The using of different hydroponic methods on the growth and yield of two pakcoy varieties (*Barissca rapa L.*)

Agus Sugianto[1*], *Anis* Sholihah[1] and *Siti* Muslikah[1]

[1]University of Islam Malang, Department of Agrotechnology, Jl. MT. Haryono 193 Malang 65144. East Java, Indonesia

Abstract. Pakcoy plants are leafy vegetables widely cultivated with Urban Farming technology because they have high economic value. One of the technologies is the DFT (Deep Flow Technique) hydroponic method, and floating rafts are popular and widely used. This study aimed to determine the differences between the DFT and floating raft hydroponic methods on the growth and yield of 2 varieties of pakcoy plants. The study was conducted in January - May 2024 at the Batu Urban Farming Green House. The design used was a Split Plot Design where the main plot of the hydroponic method (M) consisted of 2 levels: m1 = DFT and m2 = floating raft. The sub-plots were pakcoy varieties (V) consisting of (v1 = green pakcoy and v2 = red pakcoy). The results showed that the combination of the green pakcoy floating raft method treatment had the highest value in the number of leaves, leaf area, root length, root volume, total fresh weight, fresh weight for consumption, total dry weight, and dry weight for consumption.

1 Introduction

Pakcoy production in Indonesia experienced fluctuations between 2018 and 2023, influenced by various factors such as climatic conditions, changes in cultivated land area, and cultivation techniques. In 2018, pakcoy production was recorded at 635,982 tons, increasing to 667,473 tons by 2020. However, there was a slight decline in production in the subsequent years until 2022. In 2023, production showed an upward trend again, attributed to improved cultivation techniques and more efficient land use [1].

This increase in market demand is due to the growing utilization of pakcoy both for consumption and medicinal purposes. This trend contrasts with the decline in irrigated and non-irrigated paddy fields. According to data from the Central Statistics Agency (BPS) of East Java Province in 2018 [2], the area of irrigated and non-irrigated paddy fields decreased annually, from 1,176,650 hectares in 2016 to 1,174,586 hectares in 2017. This calls for efforts to cultivate crops that meet the increasing demand each year, including implementing urban farming technology.

* Corresponding author: agus.sugianto@unisma.ac.id

Urban farming can be applied to cultivation areas with limited space in urban settings [3][4]. The urban farming technology most commonly adopted utilizes hydroponic methods due to their relatively higher productivity, sterility, and ease of application. Hydroponics is a method of cultivation that does not use soil as a binding medium for the various nutrients required by plants [5][4]. One of the hydroponic methods widely employed in crop cultivation is the Deep Flow Technique (DFT) [5] [6] and the floating raft method [3][7][8].

The Deep Flow Technique (DFT)[9] is a cultivation method that uses a nutrient solution as the growing medium and provides essential elements for plants. The DFT and Floating Raft research that was conducted is (a). Continuous water flow is used to maintain sufficient oxygen supply for plant roots; (b). Automatic nutrient regulation by utilizing sensors to monitor and adjust nutrient levels and pH of the solution; (c). Efficient energy use using energy-efficient water pumps for nutrient water circulation; (d). Vertical use of space: DFT can be applied in vertical systems to maximize growing space [7][8] [9].

Research for floating raft techniques that have been conducted include (a). Making a solid and durable floating raft design using lightweight and waterproof styrofoam for rafts; (b). Use aerators by inserting aerators to maintain oxygen supply in the nutrient solution so the roots remain healthy; (c). Use greenhouses or polytunnels to protect plants from extreme weather and extend the growing season. Research that has not been done for DFT and floating rafts is the use of AI and IoT (Internet of Things) to develop artificial intelligence-based automation systems for nutrient, pH, temperature, and oxygen regulation, as well as early detection of problems such as root disease or nutrient disturbances [10][9]

The variety of pakchoy can affect yield when grown in DFT and floating raft hydroponic systems. Some varieties will be suitable for DFT due to their ability to utilize continuous water flow and good aeration. Other varieties may be better suited to floating raft systems that require adaptation to submerged root conditions [10] [11].

