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Consumption of Energy and AB Mix Nutrition in A Controlled Verticulture Hydroponic Applications of Curly Red and Green Lettuce

Hilda Agustina[1,✉], Dika Tri Angraini[1], Veby Angela Putri[1], Endo Argo Kuncoro[1], Tri Tunggal[1], Fidel Harmanda[1]

[1] Agricultural Engineering Study Program, Faculty of Agriculture, Sriwijaya University, Palembang, INDONESIA.

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Corresponding Author:
✉ hildaagustina@fp.unsri.ac.id
(Hilda Agustina)

ABSTRACT

The green lettuce and Curly red lettuce have a high potential to be developed as commercial crops on limited land with verticulture cultivation system. The use of this cultivation system must be supported by adequate nutrients and water in addition to optimal environmental conditions. By using the vertical hydroponic plant cultivation method will increase the growth of Curly red and green lettuce plants. The method used is an experimental method and the data is processed using polynomial analysis method and descriptive method. The observation parameters in this study consisted of main parameters (flow rate, power requirement, energy requirement, and water pressure calculation). In addition, supporting parameters were evaluated including plant height, leaf count, fresh weight of plants, plant productivity, and harvest yield. Data were analyzed using descriptive and regression methods. The power requirement used from the initial stage of transplanting to harvest is 640.8 W. The total energy requirement used from the initial planting process to the harvest process is 2563.2 Wh. The average AB mix requirement of each stage of plant is 972.0 ppm; 1231.9 ppm; 1158.1 ppm; 1092.4 ppm. Flow rate is directly proportional to temperature; if the temperature increases, the flow rate for nutrients will increase, and if the temperature decreases, the flow rate will decrease for the fertigation system.

1. INTRODUCTION

Lettuce is a horticultural crop with high prospects due to its popularity as a vegetable, especially among vegetable enthusiasts. Siregar *et al*. (2018) elucidated that lettuce consumption is rising due to the increasing population and technological advancements, leading to heightened awareness among the people regarding healthy living through vegetable consumption. Lettuce is increasingly favored by the public due to its raw consumption suitability and is included as ingredient in fast food that are currently trending. Lettuce cultivation is promising; apart from the taste aspect, this plant can be cultivated hydroponically, especially in urban areas with limited land (Jumiati *et al*., 2022).

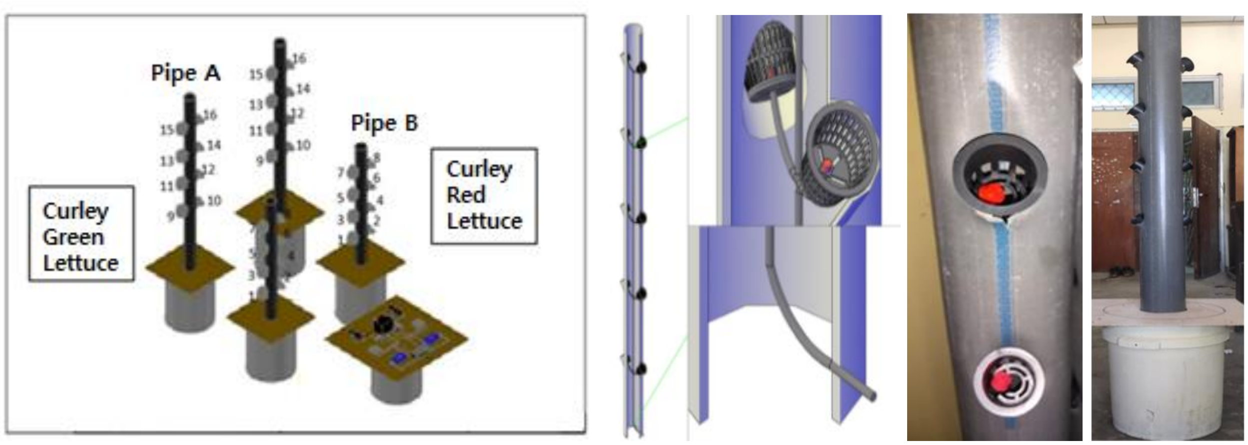
Hydroponic cultivation is rapidly expanding in urban areas (Ambarwati & Abidin, 2021; Anggraini, 2020). Land constraints and space limitations have led to increased hydroponic cultivation activities in urban areas (Kurniawati *et al*., 2020; Mazlina *et al*., 2021; Sinaga *et al*., 2022; Sulastri *et al*., 2021). Vertical hydroponic applications (Hadi *et al*., 2022; Supriyanta *et al*., 2021) support the cultivation of green lettuce (Zulkifli & Zulfida, 2021) and curly red lettuce. Verticulture hydroponic systems equipped with fertigation greatly support cultivation in limited land areas (Aini & Azizah, 2018). Fertigation is a method of simultaneous fertilizer application with irrigation for cultivated plants

(Muharomah *et al*., 2020; Nabi *et al*., 2017; Siregar *et al*., 2018). In this method, fertilization and irrigation are conducted simultaneously to optimize nutrient absorption for the growth of cultivated plants (Lanya *et al*., 2020; Muli *et al*., 2021; Pitono, 2019; Rohmah *et al*., 2018). Irrigation systems with fertigation would be easier and more controlled if applied automatically (Kholilah *et al*., 2021). Automatic fertigation irrigation systems in verticulture hydroponic cultivation would enhance water and fertilizer usage efficiency (Nikmatullah *et al*., 2023).

Air temperature can serve as a reference in the control system used in verticulture hydroponic. Temperature is one of the environmental factors that support the growth of cultivated plants (Dewanto *et al*., 2020; Riyanti & Prastyo, 2022). Increased air temperature will escalate water usage for the growth of cultivated plants (Nasution & Harahap, 2022). The design of hydroponic irrigation for plant verticulture is utilized for curly red and green lettuce cultivation using a control system based on air temperature to enhance irrigation flow for curly red and green lettuce cultivation. Controlled irrigation systems in green and red lettuce cultivation will enhance effective and efficient production of curly red and green lettuce. The use of a control system in lettuce cultivation, besides influencing increased production and efficiency, will require energy. The objective of this research is to determine the electric energy requirements and ascertain the AB Mix consumption recommendation needs for verticulture of curly red and green lettuce.

