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Effect of addition of potassium (K_2O) in deep-water hydroponic cultivation of kiwifruit using *Actinidia macrosperma* rootstock

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Abstract

Hydroponic cultivation of kiwifruit is a novel production system which aims to enhance yield and fruit quality under challenges induced by global climate change. This experiment studied the effect of additional K_2O fertilization in non-circulating deep-water hydroponic cultivation of *A. rufa* x *A. chinensis* var. *chinensis* 'Kagawa UP-Ki5' kiwifruit. Seven years old 'Kagawa UP-Ki5' kiwifruit vines grafted on waterlogging tolerant rootstock *Actinidia macrosperma* were used in the experiment. The hydroponic fertilizers, OAT (OAT House No. 1 and 2) and K_2O (OAT House No. 10) from OAT Agrio Co. Ltd., Japan were used in the experiment. Two fertilization regimes, 1/4-strength OAT and K_2O added 1/4-strength OAT nutrient were applied for five and four vines respectively in 2024. In 2025, four vines were applied with 1/4-strength OAT, and three vines were applied with K_2O added 1/4-strength OAT nutrient. Growing water solution, vegetative and fruit quality parameters were assessed to evaluate the treatment effects. Higher electrical conductivity in K_2O added 1/4-strength OAT condition resulted in less water consumption by vines in both years. Additional K_2O applied in the growing water solution did not improve the fruit weight and total soluble solid content of fruit. The fruit produced from K_2O added 1/4-strength OAT treated vines were significantly higher in potassium content indicating production potential of potassium fortified kiwifruit in deep-water hydroponic cultivation. However, further study is necessary to optimize sugar accumulation in hydroponically grown kiwifruit.

Key words: Fertilization, fruit quality, hydroponic cultivation, 'Kagawa UP-Ki5', waterlogging tolerance, K_2O, fruit potassium, deep-water culture

Introduction

Cultivation of agricultural crops hydroponically is resource-efficient, production-efficient and offers safer food production compared to soil-based production systems (Pomoni *et al.,* 2023). In hydroponic cultivation system, plants are grown in a nutrient rich water solution instead of soil and is commercially adopted in the cultivation of annual horticultural crops such as strawberries, tomatoes, cucumbers and peppers (Sathyanarayana *et al.,* 2022). Additional to commercial application of hydroponic cultivation in annual crops, few experimental research are also attempted in the cultivation of perennial fruit such as grapes, figs and blueberries (Motosugi *et al.,*1995; Teragishi *et al.,* 1998; Rosen and Allan, 1990).

Kiwifruit cultivation is facing challenges of drought and water stress induced by global climate change (Rajan *et al.,* 2024). Continuous cultivation of kiwifruit on the same land may cause depletion of certain mineral nutrients and increase the risk of soil-borne pests and diseases. Although soil-based cultivation is widely used for kiwifruit production, increasing demand for high yield of quality fruits (Marcellán, *et al.,* 2022) along with labor constraints, has raised interest in alternative cultivation approaches. However, the perennial growth habit, large vine size, and sensitivity to waterlogging make kiwifruit challenging to cultivate in hydroponic systems.

A. macrosperma is a newly identified waterlogging-tolerant rootstock (Kataoka *et al.,* 2021; Beppu *et al.,* 2022) that is resistant to kiwifruit vine decline syndrome and *Pseudomonas syringae* pv *actinidiae*. (Mian *et al.,* 2022; Wang *et al.,* 2019). Ono *et al.* (2025) reported Sanuki Kiwicco® kiwifruit vines can be successfully established in non-circulating deep-water hydroponic system when grafted with *A. macrosperma* rootstock. 'Kagawa UP-Ki5' (Sanuki Kiwicco®) is the interspecific hybrid kiwifruit (*A. rufa* x *A. chinensis* var. *chinensis*) with excellent fruit quality (TSS:TA ratio 25-28) and higher yield (Yamashita *et al.,* 2021). It can tolerate high temperatures of 45 °C (Kataoka *et al.,* 2022) and possesses prolific flowering behavior.