Based on the discussion above, this study addresses how hydroponic methods (specifically DFT and floating raft) can enhance the growth and yield of two varieties of pakcoy and mitigate the annual decrease in agricultural land, which is increasingly being converted to non-agricultural uses. This study aims to determine the interaction differences between the DFT and floating raft hydroponic methods on the growth and yield of two varieties of pakcoy.

2 Methodology

This research was conducted from January to May 2024 at the Batu Urban Farming Greenhouse “Training and Education in Hydroponic Plant Cultivation” located at Jalan Cempaka No. 12, Pesanggrahan Village, Batu City, East Java. Pesanggrahan Village is situated in an urban area of 900-1000 meters above sea level, with annual rainfall intensity between 2000-3000 mm and daily temperatures ranging from 24°C to 26°C.

The experimental design used a Split-Plot Design (SPD) arranged factorially. The first factor, serving as the main plot, was the hydroponic method (M) with two levels: M_1 (DFT Method) and M_2 (Floating Raft Method). The second factor, serving as the sub-plot, was the variety of pakcoy (V), which also had two levels: V_1 (Green Pakcoy) and V_2 (Red Pakcoy). Each treatment was replicated three times, including three sample plants.

The growth variables measured included the number of leaves and leaf area, which were calculated using a correction factor. The yield variables observed included total root length (calculated using the formula: $L = (1/4\ \pi \times (H + V) \times$ grid paper units (mm), where H = horizontal root length and V = vertical root length after being projected onto graph paper), root volume (calculated with the formula RV = V2 - V1, where V2 = final volume, and V1 = initial volume), total fresh weight of the plant, consumable fresh weight of the plant, total dry weight of the plant, consumable dry weight of the plant, and harvest index (%). The experimental data were analyzed using analysis of variance (ANOVA) with a 5% significance level to determine the effect of the treatments, followed by the Least Significant Difference (LSD) test at the 5% level if the treatment effect was significant. Correlation analysis was performed to establish relationships between the observed growth and yield variables.

3 Result and Discussion

3.1 Growth Variables

The results of the variance analysis indicated that the combination of hydroponic methods and pakcoy varieties had a significant interaction effect on the variables of leaf number (Table 1) and leaf area (Table 2) at all observation periods (1, 2, 3, 4, and 5 weeks).

Table 1. Number of leaves during the growth of pakcoy plants.

Treatments	Number of Leaves (blade, weeks)				
	1	2	3	4	5
M_1V_1	3,11 a	4,94 ab	7,83 ab	10,22 ab	12,83 ab
M_1V_2	3,11 a	4,67 a	6,33 a	8,00 ab	9,67 ab
M_2V_1	3,44 b	5,56 b	8,31 b	10,69 b	13,08 b
M_2V_2	3,61 b	5,25 b	6,53 ab	7,33 a	9,31 a
LSD 5%	0,20	0,36	1,96	3,35	4,81

Note: numbers accompanied by the same column show no significant difference in the 5% LSD test; NS= non significant; $M_{1=}$ DFT system hydroponic method; M2 = Floating Raft system hydroponic method V_1 = green pak choi variety; V_2 = red pak choi variety.

The DFT method can produce more leaves due to better aeration and more even distribution of nutrients. Plant roots remain healthy with sufficient oxygen supply, thus supporting more optimal leaf growth [12][13]. Based on Table 1. This shows that DFT has no significant difference from the floating raft method because it has been equipped with an aerator, which maintains aeration and impacts the nutrient solution being appropriately circulated [14][15]. Aerators installed on the floating raft method create good oxygenation management to avoid anaerobic conditions that can inhibit leaf growth [16] [17].

Table 2. Leaf is during the growth of pakcoy plants.

