The Journal of Agricultural Sciences - Sri Lanka
Vol. 21 No 1, January 2026. pp 84-100
https://doi.org/10.4038/jas.v21i1.11210

RESEARCH

Vermitea and SNAP's Potential as a Nutrient Solution for Lettuce (*Lactuca sativa* L.) Under a Non-circulating Hydroponics System

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Received: 18th September 2024 / Accepted: 26th October 2025

ABSTRACT

Purpose: *The study was conducted to evaluate the growth performance of lettuce on Simple Nutrient Addition Program (SNAP) solution in combination with different vermitea. It aimed to determine the combined effects of different vermitea and SNAP solution and find out if vermitea could replace 50% of the SNAP solution, and give the best result in return on investment.*

Research Method: *The STAR version 2.0.1 software was used to statistically analyse the data, and Tukey's Test was used to compare treatment means at the 1% level of significance. Three hundred fifteen lettuce plants were used in the study and distributed to fifteen experimental units, wherein each treatment was replicated three times.*

Findings and Values: *The different combinations of nutrient solutions and vermitea had significant effects on lettuce growth performance. Treatment 1 produced the highest lettuce growth and production. The treatments with different vermitea in combination with 50% SNAP. Treatment 2 (50% SNAP + 20 ml/L of vermitea-cow manure) outperformed all other treatment combinations and negative controls by a substantial margin. This significant difference obtained by Treatment 2 were attributed to the results on the leaf width, root length, root volume, weight of the roots, weight of leaves per plant, and total weight of treatments. This study may serve as a more effective approach to achieve enhanced crop productivity and mitigate the negative effect of nitrogen-based fertilizer on the environment.*

Keywords: *Fertigation, Hydroponics, Organic, pH, Vermitea*

INTRODUCTION

In order to feed the world's expanding population in a sustainable manner, strategies for producing sufficient food must evolve. A promising option for sustainable production and the preservation of rapidly diminishing land and water resources is the modification of growing media. In the present scenario, soilless cultivation can be successfully adopted and considered an alternative approach for producing healthy food plants, crops, and vegetables (Butler & Oebker 1962). In various regions of the world, particularly in Africa and Asia, soilless plant culture has emerged as one of the key technologies in smart agriculture. This system involves growing crops using nutrient solutions that may be recirculating or non-circulating, with or without soil-based media (Li *et al.* 2018).

Agriculture without soil includes hydro agriculture (hydroponics), aqua agriculture (aquaponics), and aerobic agriculture (aeroponics), as well as substrate culture. Soilless farming enables crop production under controlled conditions in areas with unfavourable farming environments, such as urban locations.

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and regions with poor soil quality (Lu *et al*. 2017). In addition to mitigating pest and disease incidence and addressing issues related to degraded soils and limited water resources, soilless farming plays a critical role in advancing the sustainability of agricultural production systems (Sambo *et al*. 2019).

Hydroponically grown plants are cultivated in nutrient solutions with or without inert media for mechanical support, such as sawdust, coir dust, peat moss, coconut fibre, gravel, or vermiculite. The term hydroponics was first introduced in the early 1930s by Professor William Gericke. It originates from the Greek words *hydros*, meaning water, and *ponos*, meaning work, collectively translating to "water work." Most hydroponic systems operate automatically, regulating water supply, nutrient concentration, and photoperiod based on plant requirements (Resh 2022).

Despite the ability of hydroponic systems to produce higher yields and quality crops, interest in organic hydroponics has increased due to growing consumer demand for organic food products. Conventional hydroponic nutrient solutions are largely based on chemical fertilizers, prompting efforts to integrate organic alternatives (Ezziddine *et al*. 2021). Another factor contributing to this interest is the potential reduction of nitrate accumulation in food crops by minimizing the use of nitrate-based fertilizers, thereby improving food safety for human consumption (Williams & Nelson 2014).

Organic hydroponic production remains relatively new and represents only a small fraction of the total organic market. Cultivating vegetable crops in hydroponic systems supplemented with organic fertilizers, particularly in liquid form, is complex and remains insufficiently explored (Ahmed *et al*. 2021). At this stage, it is essential to consider not only the agronomic potential of vermitea but also its economic feasibility, especially for commercial-scale hydroponic production. The cost-effectiveness and market viability of vermitea must be evaluated for its successful adoption (Edwards *et al*. 2011). Equally important is the challenge of maintaining consistency in the chemical composition of vermitea, as it is derived from animal manure, whose nutrient content varies depending on animal species, diet, and management practices (Saba *et al*. 2023).

Recent studies have emphasized that although vermicompost tea can improve crop yield and quality, its effectiveness is highly dependent on preparation methods and nutrient stability, making standardization essential for commercial use (Mininni *et al.* 2024). These economic and technical considerations will largely determine the practicality, reliability, and long-term adoption of vermitea in sustainable hydroponic farming systems.

In light of these challenges and opportunities, the present study examined the integration of vermitea into a non-circulating hydroponic system. Specifically, SNAP nutrient solution was combined with vermitea derived from cow, goat, and rabbit manure to evaluate their effects on the growth performance of hydroponically grown lettuce (*Lactuca sativa* L.). The study further aimed to determine whether vermitea could partially replace the SNAP solution while remaining economical and effective, thereby identifying practical strategies for organic-based hydroponic lettuce production.

MATERIALS AND METHODS

Securing of materials

The materials used in the study included styro boxes, styro cups, bamboo slats, scissors, cutting knives, tin cans, nails, polyethylene (PE) plastics, lettuce seeds, and SNAP nutrient solution. Vermicast was produced using farm animal manures from goat, rabbit, cow, and sheep. Data collection required an aerator, a 60-liter container, a ruler, a weighing scale, a caliper, a beaker, a pH meter, and a field notebook. All materials were sourced from the CEBU Hydroponics Supplier Enterprise.

Experimental site

The experiment was conducted at the

Experimental Greenhouse of the School of Agriculture and Agribusiness, Isabela State University, Roxas, Isabela, Philippines. The greenhouse facility provided temperature regulation, reduced evaporative water loss, controlled pest and disease incidence, and protected crops from adverse weather conditions such as strong winds and heavy rainfall.

Seedling production

Seedling trays were filled with a mixture of garden soil and organic material in a 1:1 ratio. One seed was sown per hole, after which the trays were placed under partial shade to minimize moisture loss and promote germination. Seedlings were maintained in a partially shaded environment for 15 days before transplanting.

Production of vermicast

A suitable shaded, flood-free site with access to water was selected for vermicast production. Animal manure, kakawate leaves, and banana trunk materials were collected and combined in a 2:2:1 ratio. The substrates were shredded, thoroughly mixed, and watered with EMAS to achieve at least 60% moisture content to promote rapid decomposition. The mixture was placed in outdoor beds and covered with plastic sheets to initiate anaerobic decomposition, which lasted approximately one and a half months. Beds were watered twice weekly to accelerate decomposition.

After this period, earthworms were introduced at a rate of 1 kg per square foot of bed. Moisture levels were maintained at approximately 60% throughout the vermicomposting process. A metal screen was installed above the beds to protect the worms from predators. After 30 days, vermicast was harvested by separating it from the worms using a screen and subsequently used for vermitea preparation.

