (2015) reporting 37.03 tonnes/ha. Forage productivity of hydroponic wheat varies across studies and also for other cereal species. Barley forage yields, according to Al-Karaki and Al-Momani (2011), were 222, 236, and 281 tonnes/ha for three barley varieties: ACSAD176, Rum, and a local cultivar, respectively, with dry matter yields of 27.1, 28.6, and 33.7 tonnes/ha.

Seed density, light intensity, and materials used for root support also influence these yields. Pettersen (1987) reported yields ranging from 1 to 65 tonnes/ha depending on light intensity and root support materials used.

CONCLUSION

Hydroponic forage production systems generate large quantities of nutritious and palatable green feed for livestock. Hydroponic germination of wheat using locally available materials has the potential to enhance the technical and economic viability of this technology among small-scale farmers. The quality and source of water play a crucial role in the productivity and nutrient content of these feeds. Regardless of the water source, hydroponic forage productivity exceeds that of traditional forage, making this method promising for areas where conventional forage production is challenging. Utilizing this technology can help sustain livestock farming in the future and create a more sustainable farming system.

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