Treatments	Leaf area (cm^2, weeks)				
	1	2	3	4	5
M_1V_1	5,53 ab	30,61 ab	160,26 ab	595,95 ab	1123,35 ab
M_1V_2	4,69 a	21,53 a	82,49 a	317,49 ab	576,59 ab
M_2V_1	7,31 b	47,14 b	259,00 b	670,98 b	1234,24 b
M_2V_2	5,82 ab	25,25 ab	87,21 ab	249,43 a	437,07 a
LSD 5%	1,50	20,00	155,16	418,11	789,73

Note: numbers accompanied by the same column show no significant difference in the 5% LSD test; NS= non significant; $M_{1=}$ DFT system hydroponic method; M_2 = Floating Raft system hydroponic method V_1 = green pak choi variety; V_2 = red pak choi variety.

Leaf area is significantly influenced by light intensity and duration, which are crucial for photosynthesis and thus affect leaf growth [18][19]. The availability and balance of nutrients [20], particularly nitrogen [21][22], phosphorus [23] [24], and potassium [25], are critical for leaf development. Additionally, in hydroponic systems, the pH and mineral content of the water must be optimal to ensure adequate nutrient absorption [26].

The cultivation of pakcoy using hydroponic methods varies and presents both advantages and disadvantages. The choice of an appropriate hydroponic method is essential for successful cultivation [27], as it can also help minimize production costs [28][29], given that the volume of nutrient solution required differs across methods.

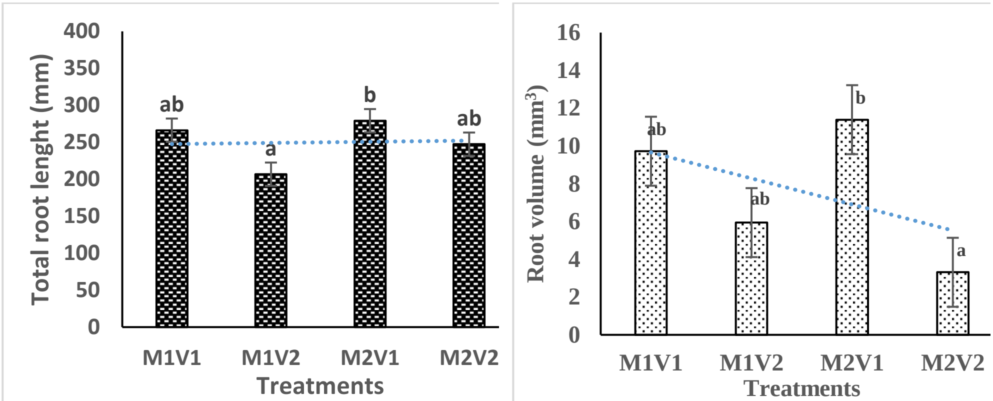
The floating raft method [30] tends to be more favorable for leaf area expansion compared to the DFT method [9][6]. This is because the water is not circulated constantly, making this system more water and nutrient-efficient. Evaporation and water loss are minimized, and nutrients can be utilized more efficiently. The DFT system [6], requiring continuous water flow, may lead to higher water and nutrient usage and potential loss if not properly managed.

The floating raft method uses a higher volume of nutrient solution than the DFT method. A higher volume of nutrient solution can help maintain a more stable temperature within the solution, unlike lower volumes. However, higher solution temperatures can reduce dissolved oxygen levels due to anaerobic respiration [31]. Oxygen deficiency at the roots occurs because the pore spaces in the plant roots are filled with water; in both the DFT and floating raft methods, plant roots are submerged in the nutrient solution [5], which can negatively impact the uptake of nutrients and water [32][13].

In the floating raft method, the green pakcoy variety exhibited the best performance in terms of leaf number and leaf area. However, these results were not significantly different from the DFT method using both the green and red pakcoy varieties. However, the red pakcoy grown using the floating raft method showed the lowest values, likely due to genetic differences and the broad leaves of the green pakcoy, which may have overshadowed the red pakcoy, reducing its sunlight exposure. Sunlight is a crucial factor in the photosynthesis process. Adequate nutrient availability and sufficient sunlight result in high photosynthate production, most of which is allocated to all parts of the plant to form leaves, roots, and stems.