2. MATERIAL AND METHODS

The equipment used in this research are as follows: 1) 12V Battery, 2) Cutter, 3) DC wattmeter, 4) Pipe dop (diameter 4 inch), 5) Plastic drum, 6) Bucket, 7) End cap / hose plug, 8) Water filter, 9) 5L measuring cup, 10) Pipe saw, 10) Grinder, 11) Hot gun, 12) Thermohygrometer, 13) Hose connector, 14) Tap/valve, 15) Pipe glue, 16) Net pot, 17) Ruler, 18) 1.5m and 2m long (diameter 4 inch) PVC pipes, 19) DC water pump, 20) Rockwool, 21) One set of drip irrigation tools with NFT hose on Verticulture pipe, 22) 0.5 cm diameter clear hose (pump input debit system) 10m long, , 24) Marker, 25) TDS/EC Meter, 26) Digital Timer. The materials used in this research are as follows: 1) AB-Mix nutrient material, 2) Green lettuce and curly red lettuce.



(a) (b) (c) (d)

Figure 1. Controlled verticulture hydroponic system: (a) system design, (b) emitter for fertigation, (c) net pot on the pipe hole, and (d) pipe for verticulture system

2.1. Preparation for Verticulture System

The vertical pot system was designed to meet the water needs of lettuce plants (Figure 1). Lettuce plant varieties were segregated within different vertical systems. The nutrient source originates from the same reservoir. The net pot was placed in a hole with a slant (about 10 degrees) so that the water does not spill out. Water was sprayed through a nozzle placed under the Net pot. The wick on the net pot was sprayed with a liquid mixture of water and nutrients (test concentration) through nozzles connected in series and in parallel. The mixture was pumped through a hose.

The 4-inch diameter PVC pipe was cut to lengths of 2 m (pipe A) and 1.5 m (pipe B). The pipe was then drilled with a diameter of 5 cm which will be used as a support for the net pot. The space between holes was 30 cm for 2 m PVC (pipe A) and 20 cm for 1.5 m PVC (pipe B). Thus, both pipes were supported with 8 plant holes. The pipe was drilled using a hole cutter according to the size of the net pot. The pipe was then heated using a hot gun until a hole can be made in the pipe using a used glass bottle. Next, the net pots were installed in the hole.

2.2. Automatic Fertigation System Construction

The prepared pipes A and B were equipped with hoses and drip emitters on the planting holes (8 pieces). Hoses and drip emitters were assembled according to the holes that have been made. The other part of the hose was connected in series to the irrigation water and AB Mix fertilizer mixture reservoir. The control system of drip flow rate (dripper) was adjusted according to the temperature in the growing medium.

2.3. Seedling and Seed Transfer to Planting Holes

Lettuce seeds are selected by soaking them in water. Seeds that sink were selected and planted in a nursery bed, which is a plastic tray with a size of 50 cm x 30 cm x 5 cm. Rockwool was cut to size of 2.5 cm x 2.5 cm x 3 cm and then arranged in the tray. A piece of rockwool was filled with one seed of curly green lettuce or curly red lettuce. Rockwool was wetted with water until saturated. The seed tray with rockwool containing the seeds was placed in a dark place for 24 h until the seeds germinated. After the seeds sprouting, the seeding tray was moved to a place exposed to sunlight for seven days until the curly lettuce seedlings grow leaves. The lettuce seeds were then transferred to the prepared planting media (net pots) (one curly lettuce seed for each netpot). One pair of pipes A and pipe B were used for red lettuce and another pair for green lettuce cultivation. Solution of Fertilizer A and Fertilizer B (500 g each) were prepared and then stored in bottles A and B. A container was filled with the nutrient solution of fertilizer A and fertilizer B and water according to the dosage (The $CaCl_2$ stock is prepared by dissolving $CaCl_2$ in 1000 mL of water.) (Kamalia *et al*., 2017). A timer is set to operate 3 times (at 07:00, 13:00, and 16:00) for 2 min a day so that the plant's water needs are always met.

2.4. Parameters and Measurements

Temperature and relative humidity data during plant growth were measured with a thermohygrometer and electrical power was measured with a DC watt meter (at 07:00, 13:00, and 16:00). Plant growth data was taken at every 16:00. The EC value of the solution in the reservoir was measured daily at 16:00 using TDS and EC meters. Lettuce water requirements were measured daily by measuring water loss in the water and nutrient reservoirs. Plant growth was recorded daily including plant height and number of leaves. After harvest, the wet weight of the plants was recorded.

Flow rate measurements were carried out to determine the performance of the DC pump used in this study. The relationship between fertigation system and flow rate is to evaluate if the generator uses more power. The higher the power used, the higher the operational cost. Flow rate also affects plant growth in the fertigation system because too rapid water flow will hinder the plant growth process, making it difficult for plant roots to absorb the nutrients contained in the water (Rosnina *et al*., 2022; Asmana *et al*., 2017). As stated by (Krishnastana *et al*., 2018), the flow rate (Q, L/min) can be calculated from the amount of water volume (V, L) delivered during a period of time (t, min) using the following equation:

$$Q = V/t \tag{1}$$

2.4.1. Power and Energy Requirement

Power (P, watt) and energy (E, Wh) requirement were simply calculated from electric current (A, ampere) and voltage (V, volt) during a time t (h) according to Equation (2) and (3), respectively (Rifki & Rijanto, 2017).

$$P = V \times I \tag{2}$$

$$E = P \times t \tag{3}$$

2.4.2. AB Mix Nutrient Concentration

Nutrient concentration of the AB Mix was observed using an EC meter. This observation was started from the first day of plant transfer to the vertical planting media until harvesting.

2.5. Data Analysis

The polynomial regression method was employed to determine the AB mix fertilizer requirements for the cultivation of curly red and green lettuce. Additionally, a regression approach was used to determine the amount of electric power and energy required to maintain red and green lettuce plants. The observation parameters in this study consisted of main parameters (flow rate, power requirement, energy requirement, and water pressure calculation). In addition, supporting parameters were evaluated including plant height, leaf count, fresh weight of plants, plant productivity, and harvest yield. Data were analyzed using descriptive and regression methods.