The nutrient concentration of the growing solution is a critical factor that affects growth and development of plants in hydroponic cultivation systems. Suitable pH, electrical conductivity (EC), and growing solution temperature enhance nutrient availability in hydroponic kiwifruit cultivation (Beppu *et al.,* 2024). The designation of hydroponic system, growing structure, fertilizer type and selection of appropriate scion-rootstock are key factors for the successful hydroponic cultivation of kiwifruit. Okuda *et al* (2024) reported total soluble solids content of hydroponically cultivated 'Kagawa UP-Ki5' kiwifruit was lower than soil-grown kiwifruit. Potassium is widely known as a critical nutrient to enhance fruit quality including sugar accumulation in fruits. For instance, Wu *et al* (2024) explained the key role of potassium to increase sugar accumulation in sweet orange and Khanal *et al* (2024) reported foliar spray of potassium increases total soluble solids content in low chill peach. Hence, we investigated the effect of additional K_2O in the nutrient solution on the growth and fruit quality of 'Kagawa UP-Ki5' kiwifruit grafted onto *A. macrosperma.* Additionally, this study explored the production potential of 'Kagawa UP-Ki5' kiwifruit under non-circulating deep-water hydroponic system.

Materials and methods

Experimental location, layout and plant materials: The experiment was conducted inside a side-less vinyl greenhouse at research farm of Faculty of Agriculture, Kagawa University, Japan (34° 15' N, 134° 07' E) in 2024-2025. Shade net (S-30, Taiho Chemical Industry, Japan) of 45-50% was installed over the top of the greenhouse. Experiment was laid out in completely randomized design. The growing containers were kept 1.40 m apart between row-to-row and 0.40 m apart between plant-to-plant distance. Ten 'Kagawa UP-Ki5' vines grafted onto *A. macrosperma* in 2017 and grown hydroponically from 2021 were used in the experiment.

Hydroponic System: Non-circulating deep-water hydroponic system was adopted, consisting of 60 L plastic containers (660 mm width × 470 mm depth × 330 mm height) (Tonbo Synthetic, Japan) for each vine. The sides and bottom of the containers were covered with silver plastic film (Silver Multi, Iwatani, Japan) to block light. The aerator (700 TAP016, Sanwa Supply, Japan) provided continuous aeration throughout the experiment period. The Polystyrene foam lid with silver plastic cover was used to cover the growing container. The volume of water added to each hydroponic container each time, was recorded using a water-saving flow meter (AS-111, Krone, Japan) attached to the hose.

Growing medium: Growing containers were filled with 50 L of tap water and supplied with a 1/4-strength OAT hydroponic nutrient solution (1x Prescription A; OAT House No. 1: 1500 g/1000 L and OAT House No. 2: 1000 g/1000 L) for five vines in 2024 and four vines in 2025 referred to as control vines. 1/4-strength OAT and 200 ppm OAT House No. 10 was supplied for four vines in 2024 and three vines in 2025 referred to as potassium-treated vines (Table 1). To meet the high potassium requirements characteristics of kiwifruit (Ciu *et al.,* 2023) the growing water solution was added with 200 ppm OAT No. 10. In 2024, 200 ppm OAT House No. 10 was applied at the same time with 1/4-strength OAT whereas in 2025, 200 ppm OAT House No. 10 was supplied two weeks after the application of 1/4-strength OAT to prevent high level of EC in growing solution. Fertilization was done continuously from April to October of each year. 1/8-strength OAT hydroponic nutrient solution of prescription A was used for dormant period (November to March). The nutrient solution was completely exchanged in every four weeks throughout the experiment period. A silver ion cloth (Octcloth, Mishima Kosan, Japan) measuring 25 cm^2 was placed in the growing medium to prevent bacterial infection.