The results of the variance analysis showed that the combination of hydroponic methods and pakcoy varieties had a significant interaction effect on all variables, including total root length, root volume, dry weight per plant, consumable dry weight, fresh weight per plant, and consumable fresh weight. The averages of these variables can be seen in Figure 1 and Table 3.

The treatment involving the floating raft method with the green pakcoy variety (M_2V_1) resulted in the highest total root length. However, it was not significantly different from the DFT method with the green pakcoy variety (M_1V_1) and the floating raft method with the red pakcoy variety (M_2V_2). For root volume, the floating raft method with the green pakcoy variety (M_2V_1) also achieved the best value, although it was not significantly different from the DFT method with the green pakcoy variety (M_1V_1) and the DFT method with the red pakcoy variety (M_1V_2).



A B

Figure 1. Total root length (A) and Root volume (B) pakcoy plants grown hydroponically using the DFT method and floating rafts.

Table 3. Total wet weight, economic wet weight, and economic dry weight.

Treatments	Total dry weight (g)	Economic dry weight (g)	Total wet weight (g)	Economic wet weight (g)
M_1V_1	32,61 ab	29,51 ab	169,40 ab	160,95 ab
M_1V_2	10,99 ab	9,07 ab	56,35 ab	53,49 ab
M_2V_1	39,23 b	33,74 b	191,48 b	180,12 b
M_2V_2	5,55 a	4,24 a	31,91 a	28,42 a
LSD 5%	32,87	29,46	159,48	151,60

Note: numbers accompanied by the same column show no significant difference in the 5% LSD test; NS= non significant; $M_{1=}$ DFT system hydroponic method; M_2 = Floating Raft system hydroponic method V_1 = green pak choi variety; V_2 = red pak choi variety.

Table 3 shows that the floating raft method with the green pakcoy variety (M_2V_1) resulted in the highest weights in the variables of dry weight per plant, consumable dry weight, fresh weight per plant, and consumable fresh weight. However, the differences were not statistically significant compared to the DFT method with the green pakcoy variety (M_1V_1) and the DFT method with the red pakcoy variety (M_1V_2).

Although the roots are fully submerged in the floating raft method, oxygenation is generally well-maintained using an aerator or natural methods. The large volume of water also helps to stabilize oxygen levels. In contrast, with its thin layer of flowing water, the DFT method may encounter high oxygen demand, mainly if flow interruptions occur, leading to plant stress [6][16].

Roots are crucial organs for plant respiration and nutrient absorption. Root development can be influenced by nutrient availability, water temperature, and dissolved oxygen levels in hydroponic systems. According to [33], the more prolonged and more extensive the root system [34], the greater the uptake of nutrients and water [35], resulting in better photosynthesis. Genetic factors of the variety also play a role in determining the growth and development of the plant, especially the roots. Apart from genetic composition, nutrient factors can also determine root growth and development. Nutrients such as Mg can affect the conductivity of the hydroponic nutrient solution. Deficiencies in nutrients like K and Mg can hinder root development in hydroponic systems, thereby impairing nutrient absorption by the plant [36].

Plant production is often determined by fresh weight, which reflects the development and accumulation of plant tissues such as leaves, stems, and roots, influenced by nutrient content and water levels within the plant's cellular tissues. Factors affecting fresh weight include nutrient levels and the application of solvents used in cultivation, such as in hydroponic methods. In hydroponic cultivation, fertilizers are applied as a solution, allowing nutrient uptake to align with the rate of solvent water absorption. Nutrient solutions must be provided at appropriate concentrations; low-concentration solutions often fail to meet the plant's needs, leading to suboptimal growth [37].

The floating raft method has advantages about the yield of pakcoy plants, primarily due to the larger volume of water, which helps maintain better stability of nutrients and oxygen [6] [38] [31][39]. The roots are fully submerged in the solution, ensuring a consistent supply of nutrients and oxygen. In contrast, the DFT system [6][16] submerges only part of the roots in the flowing water, making it more susceptible to nutrient and oxygen levels changes, mainly if pump system issues arise.