3. RESULTS AND DISCUSSION

3.1. Irrigation Flow Rate in Vertical Cultivation of Green and Curly Red Lettuce

Observation results on flow rate variables and temperature variables in the fertigation irrigation system can be seen in Figure 2. From the observed data/week, the average flow rate measured at 07:00 is 2.18 L/min, at 13:00 is 2.23 L/min, and at 16:00 is 2.19 L/m. Observation results on air temperature, the average at 07:00 is 27.7 °C, the average air temperature at 13:00 is 29.7 °C, and the average air temperature at 16:00 is 29 °C. As the temperature increases, the flow rate also increases. It can be concluded that the flow rate is directly proportional to the air temperature. From the graph, it can be observed that the fertigation system operates according to the principle of fertigation system, which is regulated according to temperature conditions.

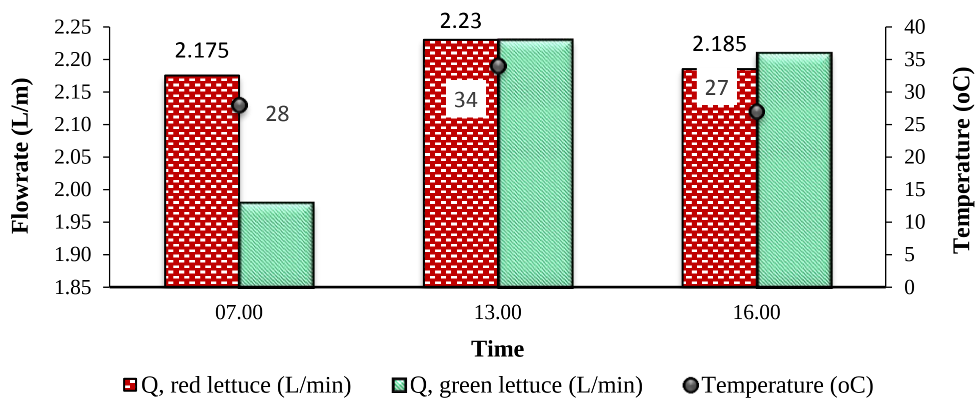


Figure 2. Average flow rate for curly red and green lettuce as well as temperature

According to the research design, the flow rate is regulated using speed controllers to adjust pump pressure, and the operation principle of the fertigation system is regulated by temperature conditions (Yerkat *et al*., 2017). The difference in flow rates occurs because the branching drip circuit causes pressure loss from the pump thrust, resulting in suboptimal flow rates, and affecting plant growth. Installation of serial pumps does not affect the increase in flow rate but significantly affects the increase in pump pressure and hydraulic power. Meanwhile, the installation of parallel pumps significantly affects the increase in flow rate but does not affect the increase in pump pressure and hydraulic power (Syahrizal & Perdana, 2019).

3.2. Power Usage

Observation results of power usage in vertical fertigation systems of curly red and green lettuce can be seen in Figure 3. From the observation data in Figure 3, the power requirements used from the initial transplanting stage to harvest for green lettuce are 640.8 W (a), while for curly red lettuce it is 450.6 W (b). This indicates that the total power usage is highest in maintaining green lettuce, with a difference of approximately 190.2 W. The relationship between power requirements during maintenance until harvest for curly red lettuce can be determined by the following equations:

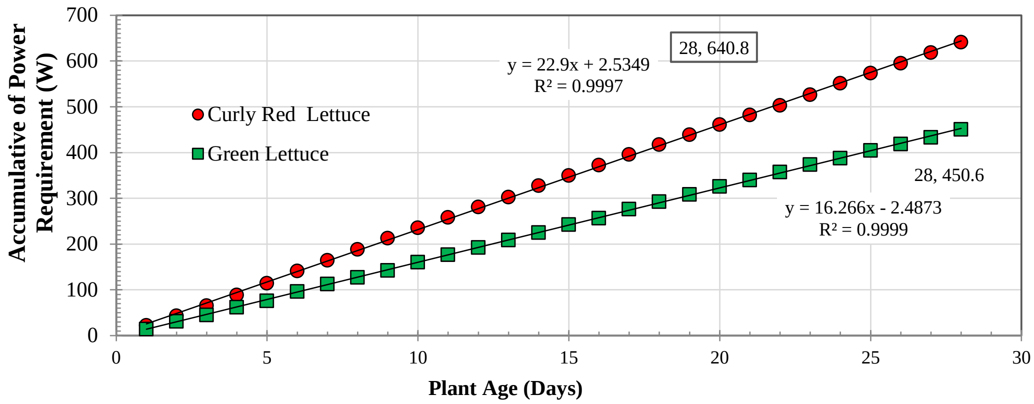


Figure 3. Accumulative power requirement for curly red lettuce and green lettuce

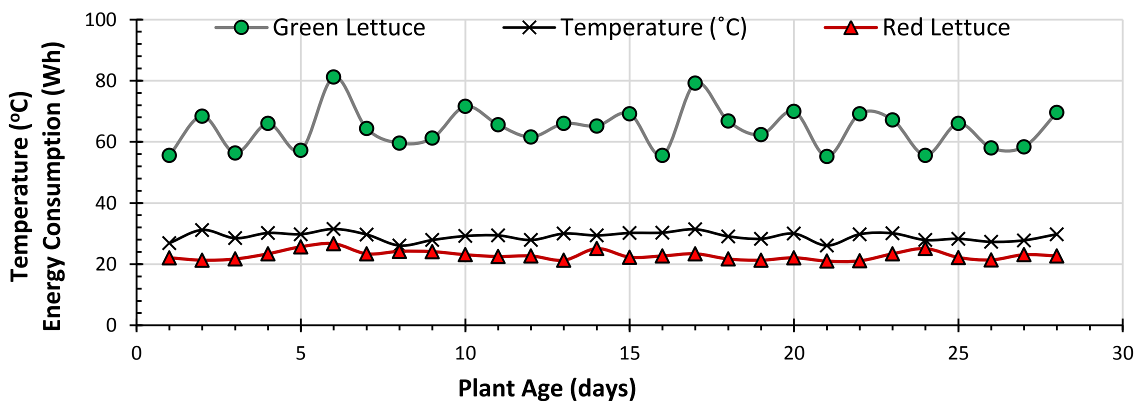


Figure 4 Air temperature (°C) and energy (Wh) for curly green lettuce and red lettuce during maintenance

The total power usage during the maintenance of green and curly red lettuce plants is 640.8 W and 450.6 W, respectively. Red and green lettuce utilize power ranging from approximately 21 to 26.1 W, depending on the air temperature. This can be observed in Figure 4. For 28 days after planting, curly red and green lettuce plants utilize the lowest power, with 21 W and 26.1 W, respectively. Meanwhile, the highest power usage during daily maintenance for curly red and green lettuce plants with automatic vertical cultivation systems is 26.7 W and 31.5 W, respectively.