Preparation of vermitea

A 60-liter container was filled with 50 liters of unchlorinated water and aerated for 30 minutes. Three kilograms of vermicast were placed in a cloth bag and suspended in the container. Molasses (500 mL) was added prior to aeration, followed by the addition of 50 mL of Indigenous Microorganisms (IMO) after 30 minutes. Vermitea was harvested after 24 hours of continuous aeration.

Preparation of seedling plugs

Lettuce seeds (green span variety) were sown in coco coir used as the growing medium. Styrofoam cups served as seedling plugs, with 4 to 6 slits made on the sides (approximately 2 inches long) and one slit at the bottom (approximately 0.5 inch) to facilitate root growth and drainage. Cups were filled with the growing medium to a depth of approximately 0.5 inch. Seedlings germinated in coco coir were transplanted into the prepared cups.

Preparation of growing boxes

Styrofoam fruit boxes measuring 24 in $\times$ 16 in $\times$ 9 in were used as culture containers for the nutrient solution. The bottom of each box was lined with plastic to prevent leakage. Eight equidistant holes were cut into the lid of each box to hold the seedling plugs securely at the neck. Prefabricated vents on the lids allowed passive root aeration, while a plastic liner was used to seal open slits to prevent mosquito entry.

Experimental design and treatments

The experiment was laid out in a Complete Randomized Design (CRD) with seven (9) treatments and three (3) replications at 15 plants per treatment. The treatments were designated as follows:

- T1- 100% SNAP (Control)
- T2- 50% SNAP + 20 mL/L of vermitea-cattle manure
- T3- 50% SNAP + 20 mL/L of vermitea-rabbit manure
- T4- 50% SNAP + 20 mL/L of vermitea-goat manure
- T5- 20 mL/L of vermitea-cattle manure
- T6- 20 mL/L of vermitea-rabbit manure
- T7- 20 mL/L of vermitea-goat manure

Treatment preparation and application

Each styrobox was filled with 15L of water mixed with 25ml SNAP A and B Nutrient Solutions. The vermitea (sourced out from the different farm animal manures as substrate) was prepared 1 day before transplanting. The vermitea was extensively combined with the SNAP solution to create treatments. After preparing and testing the hydroponic boxes for leakage, they were installed in the benches according to the research design. The boxes were then filled with 15 litres (litres) of tap water. Then several remedies were administered and completely mixed into the water. When the water level on Styrobox reached a particular level, each treatment received a second application.

Transplanting of seedlings

In accordance with the designated treatments, the seedling plugs were moved into the hydroponic boxes that had been installed. Each box contained fifteen seedling plugs, resulting in fifteen sample plants for each treatment. For the purpose of the study, 405 plant samples were transplanted under each treatment. After being inserted into the boxes, the seedling plugs were immersed 2.5 cm deep in the nutritional solutions.

Care and maintenance of the crop

The nutrient solution to water ratio was maintained at fifteen (15) liters of water and a certain percentage of nutrient solution per box. Maximum protection against insect pests and diseases was done. A daily visit to the experimental area was made to observe any presence of insect pests and diseases.

Harvesting

Harvesting was done 28 days after transplanting. Uprooting of the whole plant was done manually; thereafter, the stems were cut off just below the lower leaves of the plant with pruning shear.

Data gathered

Fertilizer Analysis of Vermitea (cattle, rabbit, and goat manures): Macro-nutrients (N, P, K), Micro-nutrients (Mg, Cu, Mn, Fe, and Iron).

Physicochemical analysis

The pH and TDS: A portable pH and TDS meter was used to measure the nutrient solution at 7, 14, 21, 28, and 35 days after transplanting.

Growth and yield parameters

Plant height at 7, 14, 21, and 28 days after transplanting: Every week, the ten typical sample plants' heights were measured. The average height of each plant was calculated by dividing the total plant height by 10.

The number of leaves harvested: At harvest, the number of leaves on the sample plants for each treatment was counted. To find the average number of leaves per plant, the total number of leaves on the sample plants was divided by ten.

Leaf length (cm): After the leaves were harvested, a standard ruler was used to measure the largest, medium-sized, and smallest fully developed leaves from each randomly three selected fully grown leaves of plant, from base to tip.

Leaf width (cm): Three randomly chosen completely expanded leaves from the lower, middle, and upper sections of the leaf after harvest were cross-sectioned with a standard ruler in order to determine the width of the leaf.

Plant root length (cm): The foot rule was used to measure the sample plants' root lengths.

Plant root volume (mL): This was determined by placing the roots within a graduated cylinder filled with water; the volume difference between the roots' pre- and post-submersion values represented the volume of the roots at harvest.

Fresh root weight each plant (g): This was determined at harvest by employing a digital analytical balance to weigh the roots.

Fresh weight in grams sample plant (without roots): A digital weighing balance was used to weigh ten sample plants; the weight was then divided by ten to determine the average.

Total fresh weight at harvest for each treatment: A digital weighing balance was used to weigh fifteen plants, and the total of three replications was divided into three.

Data on temperature

Throughout the research, the temperature was taken at 2:00 pm on a daily basis. The temperature within the greenhouse was measured using an installed thermometer.

Analysis of cost and return

The net income was multiplied by the entire number of expenses and then by 100.

Statistical analysis

The Statistical Tool for Agricultural Research (STAR version 2.0.1 software) was used to compile, tabulate, and analyse the collected data after the analysis of variance (ANOVA). The Tukey's Honestly Significant Difference (HSD) Test was then used to compare the results at the 1% level of significant.

RESULTS AND DISCUSSION

Description of the study site

The study was conducted in Roxas, Isabela, particularly in Barangay Matusalem. An East-West orientation made the greenhouse ideal for performing an experimental study, and it was part of the Agri-tech farm of Isabela State University, Roxas Campus. The greenhouse was equipped with an overhead sprinkler system, usually used to lessen the heat inside the greenhouse during the study, and the indoor ground was mulched with carbonized rice hull. The overall the greenhouse was covered with a mesh net to keep pests out and covered with a UV-treated plastic sheet to protect the experimental lettuce from heavy rain. Inside the greenhouse, a hapa net was installed to lessen the exposure of the lettuce to the heat of the sunlight. The temperature recorded during the period of the study ranged from 27 to 37 degrees Celsius. Due to the high temperature, pouring gallons of water into the floor was done to get flooded in an attempt to reduce the inside temperature.

Stand and vigor of the crop

Generally, the plants did not show any stress after transplanting. The lettuce plants showed a healthy stand as indicated by their fully developed and light green leaves and grew uniformly during the first week. Root penetration on the substrate was then observed during the second week of the study, and on the same week of the lettuce plants, differences in height and color were then observed in the different treatments, and treatments 5, 6, and 7 produced the whitish color of leaves indicating that the plants had nutrient deficiencies or toxicities – a sign of the appearance of unusual visual symptoms (McCauley *et al.* 2009).