Pollination and fruit thinning: Hand pollination was conducted using pollen from *A. chinensis var. chinensis* 'Soyu' on first week of May in both years. Hand fruit thinning was conducted on last week of May on both years. About ten fruits per shoot were retained after fruit thinning.

Growing solution parameters measurement: Electrical conductivity (EC) and pH of growing water solution were measured using a pen-type pH/conductivity meter (MPC70, As One). Potassium ion (K^+) was determined using the potassium electrode method. From each replication, 50 mL of nutrient solution was sampled by adding 400 µL of 0.05 M NaOH as a pH adjustment agent. Then, one mL of 19% NaCl solution was added as an ionic strength adjuster (sample strength adjuster ratio = 50:1). The pH meter (F-72 tabletop pH meter, HORIBA) was equipped with a potassium ion-selective electrode (6582S-10C, HORIBA) to measure the K^+ concentration. All measurements were done twice a month in 2024 and at least thrice a month in 2025 growing season.

Photosynthesis related parameters measurement: Photosynthesis rate and stomatal conductance of leaf were measured by using portable photosynthesis system (LI-6800 ; LI-COR Biosciences, Lincoln, NE, USA) in the morning (9:00 am to 12:00 pm) every month from June to September each year. Three representative leaves from each vine were sampled for the measurement. The LI-6800 chamber condition was set up at flow rate: 1000 µmol s^{-1}, relative humidity: 60%, CO_2 concentration: 400 µmol mol^{-1}, fan speed: 10000 rpm and light intensity: 800 µmol m^{-2} s^{-1} during the measurement. SPAD values of leaf were measured by chlorophyll meter (SPAD-502 plus, Konica Minolta) from five sampled leaves of each replication every month.

Trunk diameter measurement: Main trunk diameter was measured using digital vernier caliper (0.1 – 150 mm) at the scion base (above the graft union) at the beginning and end of the experiment in both experimental years.

Fruit quality evaluation: Fruits were harvested on 23rd October in both years. 500 ppm ethylene (99.5%) was used to induce ripening in fruit and quality parameters were evaluated after one week of harvesting . Fruit weight was measured by digital weighing balance (Vibra, Shinko densi Co. Ltd., Japan). Digital refractometer (PR-101α, Atago, Co. Ltd., Japan) was used to measure total soluble solids content (TSS) of juice from 20 fruits of each replication. Titratable acidity (TA) was measured using automatic titrator (TA-70, DKK-TOA corporation, Japan) of 20 fruits of each replication. For TA analysis 0.5 mL of fruit juice was diluted in 40 mL of distilled water and subjected to neutralization titration using 0.05 N NaOH solution and expressed as citric acid content.

Total polyphenol content (TPC) measurement: TPC of fruit was measured by modified method of Folin-Ciocalteu (Singleton and Rossi, 1965). Five g of fruit edible part was sampled from four fruits per replication and homogenized in 20 mL of 80% (v/v) ethanol. The homogenate mixture was incubated at 60 ºC for 30 min followed by centrifugation at 10,000 × g for 20 min at 20 ºC. To determine the TPC, one mL of sample solution was diluted in eight mL of distilled water and one mL of 1.8N phenol reagent was added. The mixture was left at room temperature for five minutes, followed by addition of preheated (50 °C) 10% sodium carbonate. The absorbance at 725 nm was measured using a spectrophotometer after two hours. The TPC of the samples was calculated and expressed as gallic acid equivalent.