This irrigation system utilizes real-time temperature data for automatic control of the pump. As the temperature rises, the flow rate automatically adjusts to ensure a higher flow rate of water to the vertical cultivation system. The power usage in this automatic vertical irrigation system is influenced by the pump's energy consumption, which functions to provide flow to this vertical cultivation system. This pump operates with speed control settings following air temperature. The greater the flow rate, the higher the power usage, leading to increased operational costs. As observed in the test, the highest power requirement is in maintaining green lettuce compared to cultivating curly red lettuce. The optimal pump flow controller based on air temperature is in cultivating curly red lettuce. Whereas, in the pump of the green lettuce vertical cultivation system, the power usage is quite high compared to cultivating curly red lettuce, even though the air temperature is the same.

3.3. Energy Consumption

Observation results on the energy consumption of the automatic vertical hydroponic cultivation system for green and curly red lettuce can be seen in Figure 5. From the observation data, the energy usage from the initial planting stage to harvest is 2563.2 Wh for green lettuce and 640.8 Wh for curly red lettuce. The highest energy requirement for green lettuce cultivation is on the thirteenth day, which is 106.8 Wh, while for curly red lettuce, the highest value is on the 6th day after transplanting, which is 31.5 Wh. The lowest energy requirement for green lettuce cultivation is on the twenty-eighth day, which is 84 Wh, and for curly red lettuce, it is 26 Wh on the 21st day. Energy requirements are directly proportional to the power requirements of the fertigation system. The higher the power requirement needed by the fertigation system, the greater the energy requirement. Fertilization activities consume 44% of the total energy usage in agricultural land (Shine *et al*., 2020), which also affects operational costs, especially in hydroponic vertical cultivation. Energy usage comes from electricity, thus increasing operational costs in agricultural production activities. To reduce costs in fertilization activities, an integrated osmosis method can be used (Dewanto *et al*., 2020).

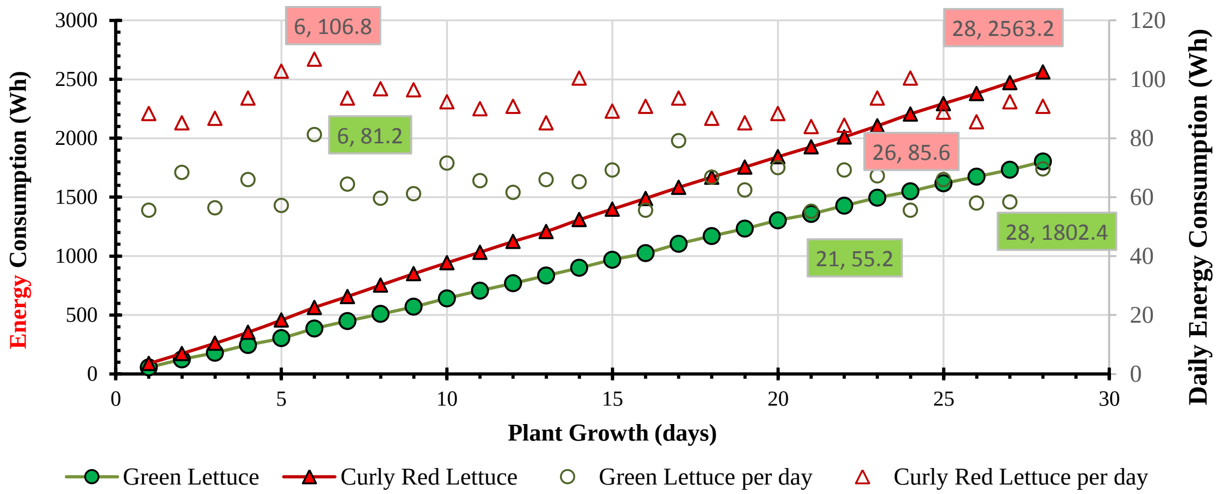


Figure 5. Energy consumption graph in vertical cultivation of green and curly red lettuce

The difference in energy requirements needed by the fertigation system is influenced by manual speed controller settings and the duration of flow rate. Hence, the longer the flow rate duration and the higher the power requirement value, the greater the energy requirement. To reduce operational costs using PLN electricity, a hybrid system with solar energy as a combination of energy usage in fertilization activities in crop cultivation is recommended (Brekel *et al*., 2023; Bina *et al*., 2018).

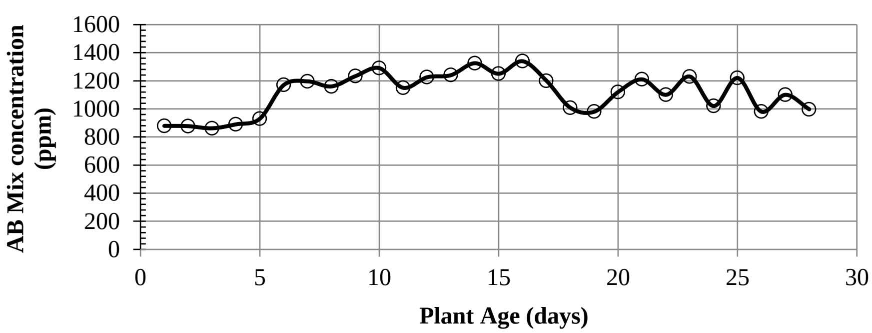


Figure 6 Graph of AB Mix nutrient solution concentration during cultivation of curly red and green lettuce

3.4. Concentration of AB Mix Solution

Observation results on the concentration of AB mix nutrient solution in the vertical cultivation system of curly red and green lettuce can be seen in Figure 6. The concentration of the AB-Mix solution varies during the observation period. This concentration is required during the growth stages of curly red and green lettuce plants. Observations during the maintenance of curly red and green lettuce plants are divided into 4 stages, starting from the first stage, which is 1 day after planting (DAP) to 7 DAP. The second stage is from 8 DAP to 14 DAP for curly red and green lettuce. The third stage is from 14 DAP to 21 DAP, and the fourth stage is from 22 DAP to 28 DAP. The concentration of AB mix in each stage of plant growth can be seen in the table below:

Table 1 Concentration of AB Mix solution (ppm) during maintenance of curly red and green lettuce plants

Stage of Plant Growth	Plants Age (DAP)	Average Concentration	Minimum Concentration	Maximum Concentration
1	1-7	972.0	862.0	1196.0
2	8-14	1231.9	1150.0	1325.0
3	14-21	1158.1	980.0	1339.0
4	22-28	1092.4	980.0	1230.0

The AB Mix solution requirement during the maintenance of curly red and green lettuce plants using the vertical cultivation method can be seen in the figure below:

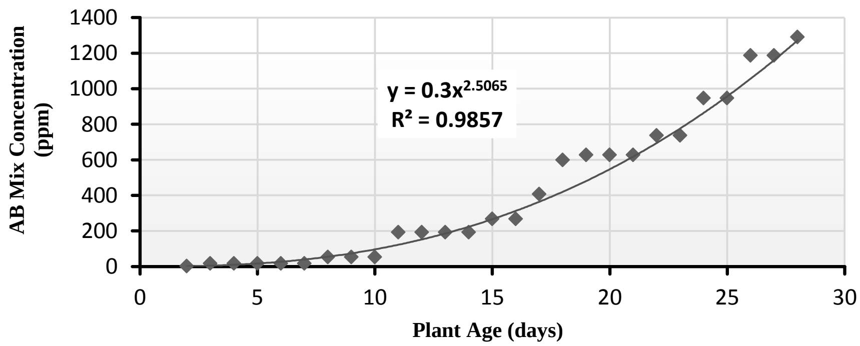


Figure 7 Graph of AB Mix solution requirement (ppm) during cultivation of curly red and green lettuce

From the observation data, at ten days old, the nutrient solution concentration used by the plants is 17 ppm. At fifteen days old, it is 53 ppm, at twenty days old, it is 193 ppm, at twenty-five days old, it is 599 ppm, at thirty days old, it is 737 ppm, and at thirty-five days old, it is 1290 ppm. The addition of AB mix nutrient solution concentration can be calculated from the plant age (x, days) using the following equation:

$$y = 0.3\,x^{2.5065} \qquad (R^2 = 0.9857) \qquad (6)$$

Nutrient deficiency can slow down plant growth and development. The optimal nutrient range for lettuce plants is 560-840 ppm (Wati & Sholihah, 2021).

3.5. Plant Height

Observation results on the height of curly red lettuce plants can be seen in Figure 8. From the observation data in Figure 8, among the 16 plant samples observed each week, the height of curly red lettuce plants increases. The tallest curly red lettuce plants are plants 3 and 5, with a height of 12.5 cm at 5 weeks after planting (WAP). The lowest height of curly red lettuce plants is on plant 16, with a height of 11.7 cm at 5 WAP.

3.6. Number of Leaves

Observation results on the leaf count of curly red lettuce plants can be seen in Figure 9. From the observation data in the curly red lettuce cultivation test, among the 16 samples, the largest number of leaves is on plants 4, 9, and 15, with 9 leaves. Meanwhile, the lowest number of leaves is on plants 1, 5, and 12, with 7 leaves. The average number of leaves per curly red lettuce plant ranges from 7 to 9 leaves. For green lettuce cultivation, there are 7 leaves at the fifth week. At 5 WAP, the number of leaves in planting hole 10 is the highest, while the lowest number is in planting holes 1, 2, 4, 5, 7, 11, 14, 15, and 16.