Pest and disease occurrence

The study was carried out in a greenhouse with semi-controlled conditions, hence no pests or diseases were recorded.

Result of macronutrients (N, P, K) and micronutrients analysis of vermitea

Three samples of vermitea from various substrates used to make vermicast were submitted in DA-RFO2 for the NPK nutrient analysis test, and another three sets of samples were submitted in DA-RFO3 for trace elements. According to the test results, the submitted samples had a low amount of nutrients, such as vermitea-CM's nitrogen at 0.33% wt./vol. Vermitea had an 18-fold lower concentration than the SNAP solution (6.10%). The nutrient content of the various substrates tells us about the prospective outcomes because lower nutrients equal poorer results from the parameters.

Macronutrients (N, P, K) and micronutrients content of SNAP solution

The nutrient analysis from Simeon and Bugawisan's 2023 study was shown in Table 2. When compared to the nutrient contents of the different vermitea, the nutrient solution's nutrient content had large gaps even though it had all the ingredients needed to grow lettuce.

Physicochemical analysis

The pH, TDS, and EC levels change over time during lettuce production. However, pH changes in number with no significant differences during the four periods of data collection. For the four

Table 1. Fertilizer composition of vermitea produced from different animal manures.

Vermitea	N (%)	P (%)	K (%)	Mg (ppm)	Cu (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)
Cattle Manure	0.33	0.01	0.01	<0.01	<0.01	3.74	1.57	<0.01
Rabbit Manure	0.19	0.09	0.01	<0.01	<0.01	3.23	<0.01	<0.01
Goat Manure	0.15	0.04	0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table 2. Macro- and micronutrient composition (%) of Simple Nutrient Addition Program (SNAP) solutions A and B.

SNAP	ELEMENTS							
	N (%)	P (%)	K (%)	Cal (%)	Mg (%)	Cu (%)	Fe (%)	Mn (%)	Zn (%)
A	6.10		3.09	4.25					
B		0.38			0.49		0.15		

Source: Simeon & Bugawisan 2023

data collection periods, Treatments 5, 6, and 7 had the lowest TDS and EC. Except for treatment 1, all treatments had lower PPM and were unable to achieve the optimal PPM for lettuce, which is 560 to 840 (Sandoya *et al.* 2021); this total dissolved solids resulted in poor growth on those treatments with low TDS which not even achieved the minimum required ppm.

These were Treatments 2 (50% SNAP + 20mL/L Vermitea-CM), Treatment 3 (50% SNAP + 20mL/L Vermitea-RM), Treatment 4 (50% SNAP + 20mL/L Vermitea-GM), Treatment 5 (20mL/L Vermitea-CM), Treatment 6 (20mL/L Vermitea-RM) and Treatment 7 (20mL/L Vermitea-GM). The available fertiliser salts are determined by the pH of the nutrient solution, while the terms TDS and EC denote the salts and nutrients that are readily available in water. Since a pH range of 5.6–5.8 is thought to be ideal for growing lettuce, and that ranges above or below the allowable range may result in nutritional inadequacies, the pH of the water from all treatments had a significant impact on the growth and development of the lettuce (Brechner *et al.* 1996).

Plant height at 7, 14, 21, and 28 DAT

Plant height changed in accordance with the rates of nutrient solutions given, as Table 4 illustrates. The treatments had a substantial impact on plant height from 7 to 28 days after transplanting, according to statistical statistics. The plant height results indicated that the SNAP solution alone had greater results than other treatments. This is explained by how much of the nutrient solutions' content was applied. As reflected in table 4, column 2, treatment 1 was not significantly different from treatments 2, 3, and 4, but was significant against treatments 5, 6, and 7. Treatment 2 (50% SNAP + Vermitea-CM) outperformed Treatment 5 (20 mL/L Vermitea-CM) by a significant margin. Treatment 3 (50% SNAP + Vermitea-RM) had a higher plant height than its negative control, treatment 6; Treatment 4 (50% SNAP + Vermitea-GM) was taller than Treatment 7.

On the 14^{th}, 21^{st}, and 28^{th} days after transplanting (DAT), the combined effect of SNAP and various vermitea, indicated in Treatments 2, 3, and 4 as opposed to their corresponding negative controls, Treatments 5, 6, and 7, had a taller height. This suggests that combining 50% SNAP with vermitea had taller lettuce plants than using vermitea alone. The nutrient solution applied to the treatments has a significant impact on the plant height. The average plant height is lower in nutrient-deficient treatments than in the control treatment. According to Nugraha & Susila (2015), in this case, the availability of nutrients—more specifically, the nutrients needed by plants for both vegetative and generative growth—will have an impact on plant growth.

The overall results on lettuce plant height using

Table 3. Recorded pH, TDS, and Electrical Conductivity (EC) of the water with nutrient solution during the research period.

Treatment	pH				TDS (ppm)				EC			
	7	14	21	28	7	14	21	28	7	14	21	28
T1 – 100% SNAP (Control)	6.39[a]	6.68	7.03	7.26	570[a]	567[a]	571[ab]	580[a]	1196[a]	1133[a]	1096[a]	1180[a]
T2 – 50% SNAP + 20 mL/L Vermitea (CM)	6.19[bc]	6.62	6.97	7.20	449[bc]	446[b]	538[b]	543[b]	880[b]	837[b]	800[b]	1090[a]
T3 – 50% SNAP + 20 mL/L Vermitea (RM)	6.11[c]	6.74	7.09	7.32	465[b]	462[b]	416[c]	420[c]	920[b]	912[b]	875[b]	760[b]
T4 – 50% SNAP + 20 mL/L Vermitea (GM)	6.18[bc]	6.77	7.05	7.21	428[c]	425[c]	601[a]	605[a]	872[b]	834[b]	806[b]	1200[a]
T5 – 20 mL/L Vermitea (CM)	6.40[a]	6.69	7.04	7.28	226[d]	223[d]	331[d]	335[d]	468[c]	428[c]	393[c]	670[b]
T6 – 20 mL/L Vermitea (RM)	6.24[b]	6.89	7.24	7.50	233d	230d	325d	330d	465[c]	425[c]	390[c]	665[b]
T7 – 20 mL/L Vermitea (GM)	6.21[b]	6.91	7.25	7.48	228[d]	225[d]	340[d]	345[d]	457[c]	417[c]	382[c]	690[b]
ANOVA	**	ns	ns	ns	**	**	**	**	**	**	**	**
CV (%)	0.52	1.93	1.60	1.76	2.14	1.99	3.31	2.86	11.73	11.06	11.13	8.9

Note: Means within a column represented by common letters are not significant at a 1% level using HSD
** - highly significant, ns - not significant

50% SNAP and various vermitea compared to the three negative controls. Similar tendencies can be seen in treatments 5, 6, and 7. Plants grown higher when SNAP and vermitea were mixed, as opposed to when vermitea was used alone. According to Sarker and Oba (2019), this may be the result of the plants decreasing the maintenance and synthesis of chlorophyll because of nutritional deficits from previous growth stages (Table 1). Plant height was reduced at those stages due to the increased need for specific nutritional elements, which resulted in these deficits.