Table 1. Nutritional composition of OAT hydroponic fertilizer

Nutrient formulation	Ingredients (ppm)											
	AN	NN	P_2O_5	K_2O	MgO	CaO	MnO	B_2O_3	Fe	Cu	Zn	Mo
Prescription A (1/4-strength OAT house No. 1 and 2)	5.75	58.25	30	101.25	57.5	15	0.375	0.375	0.675	0.0075	0.0225	0.0075
200 ppm OAT house No. 10				106								

AN: Ammonium nitrogen, NN: Nitrate nitrogen, P_2O_5: Phosphoric acid, K_2O: Potassium source from potassium sulfate, MgO: Magnesium oxide, CaO: Calcium oxide, MnO: Manganese oxide, B_2O_3: Boric oxide, Fe: Iron, Cu: Copper, Zn: Zinc, Mo: Molybdenum

Fruit potassium(K) measurement: To determine K content of fruit, four fruits from each replication were freeze dried for 48 hours at -70 °C in freeze dryer (FDU-830, EYELA, Tokyo, Japan). Two g freeze dried pulp of each fruit sample was heated at 350 °C for one hour then to 500 °C for three hours for ashing in muffle furnace (FM-21, Yamato Scientific, Tokyo, Japan). Three mL of six mol L^{-1} HNO_3 was added in each cooled sample followed by drying of sample through heating. The sample mixture was again heated in ashing furnace at 500 °C for two hours followed by adding three mL of six mol L^{-1} HCl and heated to make it dry. 30 mL distilled water was added in the dried mixture sample and centrifuged at 5000 rpm for ten minutes. After that the supernatant was collected and made 50 mL sample by adding distilled water. K electrode method was adopted to quantify the K concentration of sample, using the same procedure as described for K^+ measurement.

Statistical analysis: Recorded data were processed and analyzed by Microsoft® Excel ver. 16.107. Significance of differences between groups was assessed using a t-test assuming unequal variances, at $P \leq 0.05$.

Results

Vine health and mortality: Initially, experiment was started with five vines in each treatment. Two vines suddenly wilted and died in the potassium-treated group, one in August 2024 and other in August 2025 when maximum temperature was >35 °C. One vine in control group became very weak in 2025 and was excluded from the experiment. Visual nutrient toxicity or disease symptoms were not observed in the dead vines.

EC and pH of growing water solution: The EC of the growing water solution increased after fertilization and declined before next fertilization. The EC was significantly higher in potassium-treated vines during additional K_2O application period of 2024 and 2025. (Fig. 1) The EC range was 0.076-0.74 $mS \cdot cm^{-1}$ in control vines and 0.29-1.07 $mS \cdot cm^{-1}$ in potassium-treated vines in 2024. Similarly, in 2025 the EC range was 0.083-0.52 $mS \cdot cm^{-1}$ in control vines and 0.12-0.56 $mS \cdot cm^{-1}$ in potassium-treated vines. The pH value also increased immediately after fertilization and declined before next fertilization. The patterns of increasing and decreasing pH was similar in both treatments until August 2024. In 2025, pH of growing solution remained below less than 6.0 although the fluctuations were observed in both treatments until August. The pH value slightly increased and reached above 6.0 in potassium-group after August 2025 (Fig. 2).