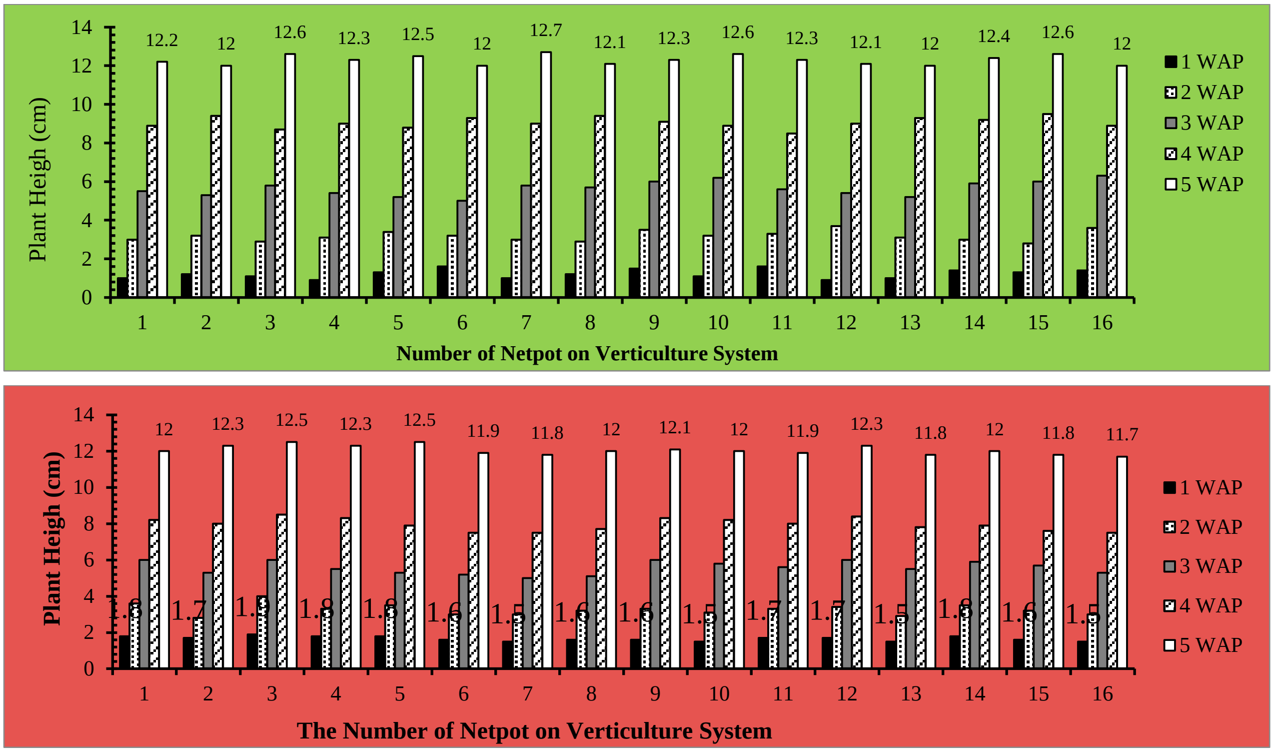


Figure 8. Height of curly green (top) and red lettuce (bottom) plants

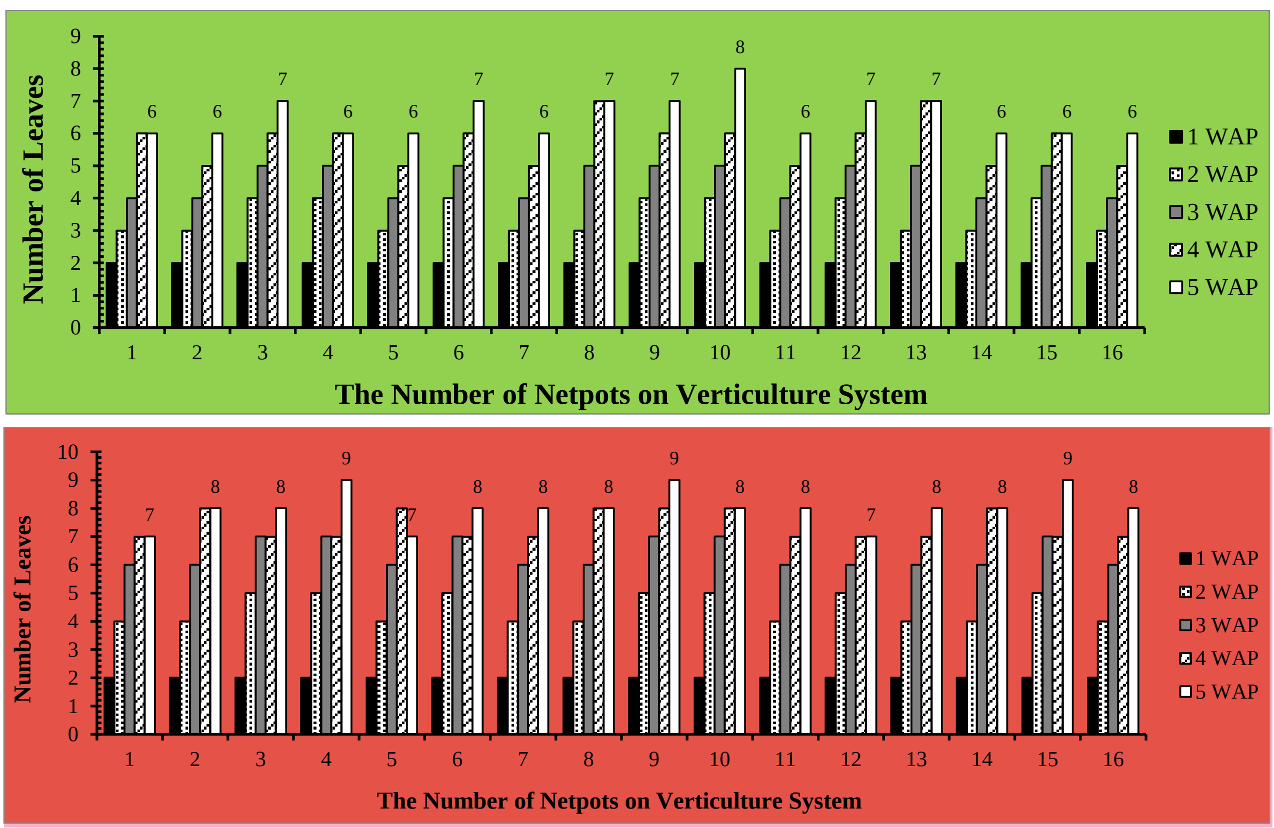


Figure 9. The number of leaves of curly green (top) and red lettuce (bottom) plants

According to (Wahyuni & Parmila, 2019; Waskito *et al*., 2017), the ability of the medium to retain water and provide nutrients will affect plant growth for optimal growth. This research shows that the optimal nutrient availability for lettuce plants is 9 leaves in curly red lettuce cultivation. The automatic temperature control vertical irrigation system provides nutrients directly with irrigation. The pump provides energy to the top with each emitter delivered to the planting hole. Optimal growth occurs in planting holes 4, 9, and 15. This means that the water seepage from the drip emitter accumulates in planting holes 4, 9, and 15. The drip is arranged in series up to the planting holes at the top. This causes the drip rate at the bottom to be less optimal than at the bottom, resulting in uneven distribution of nutrients and water delivered by the fertigation system to all plants.

4. CONCLUSIONS

The conclusions drawn from the research conducted using the verticulture method to observe the electrical energy requirements of curly red lettuce plants (*Lactuca sativa var.*) are as follows: The power requirement used from the initial stage of transplanting to harvest is 640.8 W. The difference in power requirements needed by the fertigation system is influenced by the manual adjustment of the speed controller and the duration of the flow rate. The total energy requirement used from the initial planting process to the harvest process is 2563.2 Wh. The average AB mix requirement for each plant phase is 972.0 ppm; 1231.9 ppm; 1158.1 ppm; 1092.4 ppm. Flow rate is directly proportional to temperature; if the temperature increases, the flow rate for nutrients will increase, and if the temperature decreases, the flow rate will decrease for the fertigation system. An automatic irrigation system (temperature-based) will enhance lettuce production, with increasing power and energy requirements. Differences in flow rates occur due to branching drip systems causing pressure loss from the pump's driving force, resulting in suboptimal flow rates. The recommendation from this study is that it is better if the drip system is placed from the center so that the flow rate is more even and optimal, as it significantly affects plant growth.

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REFERENCES

Aini, N., & Azizah, N. (2018). *Teknologi Budidaya Tanaman Sayuran Secara Hidroponik.* 1st edition. UB Press. Malang.

Ambarwati, D., & Abidin, Z. (2021). Rancang bangun alat pemberian nutrisi otomatis berdasarkan konduktivitas air pada budidaya hidroponik. *Jurnal Teknologi dan Sistem Informasi* (*JTSI*), ***2***(1), 29–34.