The various vermitea had a low nutrient content, particularly NPK (Nitrogen, Phosphorus, and Potassium). For example, the SNAP solution has 6.10% Nitrogen content, whereas the highest Nitrogen found in the vermitea was only 0.33%, which is 18 times lower than the Nitrogen of SNAP (shown in Tables 1 and 2). The findings demonstrated that the nutritional content of the solution that encourages lettuce development has an impact on lettuce height and that one of the most crucial elements in raising crop yields is a balanced supply of necessary nutrients (Fageria 2001).

Number of leaves at harvest

The type of fertilizer used has a significant impact on lettuce's horticultural characteristics, particularly the number of leaves per plant. As indicated in Table 5, SNAP (Treatment 1), produced the most number of leaves with 10.30, which is significantly higher overall treatments. The explanation for this is that the lettuce grown in Treatment 1 had 100% SNAP which contains higher N, P, and K, as indicated in Table 2 of SNAP solution analysis, but the other treatments had a very limited source due to the vermitea's minimal nutrient concentration (shown in Table 1), particularly the treatments that used the organic solution. The number of leaves, plant height, leaf width, leaf blade length, and leaf number of plants produced using the chemical feeding solution T1 (SNAP) were all optimal for horticultural growth and development, according to Borres *et al.* (2022). Their results are supported by this discovery.

Table 4. Plant Height at 7, 14, 21, and 28 DAT in centimeter.

TREATMENT	DAT			
	7th	**14th**	**21st**	**28th**
T1 – 100% SNAP (Control)	3.07[a]	6.48[a]	11.56[a]	16.30[a]
T2 – 50% SNAP + 20 mL/L of Vermitea (CM)	2.46[a]	4.98[b]	8.50[b]	12.48[b]
T3 – 50% SNAP + 20 mL/L of Vermitea (RM)	2.68[a]	5.10[ab]	7.92[b]	10.75[b]
T4 – 50% SNAP + 20 mL/L of Vermitea (GM)	2.52[a]	4.87[b]	8.59[b]	11.66[b]
T5 – 20 mL/L of Vermitea (CM)	1.44[b]	2.31[c]	4.34[c]	5.07[c]
T6 – 20 mL/L of Vermitea (RM)	1.64[b]	2.53[c]	4.88[c]	6.40[c]
T7 – 20 mL/L of Vermitea (GM)	1.52[b]	2.29[c]	4.66[c]	5.97[c]
F-RESULT	**	**	**	**
CV (%)	10.20	12.33	8.58	12.75

Note: Means within a column represented by common letters are not significant at 1% level using HSD.
** - highly significant, ns – not significant

Table 5. Number of leaves at harvest.

Treatment	Mean
T1 – 100% SNAP (Control)	10.30[a]
T2 – 50% SNAP + 20 mL/L of Vermitea (CM)	6.87[b]
T3 – 50% SNAP + 20 mL/L of Vermitea (RM)	6.07[b]
T4 – 50% SNAP + 20 mL/L of Vermitea (GM)	6.47[b]
T5 – 20 mL/L of Vermitea (CM)	4.53[c]
T6 – 20 mL/L of Vermitea (RM)	4.93[c]
T7 – 20 mL/L of Vermitea (GM)	5.00[c]
F-RESULT	**
CV (%)	11.70

Note: Means within a column represented by common letters are not significant at 1% level using HSD.
** - highly significant, ns – not significant

On the other hand, using vermitea in combination with 50% SNAP resulted in an incomparable mean when compared to respective negative controls. This means that plants grown in Treatments 2, 3, and 4 are taller than Treatments 5, 6, and 7. Because of the increased biological oxygen demand in the root zone brought on by the presence of dissolved organic carbon molecules, the direct use of organic fertilisers in hydroponic systems may restrict plant growth (Ezziddine *et al.* 2021, Durell 1941). Furthermore, plants cannot directly access the majority of nutrients found in organic sources, such as waste from aquaculture and agriculture, because they are not in ionic forms. One of the visually significant characteristics (phenotypes) that characterise a plant's growth and development is the number of leaves it possesses (Dobrescu *et al.* 2017). It is connected to the health and yield potential of the plant and allows for the calculation of growth rate (Telfer *et al.* 1997, Walter & Schurr 1999). Vermitea was among the treatments that generated fewer leaves, according to the findings of the various treatments. A lower yield is indicated by fewer leaves since photosynthesis, the process by which plants transform light energy into chemical energy, depends mostly on the leaf. Leaf area affects photosynthetic capacity, closely related to plant growth. Plant weights, both fresh and dried, are commonly considered the main yield indices (Goudriaan *et al.* 1985).

Leaf length at harvest (cm)

After 28 days of transplanting with vermitea and nutritional solution (SNAP), the length of the leaf had a substantial influence. Results were similar to Treatments 2, 3, and 4 with 50% SNAP and vermitea from various manures when SNAP was used at the indicated rate. The nutrient solution content of SNAP, which encourages lettuce growth by lengthening and widening its leaves, has a significant impact on this outcome. Sublett *et al.* (2018) state that the main determinant of plant growth and biomass output in hydroponic cultivation is nutrients.

When vermitea plus SNAP were compared to their respective negative controls, Treatment 2's leaves were longer than Treatment 5's, while Treatments 3 and 4 were also significantly longer than Treatments 6 and 7. This shows that employing SNAP in addition to vermitea produced better effects than using vermitea alone. In floating hydroponics, the growth and yield of spinach are influenced by nutrient solutions. Since the nutrient solution is one of the primary factors influencing the production and quality of hydroponic systems, the concentration of nutrients also affects the growth and productivity of lettuce on hydroponic substrates (Subandi *et al.* 2015). Due to the limited content of vermitea as reflected in Table 1, the poor growth resulted in a smaller length size of leaves. The leaves are vital indicators of photosynthetic activity which enables the plant to produce its food.

The least in terms of length and width, however, were produced by vermitea. The poor nutritional value of vermitea caused lettuce to mature more slowly, proving slower development of plants when they do not have enough nutrients, especially nitrogen. Farran and Mingo-Castel (2006) state that the pechay height determines the amount of nitrogen in the feeding solution.

Leaf width at harvest (cm)

The width of the leaves 28 days after transplanting showed a highly significant influence, according to the study. Though they were smaller than the control treatment (T5, T6, and T7), the plants grown on 50% SNAP plus 20% vermitea generated wider leaves. Lettuce plants cultivated in SNAP solution outperformed the other treatments in terms of leaf width, with values ranging from 10.93 to 4.60 centimetres. This finding demonstrates that the plant height, leaf breadth, leaf blade length, and number of leaves produced using chemical solution T1 (SNAP) provided the optimal amount of nutrients for horticulture growth and development, as reported by Borres *et al.* (2022). According to Nugraha and Susila (2015), plants are significantly impacted by the macro- and micronutrient composition. Fertiliser treatment must therefore be customised to the plant's requirements. Plant lengthening is a sign that nitrogen (N) is involved in vegetative growth. For instance, when studying lettuce growth and quality in a hydroponic system, Fraile *et al.* (2017) discovered that temperature, water availability, and nutrient content all had an impact on leaf size.

