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Research Article

Tuber Yield of Radish (*Raphanus sativus* L.) as Affected by Different Frequencies of Hydroponic Waste Nutrient Solution Application

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ABSTRACT

In this study, the tuber yield of Radish (*Raphanus sativus* L.) was explored under lahar-laden soil conditions treated with hydroponic waste nutrient solution at a different frequency. The experiment was arranged in a randomized complete block design (RCBD) with 4 treatments and 3 replications at Lahar-laden Technology Demonstration Area, President Ramon Magsaysay State University, San Marcelino Zambales. T1 (no application; control), T2 (once a week), T3 (twice a week) and T4 (thrice a week). Traits such as tuber length, tuber diameter, tuber weight (per plant), and tuber yield (per m^2) were measured; means of treatments were then subjected to analysis of variance (ANOVA) followed by mean comparison test with Tukey's Honestly Significant Difference Test. Rank in root tuber yield in all variables brevity of similar treatments had a $P \langle 0.001$ significant effect on root tuber yield. The first rank in maximum tuber length (21.40 cm), tuber diameter (45.03 mm), tuber weight per plant (132.09 g) and yield (6.60 kg/m^2) recorded at T4 level remained higher than other treatment units however the difference was found statistically significant up to 0.05% level of significance. T3 the next highest, and control had the lowest. Mean tuber weight per plant and yield (kg/m^2) showed an obvious dose-response relationship with significant differences among means between all treatments. Based on the results, the application of hydroponic waste nutrient solution more frequently can significantly improve radish production, and applying hydroponic waste nutrient solution three times a week was the best treatment from this study. The results indicate that the nutrient-solution can be reused and that it is an efficient growth parameter for the cultivation of radish.

Keywords: *Circular agriculture, Lahar-laden soil, Radish, Tuber yield, Nutrient reuse, Waste nutrient solution*

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Introduction

Radish (*Raphanus sativus* L.) is a short-duration root vegetable crop, and its marketable value is highly dependent on the development of relatively large enlarged storage root. Since the consumed part is the tuberous root, radish is very responsive to nutrient supply, primarily in early and mid-growth stages when roots of enlargement are established (Reis et al., 2024). The amount and timing of nutrients in hydroponic radish affect taproot growth, fresh weight and marketable size (Li et al., 2014; Sakamoto & Suzuki, 2021).

Reyes and Neue (1991) revealed that the lahar supports a number of crops given the right management and cultural practices. The volcanic material is virtually devoid of carbon and nitrogen. It has enough phosphorus but it is not in available form. This gives means of moderate solubility of cautions, but a low ability to accumulate and transport warnings. Sulfate values were at expected, normal levels. Even though the young volcanic ejecta is acidic, the pH is near neutral to alkaline. Lahars are also more acidic.

Hydroponics, as a growing technique for vegetable production, offers better control over water and nutrient application; however large amounts of residual nutrient solution are produced from post-crop cycles or the replacement of aged solutions. Instead of discarding this effluent directly, nutrient reuse has been suggested as a more sustainable approach since the remaining solution may still contain agronomically useful nutrients. Note that hydroponic nutrient-solution management reviews stress that proper monitoring and reuse can greatly improve nutrient-use efficiency and waste, if solution quality is properly renewed (Fathidarehnijeh et al., 2024). In the wider circular-agriculture literature, recovering nutrients from waste streams is similarly acknowledged as a relevant pathway to close nutrient loops and reduce fertilizer loss and environmental loading (Rosemarin et al., 2020).

This problem is especially paramount for radish because root growth has been found to be dependent on nutrient timing. Li et al. (2014) found that nitrate supply and nutrient delivery timing affected the hydroponically grown radishes growing to a size suitable for market, whereas Sakamoto et al. (2021) demonstrated that nutrient deficiency during early growth inhibited taproot growth more strongly than late- imposed nutrient deficiency. These studies suggest not only that nutrient availability but the timing and continuity of availability can mediate yield performance as well.

Similarly, data pertaining to reused hydroponic nutrient solution also supports its agronomic value. In young radish grown in a greenhouse, Hong et al. (2022), mixed applications of waste nutrient solution and nitrogen fertilizer increased fresh weight, root length, and root circumference in comparison to the untreated control, confirming that waste nutrient solution can be considered a supplement of fertilizer input. More generally, radish development and yield are highly sensitive to improved nutrient management such as the supply of key macronutrients including nitrogen and magnesium (Yousaf et al., 2021). However, little field-plot evidence is available on the frequency of hydroponic waste nutrient solution application required to maximize tuber yield under open-soil conditions. The study dealt with that gap by investigating radish tuber yield under different frequencies of hydroponic waste nutrient solution application.