Anggraini, O. (2020). Program edukasi urban farming penunjang kemandirian masyarakat. *Aplikasia: Jurnal Aplikasi Ilmu-Ilmu Agama*, ***20***(2), 129–136. https://doi.org/10.14421/aplikasia.v20i2.2396

Asmana, M.S., Abdullah, S.H., & Putra, G.M.D. (2017). Analisis keseragaman aspek fertigasi pada desain sistem hidroponik dengan perlakuan kemiringan talang. *Jurnal Ilmiah Rekayasa Pertanian dan Biosistem*, ***5***(1), 303–315. https://doi.org/10.29303/jrpb.v5i1.41.

Bina, S.M., Jalilinasrabady, S., & Fujii, H. (2018). Exergoeconomic analysis and optimization of single and double flash cycles for Sabalan Geothermal Power Plant. *Geothermics*, ***72***, 74–82. https://doi.org/10.1016/j.geothermics.2017.10.013

Brekel, J., Thorp, K.R., DeJonge, K.C., & Trout, T.J. (2023). Version 1.1.0—pyfao56: FAO-56 Evapotranspiration in Python. *SoftwareX*, 22, 101336. https://doi.org/10.1016/j.softx.2023.101336

Dewanto, A.A., Qurthobi, A., Kirom, M.R. (2020). Analisis perbandingan suhu sistem terkontrol dan sistem konvensional pada pertumbuhan tanaman kangkung hidroponik sistem rakit apung. *e-Proceeding of Engineering*, ***7***(2), 4301-4305.

Hadi, S.N., Dewi, P.S., & Widiyawati, I. (2022). Penerapan sistem budidaya hidroponik vertikultur dan konvesional di Sekolah Dasar Negeri 3 Tanjung Purmokerto Jawa Tengah. *Buletin Udaya Mengabdi*, ***21***(61), 27–33. https://doi.org/10.24843/BUM.2022.v21.i01.p05.

Hidayanti, L., & Kartika, T. (2019). Pengaruh nutrisi AB mix terhadap pertumbuhan tanaman bayam merah (A*maranthus tricolor L.*) secara hidroponik. *Sainmatika: Jurnal Ilmiah Matematika dan Ilmu Pengetahuan Alam*, ***16***(2), 166. https://doi.org/10.31851/sainmatika.v16i2.3214.

Jumiati, I.E., Tamimi, K., Buiney, M.M., Mawarni, M.I., & Dewi, Y. (2022). Pemberdayaan masyarakat dalam pemanfaatan lahan pekarangan untuk mendukung ketahanan pangan melintasi pandemi Covid-19 di Desa Kolelet, Kecamatan Picung, Kabupaten Pandeglang. *Intervensi Komunitas*, ***3***(2), 97–105. https://doi.org/10.32546/ik.v3i2.1541.

Kamalia, S., Dewanti, P., & Soedradjad, R. (2017). Teknologi hidroponik sistem sumbu pada produksi selada Lollo Rossa (*Lactuca sativa L.*) dengan penambahan $CaCl_2$ sebagai nutrisi hidroponik. *Jurnal Agroteknologi*, ***11***(1), 96-104. https://doi.org/10.19184/j-agt.v11i1.5451.

Kholilah, U., Janitra, S.P., Gumay, R., & Ferdian, A.A. (2021). Rancang bangun sistem irigasi sprinkle berbasis IoT (Internet of Things) pada tanaman hortikultura. *Journal of Agricultural and Biosystem Engineering Research*, ***2***(2), 28–36. https://doi.org/10.20884/1.jaber.2021.2.2.4851.

Krishnastana, A.K., Jasa, L., & Weking, A.I. (2018). Studi analisis perubahan debit dan tekanan air pada pemodelan pembangkit listrik tenaga mikro hidro. *Majalah Ilmiah Teknologi Elektro*, ***17***(2), 257. https://doi.org/10.24843/mite.2018.v17i02.p14

Kurniawati, W., Erviana, L., & Desstya, A. (2020). Solusi ketahanan pangan rumah tangga perkotaan saat pandemi Covid - 19. In H. Pondo, E.P.E. Syafril, A. Rosadi, Indriansyah, A.M. Fajri, & D. Wijiyanto (Eds.), *International Webinar : Malay Local Wisdom in the Period and After the Plague*, ***1***(1), 1689–1699. Creole Institute Research and Education Development.

Lanya, B., Laksono, P.A., Amin, M., & Zahab, R. (2020). Rancang bangun sistem fertigasi dengan menggunakan venturimeter. *Jurnal Teknik Pertanian Lampung*, ***9***(2), 122-130. https://doi.org/10.23960/jtep-l.v9i2.122-130

Mazlina, M., Koryati, T., Yunidawati, W., Purba, E., & Sihaloho, M.A. (2021). Peningkatan ekonomi keluarga dengan memanfaatkan sistem hidroponik pada masa pandemi di Desa Marindal-I Kecamatan Patumbak. *Prioritas: Jurnal Pengabdian Kepada Masyarakat*, ***3***(01), 56–64. https://doi.org/10.35447/prioritas.v3i01.384

Meriaty, Arvita, S., & Dwi, P. K. (2021). Pertumbuhan dan hasil tanaman selada (*Lactuca sativa* L.) akibat jenis media tanam hidroponik dan nutrisi AB mix. *Jurnal Agroprimatech*, ***4***(2), 75–84. https://doi.org/10.34012/agroprimatech.v4i2.1698

Muharomah, R., Setiawan, B.I., Purwanto, M.Y.J., & Liyantono. (2020). Temporal crop coefficients and water productivity of lettuce (Lactuca sativa l.) hydroponics in planthouse. *Agricultural Engineering International: CIGR Journal*, ***22***(1), 22–29.

Muli, R., Wibowo, N.I., & Bissalam, A.I. (2021). Pengaruh sistem fertigasi dengan pupuk organik cair limbah ikan pada pertumbuhan tanaman cabai (*Capsicum annum. L*). *Agroscience*, ***11***(1), 58-65. https://doi.org/10.35194/agsci.v11i1.1574.