In the comparison of vermitea combined with SNAP solution to their respective negative controls, it resulted in significant differences among treatments. Treatment 2 was comparable to Treatment 5 while Treatments 3 was comparable to Treatment 6 and Treatment 4 was significant to Treatment 7.

On the other hand, the use of vermitea alone is very different from Treatment 1. Lettuce developed too slowly to produce wide leaves because vermitea's nutritional content was not enough to support this growth. This outcome is consistent with the findings of Eudoxie *et al.* (2017), who reported that although vermicompost teas supply certain organic compounds and microbial activity, they generally lack adequate nitrogen and other essential nutrients required for sustained vegetative growth.

Root length (cm), volume (mL), fresh weight (g) per plant

The type of fertilizer solution had a profound impact on the root characteristics of lettuce cultivated hydroponically. As shown in Table 7, (Treatment 1) had a greater effect on lettuce root development, particularly root length, achieving 31.75 centimeters compared to treatments 2-7, which ranged from 11.66 to 22.55 centimeters. Treatment 1 (50% SNAP + 20 mL/L of Vermitea-CM) was comparable to treatment 5 (20 mL/L of Vermitea-CM) with 11.66 centimeters while treatment 3 (50% SNAP + 20 mL/L of Vermitea-RM) is comparable to treatment 6 (20 mL/L of Vermitea-RM),

Table 6. Leaf length at harvest (cm).

Treatment	Mean
T1 – 100% SNAP (Control)	16.77^{a}
T2 – 50% SNAP + 20 mL/L of Vermitea (CM)	14.30^{ab}
T3 – 50% SNAP + 20 mL/L of Vermitea (RM)	11.60^{bc}
T4 – 50% SNAP + 20 mL/L of Vermitea (GM)	12.00^{ab}
T5 – 20 mL/L of Vermitea (CM)	6.40^{d}
T6 – 20 mL/L of Vermitea (RM)	6.47^{d}
T7 – 20 mL/L of Vermitea (GM)	6.93^{cd}
F-RESULT	**
CV (%)	16.91

Note: Means within a column represented by common letters are not significant at 1% level using HSD.
** - highly significant, ns – not significant

Table 7. Leaf width at harvest (cm).

Treatment	Mean
T1 – 100% SNAP (Control)	12.60^{a}
T2 – 50% SNAP + 20 mL/L of Vermitea (CM)	10.93^{b}
T3 – 50% SNAP + 20 mL/L of Vermitea (RM)	9.13^{c}
T4 – 50% SNAP + 20 mL/L of Vermitea (GM)	9.37^{c}
T5 – 20 mL/L of Vermitea (CM)	4.60^{d}
T6 – 20 mL/L of Vermitea (RM)	4.63^{d}
T7 – 20 mL/L of Vermitea (GM)	4.87^{d}
F-RESULT	**
CV (%)	5.47

Note: Means within a column represented by common letters are not significant at 1% level using HSD.
** - highly significant, ns – not significant

Table 8. Root length per plant (centimeter).

Treatment	Mean
T1 – 100% SNAP (Control)	31.75^{a}
T2 – 50% SNAP + 20 mL/L of Vermitea (CM)	22.55^{b}
T3 – 50% SNAP + 20 mL/L of Vermitea (RM)	15.62^{c}
T4 – 50% SNAP + 20 mL/L of Vermitea (GM)	24.68^{b}
T5 – 20 mL/L of Vermitea (CM)	11.66^{c}
T6 – 20 mL/L of Vermitea (RM)	14.54^{c}
T7 – 20 mL/L of Vermitea (GM)	11.70^{c}
F-RESULT	**
CV (%)	8.08

Note: Means within a column represented by common letters are not significant at 1% level using HSD.
** - highly significant, ns – not significant

Table 9. Root volume per plant (milliliter).

Treatment	Mean
T1 – 100% SNAP (Control)	36.00[a]
T2 – 50% SNAP + 20 mL/L of Vermitea (CM)	32.17[b]
T3 – 50% SNAP + 20 mL/L of Vermitea (RM)	29.33[cd]
T4 – 50% SNAP + 20 mL/L of Vermitea (GM)	30.67[bc]
T5 – 20 mL/L of Vermitea (CM)	28.00[d]
T6 – 20 mL/L of Vermitea (RM)	29.17[cd]
T7 – 20 mL/L of Vermitea (GM)	28.33[d]
F-RESULT	**
CV (%)	2.67

Note: Means within a column represented by common letters are not significant at 1% level using HSD.
** - highly significant, ns – not significant

Table 10. Root weight per plant (g).

Treatment	MEAN
T1 – 100% SNAP (Control)	12.33[a]
T2 – 50% SNAP + 20 mL/L of Vermitea (CM)	6.56[b]
T3 – 50% SNAP + 20 mL/L of Vermitea (RM)	4.41[c]
T4 – 50% SNAP + 20 mL/L of Vermitea (GM)	4.77[c]
T5 – 20 mL/L of Vermitea (CM)	1.67[c]
T6 – 20 mL/L of Vermitea (RM)	2.02[c]
T7 – 20 mL/L of Vermitea (GM)	2.10[c]
F-RESULT	**
CV (%)	27.60

Note: Means within a column represented by common letters are not significant at 1% level using HSD. ** – highly significant, ns – not significant

Lastly, 50% SNAP + 20 mL/L of Vermitea-GM (T4) was comparable to treatment 5 (20 mL/L of Vermitea-CM). Vermitea lacked the necessary nutrients for growth, resulting in shorter roots. As demonstrated in Table 7, Snap had a stronger effect on lettuce root development, specifically root length, reaching 31.75 centimeters compared to treatments 2-7, which ranged from 11.66 to 22.55. According to Sublett *et al.* (2018), nutrients are the key elements influencing plant growth and biomass production in hydroponic cultivation. On the root volume, SNAP achieved 36.00 centimeters and had a significant difference between all other treatments, which obtained a mean ranging from 28.00 up to 32.17 centimeters. The combined effects of SNAP and vermitea, the 50% SNAP + 20 mL/L of Vermitea-CM (T2) had a comparable effect over 20 mL/L of Vermitea-CM (T5) and also with 50% SNAP + 20 mL/L of Vermitea-GM (T4) over 20 mL/L of Vermitea-GM (T7). While the 50% SNAP + 20 mL/L of Vermitea-RM (T3) was comparable to its negative control. N, P and K are essential for crop growth and development, and their amounts influence plant results. These essential elements are required for crop growth and development, particularly during specific stages of crop development. For example, nitrogen is required by plants during the vegetative stage and potassium during the reproductive stage, whereas phosphorus is responsible for root development. Roots are indicators of how a plant absorbs and how much nutrients a root can accommodate. In the case of vermitea, the minimal nutrients available in the solution hampered the development of healthier roots, which indirectly affected the plant height, number of leaves, leaf width and length, and weight. On the other hand, the nutrient solution employed had a substantial effect on root fresh weight, with SNAP obtaining 12.33 grams of root fresh weight compared to the other treatments. Treatment 2 obtained a result four times more than Treatment 5.