The dry weight of the harvest is an accumulation of organic matter produced through photosynthesis occurring in the vegetative parts of pakcoy during the growth phase. The amount of photosynthate produced can be inferred from the plant's dry weight; higher dry weight indicates better photosynthetic efficiency. The harvest index is closely related to the fresh and consumable fresh weights per plant. A slight difference between these two weight parameters results in a high harvest index, whereas a more significant difference lowers the harvest index. In pakcoy cultivation, the fresh weight of the harvest is a crucial indicator of success in leafy vegetable cultivation.

3.2 Correlation Coefficients between Growth and Yield of Two Pakcoy Varieties with Different Hydroponic Methods

The relationship between growth variables, production, and Fe content was determined based on the correlation coefficient (r). The r values, indicating the relationship between growth and yield variables, are illustrated in Table 4. The number of leaves and leaf area strongly correlated with yield variables, except for the total root length, which exhibited strong to moderate correlations with r values of 0.64 and 0.58, respectively. Total root length correlated moderately to firmly with yield variables, with r values ranging from 0.43 to 0.60, while root volume had a robust correlation with all other yield variables, with r values ranging from 0.96 to 0.99.

The correlation relationships between variables in Table 4 indicate that total root length has a moderate relationship with all variables except for the total dry weight of the Pakcoy plants. The correlation between root length and root volume, total fresh weight, economic fresh weight, and economic dry weight in Pakcoy plants grown using hydroponic methods tends to be moderate due to several influencing factors. While root length is essential for water and nutrient absorption, longer roots do not necessarily translate into greater root volume or higher weight. Other factors, such as root branching and thickness, affect root volume and weight.

Table 4. The correlation coefficient of growth and yield variable.

Variable	Number of Leaves	Leaf Area	Total Root Length	Root Volume	Total Wet Weight	Wet Weight Economic	Total Dry Weight	Dry Weight Economic
Number of Leaves		0,99	0,64	0,93	0,99	0,99	0,98	0,99
Leaf Area			0,58	0,97	0,99	0,99	0,99	0,99
Total Root Lenght				0,43	0,43	0,59	0,60	0,59
Root Volume					0,96	0,97	0,97	0,97
Total Wet Weight						0,99	0,99	0,99
Wet Weight Economic							0,99	0,99
Total Dry Weight								0,99
Dry Weight Economic								

Note = =0,80-1,00 (very strong); =0,60-0,79 (strong); =0,40-0,59 (moderate) = =0,20-0,39 (weak); ;0,00-0,19 (very weak)

In a hydroponic system, Pakcoy plants receive water and nutrients optimally, so root growth is not necessarily limited by the need to seek water or nutrients in the soil [6]. The roots may not need to grow long but can still have adequate volume and mass. Another factor is the high efficiency of nutrient absorption because nutrients are directly available around the roots [27]. This can result in shorter roots with high absorption capacity, leading to significant root volume and plant weight despite relatively short root lengths.

In a hydroponic system, the uniform distribution of water and nutrients can reduce the reliance on root length as the main factor for optimal growth. As a result, the correlation between root length and other parameters may be weaker than in conventional soil-based systems, where root length is more critical for successful growth.

4 Conclusion and Recommendations

The study results show that the combination of the floating raft method and green Pakcoy yielded high values in the number of leaves, leaf area, root length, root volume, total fresh weight, consumable fresh weight, total dry weight, and consumable dry weight.

The floating raft method is more effective when simplicity, nutrient stability, water efficiency, and ease of maintenance are prioritized. Meanwhile, the DFT method may be more suitable for situations where precise control over the root environment and good water management can be ensured. The floating raft method combined with green Pakcoy is recommended to farmers as it is more advantageous than red Pakcoy.