Here we have investigated the effect of varying application frequencies of hydroponic waste nutrient solution on radish tuber length, tuber diameter, tuber weight per plant and tuber yield per m^2 as well as knowing which treatment obtained highest yield performance.

Materials and Methods

Study site and experimental design

Conducted at the Technology Demonstration Area of Lahar-laden, College of Agriculture, President Ramon Magsaysay State University, San Marcelino Campus, Zambales, Philippines in 2025 cropping season. Four treatments with three replications were used to lay out the experiment in a randomized complete block design (RCBD), making twelve experimental plots. Each plot was 2 x 2 m in size, while the treatments were T1 - (control) no application, T2 - once-a-week application, T3 - twice-a-week application and T4 - thrice-a-week application of hydroponic waste nutrient solution.

Plot preparation, planting, and crop management

Weed and debris were removed to prepare a total of twelve plots, and 2 kg of decomposed cattle manure was added per plot to ameliorate the lahar-laden soils. After preparing plots, rice straw mulch was added. Radish seeds was direct seeded at a 10 x 20 cm spacing (two seeds per hill, ~200 hills/plot). Two weeks after sowing, thinning was done to leave a good seedling on the hill. Watering, as well as protection against pests, were applied equally to all plots. Harvesting was done six weeks post-sowing.

Source and application of hydroponic waste nutrient solution

The nutrient solution of the hydroponic waste was gathered from the Kratky-method lettuce plant in the demonstration site. The average pH value is 5.68 and the electrical conductivity (EC) is 1539.66. Treatment application was from the second week after sowing to the fifth week. Each treatment frequency of the solution was applied as a soil drench through 2 L/m^2. Other cultural practices were maintained uniformly so that differences in treatment could be attributed primarily to the frequency of application of the nutrient solution.

Data collection and statistical analysis

Tubers were measured for length from the crown to end of tuber with a tape measure. The tuber diameter was measured at the widest part of the tuber using digital caliper. A digital weighing scale was used to record the tuber weight per plant. Tuber yield per m^2 was estimated from tuber weight and the density of the plant stand. Mean separation using Tukey's honest significant difference (HSD) test at 5% level of significance in Analysis of variance for RCBD.

Results and Discussion

Table 1. Summary of treatment means for radish tuber-yield variables.

Treatment	Average Tuber Length (cm)	Average Tuber Diameter (mm)	Average Tuber Weight (g)	Average Tuber Yield (kg/m^2)
Treatment 1 (control)	14.93^{c}	39.23^{c}	87.76^{d}	4.39^{d}
Treatment 2 (Once a week)	18.03^{bc}	40.86^{b}	107.81^{c}	5.39^{c}
Treatment 3 (Twice a week)	19.73^{b}	42.10^{bc}	120.17^{b}	6.01^{b}
Treatment 4 (Three times a week)	21.40^{a}	45.03^{a}	132.09^{a}	6.60^{a}

Note: Means followed by different letters within a column are significantly different at $p \leq 0.05$ (Tukey's HSD).

Tuber length

Means tuber length differed by treatment ($F = 54.55$, $p < 0.01$). The shortest tubers were produced in the control (14.93 cm) as tuber length improved to 18.03 cm, 19.73 cm and 21.40 cm for T2, T3 and T4 respectively All fertilized treatments were significantly longer than the control according to Tukey's HSD, with T4 significantly longer than T2. The differences among T2 and T3, and T3 and T4 were not statistically significant. This indicated that the highest gain occurred when waste nutrient solution was applied compared to control (without application), which further increased with more applications.

This pattern fits with studies showing that radish tuber growth is very sensitive to nutrient timing. Li et al. (2014) found that the timing and interval of nitrate supply affected hydroponic radish growth to a marketable size, whereas Sakamoto et al. (2021) observed that a nutrient limitation applied in early development limited taproot expansion. The increasing tuber lengths recorded in T3 and T4 indicated that replenishment of residual nutrients at shorter intervals would support a better nutrient availability during the period of rapid root enlargement. Hong et al. (2022) also found that in young radish cultured on waste nutrient solution reported the larger tuber length of treated than untreated control.

Tuber diameter

Treatment effects on tuber diameter were also significant ($F = 52.91$, $p < 0.01$). Mean tuber diameter ranged from 39.23 mm in the control to 40.86 mm in T2, with T3 and T4 averaging 42.10 mm and 45.03 mm, respectively. Tukey's HSD showed that tubers of T4 were significantly wider than all other treatments, while tubers of T3 were significantly wider than the control. T1 and T2 and T2 and T3 were not significantly different, suggesting that the frequency of application (two as opposed to one per week) had a greater effect on tuber thickening than an increase in loading rates.