However, treatments 3 and 4 were comparable to their respective negative controls, indicating that roots of plants cultivated with vermitea alone and vermitea plus 50% SNAP have a similar effect on root development except for Treatments 2 and 5. As shown in Figure 2 and Table 10, Treatments 5, 6, and 7 had shorter, lighter roots and a lower percentage of roots per volume, which can be attributed to factors such as nutrient availability, aeration, temperature, and light intensity. Nutrient supply can have a significant impact on root growth, morphology, and distribution of root systems in the substrate, with N having the strongest effect, P having a less obvious effect, and other nutrients, with the exception of Mg, usually being absent. (Lynch *et al.* 2012). Furthermore, the presence of organic carbon compounds in a hydroponic system causes the root zone to have a high biological demand for oxygen (Ezziddine *et al.* 2021), which the system used in the study was unable to provide due to its passive energy system. In the research study of Ramos (2022), he stated that aerated hydroponics produced longer roots and higher yields than non-aerated hydroponics.

Fresh weight (without roots) per sample plant (g)

The average weight of lettuce per plant is highly influenced by the use of different vermitea and SNAP solutions. The highest average weight ever recorded is obtained when the suggested rate of SNAP is applied; this is not comparable to any other treatment. This resulted from SNAP's nutritious content providing the nutrients lettuce needed for growth and development. Since the nutrient solution is the only source of mineral nutrients for plants grown hydroponically, fertilisers are provided as ions in the nutrient solution in hydroponics (Savvas 2003). The chemical composition of the hydroponic solution can be easily adjusted to meet the diverse nutritional requirements of various crops (Caruso *et al.* 2011).

Distinct patterns were seen when comparing the treatments utilized vermitea exclusively and those combined with SNAP with vermitea. Although Treatment 2 (50% SNAP + 20 mL/L of Vermitea-CM) is not comparable to Treatment 5 (20mL/L of Vermitea-CM). On the other hand, even without the 50% SNAP, the plants nevertheless produced a comparable outcome when vermitea was the only treatment utilized, as evidenced by Treatment 3 (50% SNAP + 20 mL/L of Vermitea-RM), comparison to its negative control, Treatment 6 (20 mL/L of Vermitea-RM. Similar noteworthy outcomes were also attained with Treatment 4 (50% SNAP + 20 mL/L of Vermitea-GM), yielding a weight that was comparable to Treatment 7 (20 mL/L of Vermitea-RM) with a weight of 11.15 grams. All of these show that the plants still produced results that were comparable even in the absence of the 50% SNAP specifically to Treatments 6 and 7, this outcome is related to the vermitea's extremely low nutrient content, as shown in Table 1 and also the majority of nutrients in organic sources are not in ionic forms and are hence not readily available to plants (Ezziddine *et al.* (2021). Depending on their growth stage, plants have varying nutritional needs (Fageria & Baligar 2005). Several studies have shown that changes in nutrient solution concentration have an impact on the growth characteristics of plants (Maruyama *et al.* 2010). Plants with optimal growth in terms of leaf length, width, and weight are those that obtain adequate nutrients from SNAP. This result is comparable to that of Dalla *et al.* (2011), who found that post-harvest quality, root biomass, leaf area, and greenness were all positively impacted by providing enough nutrients for plant growth and development.

Additionally, all necessary plant nutrients are frequently present in nutrient solutions in water-soluble forms and in the right amounts. The average weight of lettuce was decreased by the application of vermitea alone due to the quantity of nutrients present in the nutrient solution. Because very low concentrations of nutrients typically result in growth inhibition in hydroponically grown plants, the nutrient solution serves as the sole supply of mineral nutrients. Conversely, growth limitation, ionic toxicity, and osmotic stress are brought on by exceptionally high nutritional solution concentrations (Savvas & Adamidis 1999). However, a nutrient solution's supply buffering

Table 11. Fresh weight (without roots) per sample plant (g).

TREATMENT	MEAN
T1 – 100% SNAP (Control)	38.90^{a}
T2 – 50% SNAP + 20 mL/L of Vermitea (CM)	16.52^{b}
T3 – 50% SNAP + 20 mL/L of Vermitea (RM)	12.92b^{c}
T4 – 50% SNAP + 20 mL/L of Vermitea (GM)	12.67^{bc}
T5 – 20 mL/L of Vermitea (CM)	5.07^{d}
T6 – 20 mL/L of Vermitea (RM)	12.32^{c}
T7 – 20 mL/L of Vermitea (GM)	11.15^{c}
F-RESULT	**
CV (%)	9.08

Note: Means within a column represented by common letters are not significant at 1% level using HSD. ** - highly significant, ns – not significant

Table 12. Total fresh weight per treatment (g).

TREATMENT	MEAN
T1 – 100% SNAP (Control)	583.55^{a}
T2 – 50% SNAP + 20 mL/L of Vermitea (CM)	247.75^{b}
T3 – 50% SNAP + 20 mL/L of Vermitea (RM)	193.75^{bc}
T4 – 50% SNAP + 20 mL/L of Vermitea (GM)	190.10^{bc}
T5 – 20 mL/L of Vermitea (CM)	76.00^{d}
T6 – 20 mL/L of Vermitea (RM)	184.75^{c}
T7 – 20 mL/L of Vermitea (GM)	167.25^{c}
F-RESULT	**
CV (%)	9.08

Note: Means within a column represented by common letters are not significant at 1% level using HSD. ** - highly significant, ns – not significant

capability is essentially nonexistent (Sánchez 2009), which puts hydroponic plants at significant risk of ion toxicity and nutrient shortage (Gorbe & Calatayud 2010).

Total fresh weight of lettuce per treatment (g)

The total fresh weight of lettuce per treatment was significantly affected by various vermitea and SNAP solutions. The application of the showed SNAP rate resulted in the heaviest total fresh weight per treatment, and was incomparable to all treatments. This result is attributed to the total nutrients available to the SNAP (Table 2), and the pH, TDS, and electrical conductivity adequate for lettuce was only attained by treatment 1 with 100% SNAP (Table 3); lettuce requires 560 to 840 ppm to excel in growth (Sandoya *et al.* 2021). This total dissolved solids resulted in poor development on treatments with low TDS, which did not even meet the minimum needed ppm. Treatment 2 (50% SNAP + 20ml/L of Vermitea-CM) is significantly heavier than Treatment 5 (20 ml/L of Vermitea-CM) while Treatment 6 (50% SNAP plus 20 mL/L of Vermitea-RM) and 50% SNAP plus 20 mL/L of Vemitea-GM were comparable to their negative controls, Treatments 6 and 7. The results of unstable pH from all the treatments highly affected the growth and development of the lettuce because a pH value of 5.6–5.8 is considered optimal for lettuce growing, and nutritional shortages may emerge at ranges above or below the permissible range (Brechner *et al.*, 1996), the pH of the water in all treatments from the 7th up to 28th days after transplanting was not achieved resulted to lower yields. Another factor that greatly affected the weight of the lettuce per treatment is the temperature, knowing that lettuce seeks a low temperature to maximize its growth, the research was conducted during the rainy season from August to September, however, the prevailing temperature during the research period ranged from 27 to 37 degrees Celsius, where the suitable air temperatures required by lettuce range from 12–21°C, with 18°C the optimum. The most successful lettuce production occurs during periods when there are at least two months with maximum daytime temperatures of 17–28°C and nighttime temperatures not exceeding 15°C (Rogers 2025).