References

1. Badan Pusat Statistik, "Produksi Tanaman Sayuran Menurut Provinsi dan Jenis Tanaman," pp. 1–17.(2023).
2. J. BPS, "Badan Pusat Statistik.. Produksi Tanaman Sayuran, (2018).
3. W. Anggraini, M. Zulfa, N. N. Prihantini, F. Batubara, and R. Indriyani, "Utilization of Tofu Wastewater for the Growth of Red Spinach (Alternanteraamoenavoss) in Floating Raft Hydroponic Cultures," *J. Phys. Conf. Ser.* **1467** 1 (2020). doi:10.1088/1742-6596/1467/1/012005.
4. D. Kim and H. Sim, "Study of Plans to Ensure the Sustainability of Urban Farming in Apartment Complexes," *Sustain.* **15** 24 (2023). https://doi.org/10.3390/su152416797.
5. S. ur Rehman, A. Aprile, F. D. Castro, C. Negro, D. Migoni, M. Benedetti, E. Sabella, and F. P. Fanizzi, "Assessing the Effectiveness of Vermi-Liquids as a Sustainable Alternative to Inorganic Nutrient Solutions in Hydroponic Agriculture: A Study on Diplotaxis muralis," *Agronomy*. **14** 6 (2024). https://doi.org/10.3390/agronomy14061310.
6. W. A. Saidah, A. Nirma, Damayanti, A. F. Muchtar, I. S. Amalia, Padang, Risna, A. Nurmasitah, Dalapati, and I. K. Suwitra, "Utilization of agricultural waste as hydroponic media for the Deep Flow Technique system and combination of nutrients for shallot plants from seeds," *IOP Conf. Ser. Earth Environ. Sci.* **1287** 1 (2023). doi:10.1088/1755-1315/1287/1/012012.
7. M. K. A. Sobuj, S. Rahman and M. Z. Ali, "Floating raft culture of Gracilariopsis longissima for optimum biomass yield performance on the coast of Cox's Bazar, Bangladesh," *Sci. Rep,* **13** 1 (2023). https://doi.org/10.1038/s41598-023-28675-0.
8. L. Ren, Y. Li, X. Huang, and H. Hua, "Dynamic Modeling and Characteristic Analysis of Floating Raft System with Attached Pipes," *Shock Vib.* **1** 9135715 (2017). https://doi.org/10.1155/2017/9135715.
9. I. Vega, D. Bien-Amié, G. Augustin, W. Heiden, and N. Heiden, "Intermittent circulation of simplified deep flow technique hydroponic system increases yield efficiency and allows application of systems without electricity in Haiti," *Agric. Food Secur*. **12** 1 (2023). doi: https://doi.org/10.1186/s40066-023-00422-8.
10. K. Wang, N. Li, L. Song, J. Wu, and H. Jiang, "Application of a VOF Multiphase Flow Model for Issues concerning Floating Raft Aquaculture." *Water (Switzerland)*. **15** 19 (2023). https://doi.org/10.3390/w15193450.
11. G. P. S. R F Syah, and W.D.U. Parwati, "Strategy to increase melon (Cucumis melo L.) growth and yield hydroponically with types of installation and number of plant in the greenhouse." *IOP Conf. Ser. Earth Environ. Sci. 1377 012015*. **1377** (2024). doi:10.1088/1755-1315/1377/1/012015.
12. Y. Kuzyakov, "Separating microbial respiration of exudates from root respiration in non-sterile soils: A comparison of four methods," *Soil Biol. Biochem.* **34** 11 (2002). https://doi.org/10.1016/S0038-0717(02)00146-3.
13. H. R. Roosta, "The responses of pepper plants to nitrogen form and dissolved oxygen concentration of nutrient solution in hydroponics," *BMC Plant Biol.* **24** 1 (2024). https://doi.org/10.1186/s12870-024-04943-7.
14. S. D. 1 and L. C. 1 Jingang Li 1 , Pingru He 1,* , Qiu Jin 2, Jing Chen 1, and Chen 1,

Xiaoping Dai 1, "Aeration Alleviated the Adverse Effects of Nitrogen Topdressing," **13** 10 (2024). https://doi.org/10.3390/plants13101378.