Nabi, A., Narayan, S., Afroza, B., Mushtaq, F., Mufti, S., HM, U., & Malik, A. (2017). Precision farming in vegetables. *Journal of Pharmacognosy and Phytochemistry*, ***6***(6), 370–375.

Naiborhu, S.A.A., Barus, W.A., & Lubis, E. (2021). Pertumbuhan dan hasil tanaman kailan dengan pemberian beberapa kombinasi jenis dan dosis pupuk Bokashi. *Jurnal Rhizobia*, ***3***(1), 58–66.

Nasution, M.I., & Harahap, M.Y.S. (2022). Rancang bangun pemberian nutrisi otomatis pada budidaya hidroponik berbasis mikrokontroler. *EINSTEIN (e-Journal)*, ***10***(3), 21–27. http://dx.doi.org/10.24114/einstein.v10i3.39511

Nikmatullah, A., Haryanto, H., Nurrachman, N., Qomar, M., Apriani, A., Anton, A., Khotimah, H., Aulia, J., Rahman, A., & Faturrahman, F. (2023). Sosialisasi pertanian organik sistem hidroponik untuk membangun ketahanan pangan keluarga di Desa Meraran KSB. *Jurnal Pengabdian Magister Pendidikan IPA*, 6(3), 778-782.

Pitono, J. (2019). Prospek fertigasi untuk pengelolaan hara pada budidaya lada. *Perspektif*, ***17***(2), 117-128. http://dx.doi.org/10.21082/psp.v17n2.2018.117-128

Rifki, M., & Rijanto, T. (2017). Pengaturan prototype lampu rumah dengan solar cell berbasis IoT (Internet of Things). *Jurnal Mahasiswa Universitas Negeri Surabaya*, ***6***(3), 203–212.

Riyanti, K.P.K., & Prastyo, Y. (2022). Analysis of the use of temperature and humidity sensors for Arduino-based greenhouse environment monitoring. *Antivirus: Jurnal Ilmiah Teknik Informatika*, ***16***(2), 200–210. https://doi.org/10.35457/antivirus.v16i2.2512.

Rohmah, L.N., Sunaryo, Y., & Darnawi, D. (2018). Pengaruh media tanam dan sistem fertigasi terhadap pertumbuhan serta hasil tanaman cabai rawit (*Capsicum frustescens L*) secara semi hidroponik. *Jurnal Ilmiah Agroust*, ***2***(1), 76–88.

Rokhmah, N.A., Sutardi, S., & Sastro, Y. (2022). Hidroponik indoor, solusi keterbatasan lahan terbuka untuk budidaya tanaman di perkotaan. In *Dinamika Kemajuan Dalam Studi Pembangunan Pertanian: Membangun Kesadaran dan Pengembangan Inovasi Pertanian* (Apriyanti, R.N., editor). Syiah Kuala University Press, Aceh: 151-166.

Rosnina, A.G., Ernita, E., & Nilahayati, N. (2022). Efek penggunaan jenis media dan konsentrasi nutrisi pada pertumbuhan tanaman seledri (*Apium graveolens L*.) secara hidroponik. *Jurnal Agrium*, ***19***(3), 265–273. https://doi.org/10.29103/agrium.v19i3.8755.

Shine, P., Upton, J., Sefeedpari, P., & Murphy, M.D. (2020). Energy consumption on dairy farms: A review of monitoring, prediction modelling, and analyses. *Energies*, ***13***(5), 1288. https://doi.org/10.3390/en13051288.

Sinaga, G.A.D., Kurniawan, Y., & Kusumawati, A. (2022). Urgensi komunitas budaya lokal dan ketahanan pangan dalam gerakan urban farming di masa pandemi Covid-19. *Jurnal Ilmu Sosial dan Humaniora*, ***11***(2), 337–351. https://doi.org/10.23887/jish.v11i2.45041.

Siregar, M., Sulardi, S., Samrin, S., Rusiadi, R., Setiawan, A., Siahaan, A.P.U., Ismail, D., & Luta, D.A. (2018). Pruning test enclosure fertilizer for growth and production technology of salibu rice. *International Journal of Civil Engineering and Technology (IJCIET)*, ***9***(10), 234–241.

Sulastri, F., Manik, V.T., Srigustini, A., & Dewi, E.N,F. (2021). Pelatihan berkebun hidroponik sebagai upaya dalam menjaga ketahanan pangan keluarga di masa pandemi. *Jurnal Pendidikan dan Pengabdian Masyarakat*, ***04***(1), 109–112.

Supriyanta, B., Puspitaningrum, D.A., & Rosyid, A.H.A. (2021). *Potensi Sistem Tanam Vertikal di Lahan Pekarangan*. UPN Veteran Yogyakarta Press, Yogyakarta.

Syahrizal, I., & Perdana, D. (2019). Kajian eksperimen instalasi pompa seri dan paralel terhadap efisiensi penggunaan energi. *Jurnal Program Studi Teknik Mesin UM Metro* (*TURBO*), ***8***(2), 194–200.

Wahyuni, P.S., & Parmila, P. (2019). Peran bioteknologi dalam pembuatan pupuk hayati. *Agro Bali: Agricultural Journal*, ***2***(1), 46–57.

Waskito, K., Aini, N., & Koesriharti. (2017). Pengaruh komposisi media tanam dan pupuk nitrogen terhadap pertumbuhn dan hasil tanaman Terong (*Solanum melongena* L.). *Produksi Tanaman*, ***5***(10), 1588–1593.

Wati, D.R., & Sholihah, W. (2021). Pengontrol pH dan nutrisi tanaman selada pada hidroponik sistem NFT berbasis Arduino. *Multinetics*, ***7***(1), 12–20. https://doi.org/10.32722/multinetics.v7i1.3504

Yerkat, M., Kamshat, Z., Assel, O., Shayhmetov, N., & Alimbaev, C. (2017). Section green design and sustainable architecture. *International Multidisciplinary Scientific GeoConference: SGEM*, ***17***, 699-703.

Zulkifli, Z., & Zulfida, I. (2021). Optimalisasi pemanfaatan lahan sempit menggunakan teknik vertikultur mikrohidroponik dengan media tanam dan pupuk AB mix pada tanaman selada (*Lactuca sativa* L.). *Agroscience,* ***11***(2), 101–110. https://doi.org/10.35194/agsci.v11i2.1771.