The result on this yield parameter proves that the organic nutrient solution had a poorer effect, especially when it is used alone. Furthermore, the majority of nutrients in organic sources are not in ionic form and so are not immediately available to plants (Ezziddine *et al.* 2021). Organic fertilizer has the potential for sustainable production, however, its slow action affects the growth and development of the crops, and takes longer time for the organic particles to be converted into inorganic or readily form for plant absorption than synthetic where the effect can be seen 4 to 7 days upon application. The result on the total weight per treatment is in contrast to that of Phibunwatthanawong and Riddech (2019), who found that organic fertilizer had similar effects on chemical fertilizers. This poor performance is consistent with the findings of Eudoxie *et al.* (2017), who noted that vermicompost teas, while beneficial in supplying some organic compounds and microbial activity, generally lack sufficient nitrogen and other essential nutrients to sustain robust vegetative growth.

CONCLUSION

The study was conducted to evaluate the growth performance of lettuce using the Simple Nutrient Addition Program (SNAP) solution in combination with different types of vermitea. Specifically, it aimed to assess the combined effects of vermitea and SNAP solution, determine whether vermitea could replace 50% of the SNAP nutrient solution, and identify which treatment would provide the best return on investment (ROI). The experiment was conducted from January 5 to February 15, 2024, at Isabela State University, Matusalem, Roxas, Isabela.

Three types of vermitea, derived from cattle, rabbit, and goat manure, were used either in combination with SNAP or as sole treatments. A Completely Randomized Design (CRD) was employed with seven treatments: T1 (100% SNAP), T2 (50% SNAP + 20 mL/L Vermitea-CM), T3 (50% SNAP + 20 mL/L Vermitea-RM), T4 (50% SNAP + 20 mL/L Vermitea-GM), T5 (20 mL/L Vermitea-CM), T6 (20 mL/L Vermitea-RM), and T7 (20 mL/L Vermitea-GM). Each treatment was replicated three times with a total of fifteen (15) experimental units, consisting of seventy-five (75) plants per replication.

Results revealed that plants treated with 50% SNAP plus vermitea (cattle, rabbit, and goat manure) were significantly taller than those grown with vermitea alone from the first to the fourth week of observation. The number of leaves was significantly higher in plants treated with 100% SNAP compared to 50% SNAP plus vermitea and vermitea alone. Leaf length and width were greater in plants treated with 50% SNAP plus vermitea than in those treated with vermitea alone. Plants grown on vermitea alone exhibited shorter roots, while those treated with 50% SNAP plus Vermitea-CM (T2) showed significantly higher root volume and fresh weight than T5. Treatments 3 and 4 (SNAP + Vermitea-RM/GM) were statistically similar to T6 and T7. Moreover, T2 produced a 31% increase in fresh weight (without roots) compared to T5. Overall, T1 (100% SNAP) produced the tallest, longest, and heaviest lettuce.

Findings indicate that SNAP nutrient solution remains the most effective nutrient source for hydroponic lettuce production. Vermitea application alone was not sufficient to compensate for a 50% reduction in SNAP due to its lower nutrient content. This study focused primarily on growth and yield parameters. Future research should evaluate nutritional and medicinal properties of lettuce under vermitea treatments, as well as explore the role of nitrogen manipulation to optimize the performance and consistency of vermitea formulations. Full application of SNAP solution is therefore recommended, with vermitea from cattle manure as a potential supplement owing to its higher iron and manganese content. Future studies should investigate whether a smaller reduction (25%) in SNAP solution, supplemented with vermitea, could sustain optimal lettuce growth and yield.

REFERENCES

Ahmed ZFR, Alnuaimi AKH, Askri A, Tzortzakis N (2021) Evaluation of lettuce (*Lactuca sativa* L.) production under hydroponic system: Nutrient solution derived from fish waste vs. inorganic nutrient solution. *Horticulturae*, 7(9), 292. https://doi.org/10.3390/horticulturae7090292.

Borres E, Basulgan E, Dalanon RM (2022) Potentialities of lettuce (*Lactuca sativa* L.) in hydroponics system under Simple Nutrient Addition Program (SNAP). *Journal of Education, Management and Development Studies*, 2(1), 76–85. https://doi.org/10.52631/jemds.v2i1.62.

Brechner M, Both AJ, Staff CEA (1996) *Hydroponic lettuce handbook*. Cornell Controlled Environment Agriculture, 834, 504–509.

Butler JD, Oebker NF (1962) *Hydroponics as a hobby: growing plants without soil*. Circular, 844.

Caruso G, Villari G, Melchionna G, Conti S (2011) Effects of cultural cycles and nutrient solutions on plant growth, yield and fruit quality of alpine strawberry (*Fragaria vesca* L.) grown in hydroponics. *Scientia Horticulturae*, 129, 479–485. https://doi.org/10.1016/j.scienta.2011.04.020.

Dalla Costa L, Tomasi N, Gottardi S, Iacuzzo F, Cortella G, Manzocco L, Pinton R, Mimmo T, Cesco S (2011) The effect of growth medium temperature on corn salad (*Valerianella locusta* L.) baby leaf yield and quality. *HortScience*, 46(12), 1619–1625. https://doi.org/10.21273/HORTSCI.46.12.1619.

Dobrescu A, Giuffrida MV, Tsaftaris SA (2017) Leveraging multiple datasets for deep leaf counting. In *Proceedings of the IEEE International Conference on Computer Vision Workshops*, 2072–2079.

Durell WD (1941) The effect of aeration on growth of the tomato in nutrient solution. *Plant Physiology*, 16(2), 327. https://doi.org/10.1104/pp.16.2.327.

Edwards CA, Arancon NQ, Sherman R (2011) *Vermiculture technology: Earthworms, organic wastes, and environmental management*. CRC Press. https://doi.org/10.1201/b10453.

Eudoxie GD, Khan A, Martin MA (2017) Effects of compost tea source and application method on lettuce yield and nutrient content grown in a vermicompost-amended medium. *Acta Horticulturae*, 1168, 137–144. https://doi.org/10.17660/ActaHortic.2017.1168.23.

Ezziddine M, Liltved H, Seljåsen R (2021) Hydroponic lettuce cultivation using organic nutrient solution from aerobic digested aquacultural sludge. *Agronomy*, 11(8), 1484. https://doi.org/10.3390/agronomy11081484.

Fageria NK, Baligar VC (2005) Enhancing nitrogen use efficiency in crop plants. *Advances in Agronomy*, 88, 97–185. https://doi.org/10.1016/S0065-2113(05)88004-6.