15. Y. Li, M. Zhang, X. Cao, J. Wang, Z. Zhang, and Q. Niu, "Subsurface aeration alters the fungal composition of rhizosphere soil and tomato plant performance in Northwest China," *Int. J. Agric. Biol. Eng*. **16** 1 (2023).
16. A. Nurbaity, N. Istifadah, B. A. Haryantini, M. F. Ilhami, M. I. Habibullah, and M. Arifin, "Optimization of hydroponic technology for production of mycorrhiza biofertilizer," *IOP Conf. Ser. Earth Environ. Sci.* **347** 1 (2019).
17. G. C. Modarelli, L. Vanacore, Y. Rouphael, A.L. Masi, P.D. Pascale, and C. Cirillo, "Hydroponic and Aquaponic Floating Raft Systems Elicit Differential Growth and Quality Responses to Consecutive Cuts of Basil Crop," *Plants*, **12** 6 (2023). https://doi.org/10.3390/plants12061355.
18. L. T. Verryckt, S. Vicca, L. V. Langenhove, C. Stahl, D. Asensio, I. Urbina and I. A. Jansse, "Vertical profiles of leaf photosynthesis and leaf traits and soil nutrients in two tropical rainforests in French Guiana before and after a 3-year nitrogen and phosphorus addition experiment," *Earth Syst. Sci. Data*, **14** 1 (2022). https://doi.org/10.5194/essd-14-5-2022.
19. J. Mao, Y. Luo, C. Jin, M. Xu, X. Li, and Y. Tian, "Response of Leaf Photosynthesis–Transpiration Coupling to Biotic and Abiotic Factors in the Typical Desert Shrub Artemisia ordosica," *Sustain.* **15** 13 (2023). https://doi.org/10.3390/su151310216.
20. A. Rebolledo-Roa and R. A. Burbano-Diaz, "Nutrient Balance in Hass Avocado Trees as a Tool to Optimize Crop Fertilization Management," *Agronomy*, **13**. 8, (2023). https://doi.org/10.3390/agronomy13081956.
21. S. Yadvinder, S. Bijay, and J. Timsina, "Crop Residue Management for Nutrient Cycling and Improving Soil Productivity in Rice-Based Cropping Systems in the Tropics," *Adv. Agron.*, 85 **269** (2005).
22. S. S. Dhaliwal, V. Sharma, A. K. Shukla, and R. K. Gupta, "Residual Effect of Organic and Inorganic Fertilizers on Growth , Yield and Nutrient Uptake in Wheat under a Basmati Rice–Wheat Cropping System in North-Western India," **13** 3 (2023). https://doi.org/10.3390/agriculture13030556.
23. V. V. Shenoy and G. M. Kalagudi, "Enhancing plant phosphorus use efficiency for sustainable cropping," *Biotechnol. Adv*, **23** 7–8 (2005).
24. C. K. Chepkwony, R. J. Haynes, R. S. Swift, and R. Harrison, "Mineralization of soil organic P induced by drying and rewetting as a source of plant-available P in limed and unlimed samples of an acid soil," *Plant Soil*. **234** 83-90 (2001). https://doi.org/10.1023/A:1010541000437.
25. G. Suntoro, H. Herdiansyah, A. D. Widijanto, C. Tjahjanto, Puspitasari, and H. R. Wardhana, "Effect of green manure on the availability of Phosphorus and Potassium nutrients in Vertisols," *IOP Conf. Ser. Earth Environ. Sci.*. **1362** 1 (2024).
26. M. Zhang, W. Wang, L. Zhong, F. Ji, and D. He, "Bicarbonate used as a buffer for controlling nutrient solution pH value during the growth of hydroponic lettuce," *Int. J. Agric. Biol. Eng.* **17** 3 (2024). 10.25165/j.ijabe.20241703.8692.
27. U. Indarto, A. Qoniah, Ulmillah, G. Fatimatuzzahra, Maretta, and I. Sugiharta, "Gamal Leaves (Gliricidia sepium) as Hydroponic Nutrition for Lettuce (Lactucasativa L.)," *J. Phys. Conf. Ser*. **1467** 1 (2020). 10.1088/1742-6596/1467/1/012019.
28. M. Rahmawati, A. N. Irawan, and M. Hayati, "Growth and yield of pakcoy (Brassica rapa L.) due to different concentration of AB Mix nutrient and foliar fertilizer in the floating hydroponic system," *IOP Conf. Ser. Earth Environ. Sci.* **1297** 1 (2024).
29. D. M. Kaleel and E. H. Ali, "Economic Feasibility Study for the Project of Cultured Barley Production With Hydroponic Method," *Iraqi J. Agric. Sci.* **55** 233–245 (2024). https://orcid.org/0000-0002-5035-9623.