This suggests that repeated addition of nutrients improved the thickening process of radish tubers, which may have occurred because a continuous supply of nutrients allowed assimilation to be repeatedly produced and partitioned to the root. Fathidarehnijeh et al. (2024) highlighted that hydroponic nutrient-solution management has a substantial influence on crop performance because the output of substrate metabolism heavily relies on the concentration and balance between macro- and micronutrients, respectively. Yousaf et al. (2021) also observed that enhanced nutrient supply boosted growth and yield characteristics in radish including root size parameters. The larger diameter found in the T4 can be attributed to the fact that more favorable nutrient environment for tuber enlargement was kept by nourishing their plants three times a week, as it has been done in this study.

Tuber weight per plant

There were very clear treatment separations for fresh tuber weight per plant ($F = 211.95$, $p < 0.01$). Mean tuber weight increased significantly over time, with mean weights of 87.76 and trend T1 mean (T2, 107.81 g; T3, 120.17 g; and T4, 132.09 g) Tukey's HSD showed that all pairwise comparisons were significant with a strong dose-response relationship between application frequency and fresh tuber mass. This result demonstrated that even incremental increases in application frequency translated to measurable differences in yield per plant, and the difference was statistically significant.

Although based on crop length and diameter, fresh root weight is an integrative expression of radish yield. The current findings are in concordance with those of Hong et al. (2022) observed that the fresh weight of young aerobic radish plants cultivated with waste nutrient solution was significantly greater than that of untreated plants. They also echo Li et al. (2014) whose study demonstrated that radish fresh weight is determined for a large part by the rate of nutrient availability and with Yousaf et al. (2021) and improved yield traits of radish with better nutrient management. As the hydroponic waste nutrient solution utilized in this study was applied as a supplementary nutrient source, the steady increase in tuber weight from T1 to T4 indicates that enhanced application frequency minimized nutrient limitation during the root-bulking stage.

Tuber yield per m²

Tuber yield estimated per m^2 followed a similar trend as tuber weight and was significantly different ($F = 206.42$, $p <0.01$) between the treatments; The control produced 4.39 kg/m^2, compared to T2 (5.39 kg/m^2), T3 (6.01 kg/m^2), and T4 (6.60 kg/m^2). Tukey's HSD indicated all pairwise comparisons were significant and thus every increase in frequency improved plot-level productivity. In the experimental treatments, this led to a yield increase of about 50.3% by T4 compared with control; and T3 and T2 showed a 36.9% or less than 22.8% increase in yield based on control specimens, respectively.

These increases support a case for nutrient-solution reuse contributing to productivity and resource efficiency. Rosemarin et al. (2020) underscored nutrient recovery and reuse as key circular agriculture strategies, and Fathidarehnijeh et al. (2024) stated that a higher precision in nutrient management may lead to improvements in hydroponic systems and will ultimately increase nutrient-use efficiency. The current findings expand on that reasoning to the field application of waste nutrient solution as well: if applied frequently enough, residual nutrients contributed to higher radish yield instead of being a wasted effluent stream. Similarly, the positive response to frequency indicates that management is important, because agronomic value of reused solution will not be based solely on its availability but how often it gets delivered to the crop.

Conclusions and Recommendations

Conclusion

Tuber yield of radish was significantly influenced by the frequency of similar hydroponic waste nutrient solution application. The control always shows the lowest values for tuber length, tuber diameter, tuber weight per plant and yield per square meter. The yield was enhanced by increasing application frequency, and the highest values for all parameters studied were obtained with thrice-weekly treatment. The findings show that hydroponic waste nutrient solution can be an effective supplementary source of nutrients for radish, with more frequent application proving to be more beneficial under the experiment conditions.

Recommendations

The results allow us to recommend the application of hydroponic waste nutrient solution at least three times a week for radish production with high tuber yield at lahar-laden soil condition. For growers recycling hydroponic nutrient solution, it is important to monitor both the source of the recycled solution as well as, within reason fundamental properties such as pH and ECs in order to ensure consistency with respect to application quality. They must also study how the chemical composition of waste nutrient solution changes with time, replicate validation studies in different seasons and soils, and compare economic returns and nutrient-use efficiency under repeated reuse strategies.

Declarations

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Data availability: The dataset used in this article is available from the authors upon reasonable request.

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