Fageria VD (2001) Nutrient interactions in crop plants. *Journal of Plant Nutrition*, 24(8), 1269–1290. https://doi.org/10.1081/PLN-100106981.

Farran I, Mingo-Castel AM (2006) Potato minituber production using aeroponics: effect of plant density and harvesting intervals. *American Journal of Potato Research*, 83(1), 47–53. https://doi.org/10.1007/BF02869609.

Fraile-Robayo RD, Álvarez-Herrera JG, Reyes MAJ, Álvarez-Herrera OF, Fraile-Robayo AL (2017) Evaluation of the growth and quality of lettuce (*Lactuca sativa* L.) in a closed recirculating hydroponic system. *Agronomía Colombiana*, 35(2), 216–222.

Gorbe E, Calatayud Á (2010) Optimization of nutrition in soilless systems: a review. *Advances in Botanical Research*, 53, 193–245. https://doi.org/10.1016/S0065-2296(10)53006-4.

Goudriaan J, Van Laar HH, Van Keulen H, Louwerse W (1985) Photosynthesis, CO_2 and plant production. In *Wheat growth and modelling*, 107–122. Springer, Boston, MA. https://doi.org/10.1007/978-1-4899-3665-3_10.

Li Q, Li X, Tang B, Gu M (2018) Growth responses and root characteristics of lettuce grown in aeroponics, hydroponics, and substrate culture. *Horticulturae*, 4(4), 35. https://doi.org/10.3390/horticulturae4040035.

Lu J, Wang J, Liu J, Lu H, Li P (2017) Water distribution of mixed media in elevated strawberry cultivation. *Journal of Irrigation and Drainage Engineering*, 35, 535–540.

Lynch J, Marschner P, Rengel Z (2012) Effect of internal and external factors on root growth and development. In *Marschner's mineral nutrition of higher plants*, 331–346. Academic Press. https://doi.org/10.1016/B978-0-12-384905-2.00013-3.

Maruyama S, Ishigami Y, Goto E (2010) Effect of nutrient solution concentration at the heading time on the growth, development, and seed storage protein content of rice plants in a controlled environment. *Environmental Control in Biology*, 48(1), 17–24. https://doi.org/10.2525/ecb.48.17.

McCauley A, Jones C, Jacobsen J (2009) *Plant nutrient functions and deficiency and toxicity symptoms*. Nutrient management module, 9, 1–16.

Mininni C, Santoro V, D'Imperio M (2024) Evaluation of vermicompost tea and its potential use in sustainable agriculture: A review of physico-chemical properties and agronomic effects. *Agronomy*, 14(2), 345. https://doi.org/10.3390/agronomy14020345.

Nugraha RU, Susila AD (2015) Sumber sebagai hara pengganti AB mix pada budidaya sayuran daun secara hidroponik. *Jurnal Hortikultura Indonesia (JHI)*, 6(1), 11–19. https://doi.org/10.29244/jhi.6.1.11-19.

Phibunwatthanawong T, Riddech N (2019) Liquid organic fertilizer production for growing vegetables under hydroponic condition. *International Journal of Recycling of Organic Waste in Agriculture*, 8(4), 369–380. https://doi.org/10.1007/s40093-019-0257-7.

Ramos AP (2022) Hydroponic treatment of lettuce (*Lactuca sativa*). *International Journal of Farm Sciences*, 12(2), 13–18. Retrieved from https://www.indianjournals.com/article/ijfs-12-2-004.

Resh HM (2022) *Hydroponic food production: A definitive guidebook for the advanced home gardener and the commercial hydroponic grower*. CRC Press.

Rogers G (2025) Impacts of climate on the Australian vegetable industry. Retrieved from https://www.vegetableclimate.com/cropimpacts/lettuce/.

Saba Z, Magwaza LS, Sithole NJ, Mditshwa A, Odindo AO (2023) Physico-chemical analysis of vermicompost mixtures for sustainable agriculture. *Agronomy*, 13(4), 1056. https://doi.org/10.3390/agronomy13041056.

Sambo P, Nicoletto C, Giro A, Pii Y, Valentinuzzi F, Mimmo T, Lugli P, Orzes G, Mazzetto F, Astolfi S, Terzano R (2019) Hydroponic solutions for soilless production systems: issues and opportunities in a smart agriculture perspective. *Frontiers in Plant Science*, 10, 923. https://doi.org/10.3389/fpls.2019.00923.

Sánchez EG (2009) Study of nutrient solution management in soilless rose cultivation, through the analysis of physiological parameters and nutrient absorption. Doctoral dissertation, Universidad Politécnica de Valencia, 174.

Sandoya GV, Bosques J, Rivera F, Campoverde EV (2021) Growing lettuce in small hydroponic systems: HS1422, 9/2021. *EDIS*, 2021(5). https://doi.org/10.32473/edis-hs1422-2021.

Sarker U, Oba S (2019) Salinity stress enhances color parameters, bioactive leaf pigments, vitamins, polyphenols, flavonoids, and antioxidant activity in selected *Amaranthus* leafy vegetables. *Journal of the Science of Food and Agriculture*, 99, 2275–2284. https://doi.org/10.1002/jsfa.9423.

Savvas D, Adamidis K (1999) Automated management of nutrient solutions based on target electrical conductivity, pH, and nutrient concentration ratios. *Journal of Plant Nutrition*, 22(9), 1415–1432. https://doi.org/10.1080/01904169909365723.

Savvas D (2003) *Hydroponics: A modern technology supporting the application of integrated crop management in greenhouse*. Retrieved from http://www.world-food.net.

Simeon LB, Bugawisan EP (2023) Potential of vermitea and nutrient solution under non-circulating hydroponic system on production performance of pechay (*Brassica rapa* L.). *EPRA International Journal of Agriculture and Rural Economic Research*, 11, 40–51.

Subandi M, Salam NP, Frasetya DB (2015) Pengaruh berbagai nilai EC (Electrical Conductivity) terhadap pertumbuhan dan hasil bayam (*Amaranthus* Sp.) pada hidroponik sistem rakit apung (floating hydroponics system). *Jurnal UIN Sunan Gunung Djati*, 9(2), 136–151.

Sublett W, Barickman T, Sams C (2018) The effect of environment and nutrients on hydroponic lettuce yield, quality, and phytonutrients. *Horticulturae*, 4, 48. https://doi.org/10.3390/horticulturae4040048.

Telfer A, Bollman KM, Poethig RS (1997) Phase change and the regulation of trichome distribution in *Arabidopsis thaliana*. *Development*, 124(3), 645–654. https://doi.org/10.1242/dev.124.3.645.

Walter A, Schurr U (1999) The modular character of growth in *Nicotiana tabacum* plants under steady-state nutrition. *Journal of Experimental Botany*, 50(336), 1169–1177. https://doi.org/10.1093/jxb/50.336.1169.

Williams KA, Nelson JS (2014) Challenges of using organic fertilizers in hydroponic production systems. In *XXIX International Horticultural Congress on Horticulture: Sustaining Lives, Livelihoods and Landscapes (IHC2014)*, 1112, 365–370. https://doi.org/10.17660/ActaHortic.2016.1112.49.