30. B. Frasetya, M. Subandi, and I. H. Sofiani, "The effect of silica source concentration to improve growth of Lactuca sativa L. On floating hydroponic system," *IOP Conf. Ser. Earth Environ. Sci.* **782** 4 (2021).
31. O. A. Nitu, E. Ş. Ivan, A. S. Tronac, and A. Arshad, "Optimizing Lettuce Growth in Nutrient Film Technique Hydroponics: Evaluating the Impact of Elevated Oxygen Concentrations in the Root Zone under LED Illumination," *Agronomy*. **14** 9 1896 (2024). https://doi.org/10.3390/agronomy14091896.
32. Y. T. Cai, H. Zhang, Y. Ping Qi, X. Ye, Z. Rong Huang, J. X. Guo, L. Song Chen, and L. Tong Yang, "Responses of reactive oxygen species and methylglyoxal metabolisms to magnesium-deficiency differ greatly among the roots, upper and lower leaves of Citrus sinensis," *BMC Plant Biol.* **19** 1 (2019). https://doi.org/10.1186/s12870-019-1683-4.
33. L. T. Dinh, Y. Ueda, D. Gonzalez, J. P. Tanaka, H. Takanashi, and M. Wissuwa, "Novel QTL for Lateral Root Density and Length Improve Phosphorus Uptake in Rice (Oryza sativa L.)," *Rice*. **16** 1 (2023). https://doi.org/10.1186/s12284-023-00654-z.
34. T. Roose, A. C. Fowler, and P. R. Darrah, "A mathematical model of plant nutrient uptake," *J. Math. Biol.* **42** 4 (2001).
35. A. A. Hassane Sidikou, D. Drissi, A. Bouaziz, K. Dhasi, F. Amlal, N. Darrhal and A. A. Houssa, "Productivity, quality, and nutrient uptake of intensive forage crop rotations based on corn in sandy soil (northern Morocco)," *SAINS TANAH - J. Soil Sci. Agroclimatol.* **20** 1 (2023). https://dx.doi.org/10.20961/stjssa.v20i1.64323.
36. A. Ünlükara, B. Cemek, S. Karaman, and S. Ersahin, "Response of lettuce (Lactuca sativa var. crispa) to salinity of irrigation water," *New Zeal. J. Crop Hortic. Sci.*, **36** 265–273 (2008). https://doi.org/10.1080/01140670809510243.
37. F. Albornoz, J. Heinrich Lieth, and J. A. González-Fuentes, "Effect of different day and night nutrient solution concentrations on growth, photosynthesis, and leaf NO3- content of aeroponically grown lettuce," *Chil. J. Agric. Res.* **74** 2 (2014).
38. N. Widiani, N. Ulfa, O. P. Winandari, and M. Kamelia, "Effect of Tapioka Liquid Waste on Growth of Ipomoea Reptans Poir Using Floating Raft Hydroponic Technique," *J. Phys. Conf. Ser.* **1338** 1 (2019).
39. K. Janiak and M. Janicka, "Water and Nutrient Recovery for Cucumber Hydroponic Grey Water," *Plants*. **13** (2023). https://doi.org/10.3390/plants12061286.