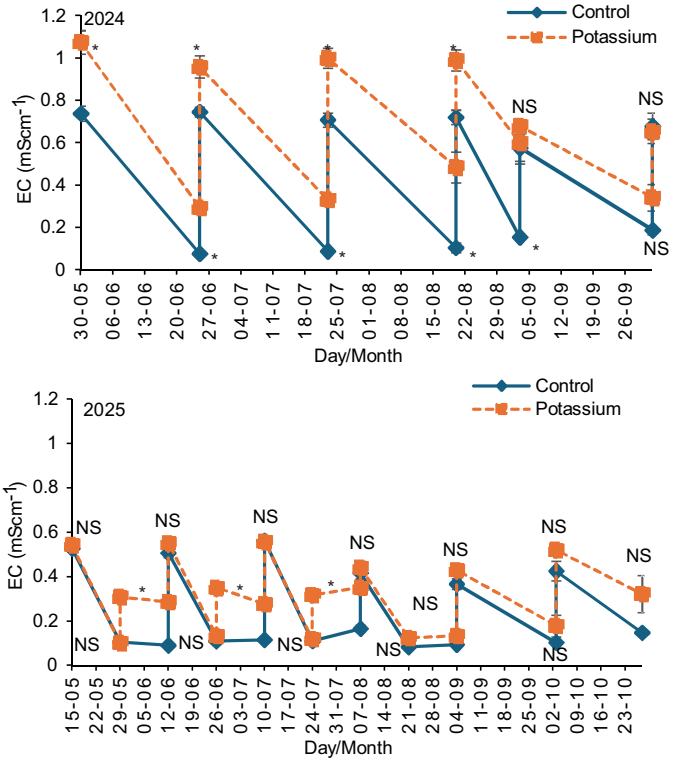


Fig. 1. Electrical conductivity (EC) under 1/4-strength OAT (control) and K_2O added 1/4-strength OAT (potassium) over two consecutive years. Individual replicates for 2024, control; n=5 and potassium; n=4 and for 2025, control; n= 4 and potassium; n= 3. Error bar indicate standard error. * indicate significantly different and NS indicate not significantly different value at $P \leq 0.05$.

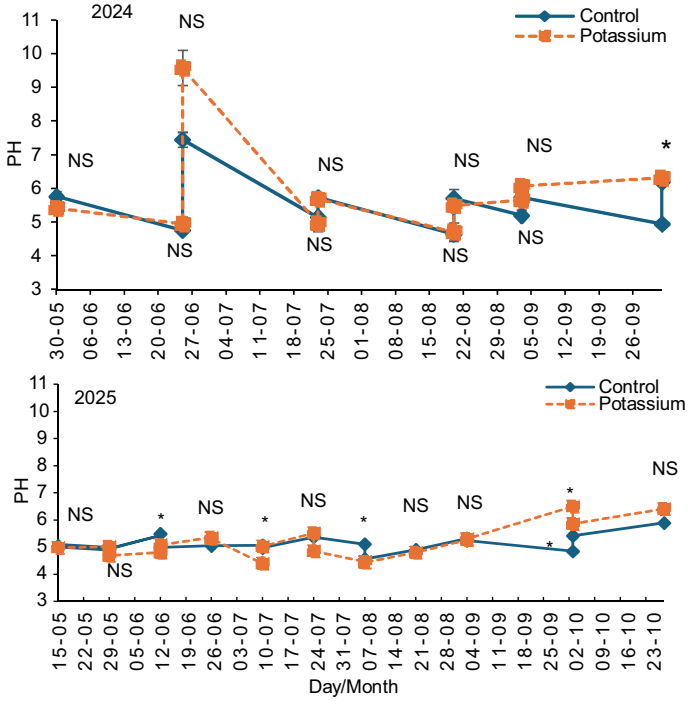


Fig. 2. pH value under 1/4-strength OAT (control) and K_2O added 1/4-strength OAT (potassium) over two consecutive years. Individual replicates for 2024, control; n=5 and potassium; n=4 and for 2025, control; n= 4 and potassium; n= 3. Error bar indicate standard error. * indicate significantly different and NS indicate not significantly different value at $P \leq 0.05$.

Residual K^+ concentration of growing water solution: K^+ was absorbed better in June and July under both treatment conditions. Higher concentrations of K^+ were recorded in residual growing water solution in August, September and October of potassium-treated vines in both years. The variation of residual K^+ in the growing solution of potassium treated vines in August and September of 2025 indicates high variation in absorption capacity of K^+. (Table 2).

Volume of water consumption (Evapotranspiration volume): Each control vine consumed 93.47±4.54 L and 126.03±4.02 L of water monthly in 2024 and 2025 respectively whereas each potassium-treated vine consumed 74.64±8.12 L and 96.43±14.41 L volume of water monthly in 2024 and 2025 respectively. The water consumption by potassium-treated vines was significantly lower in July 2024 and June 2025 (Fig. 3).

Photosynthesis related parameters: There was a similar tendency in the photosynthesis rate and stomatal conductance of both treatments in 2024 growing season, but significantly lower

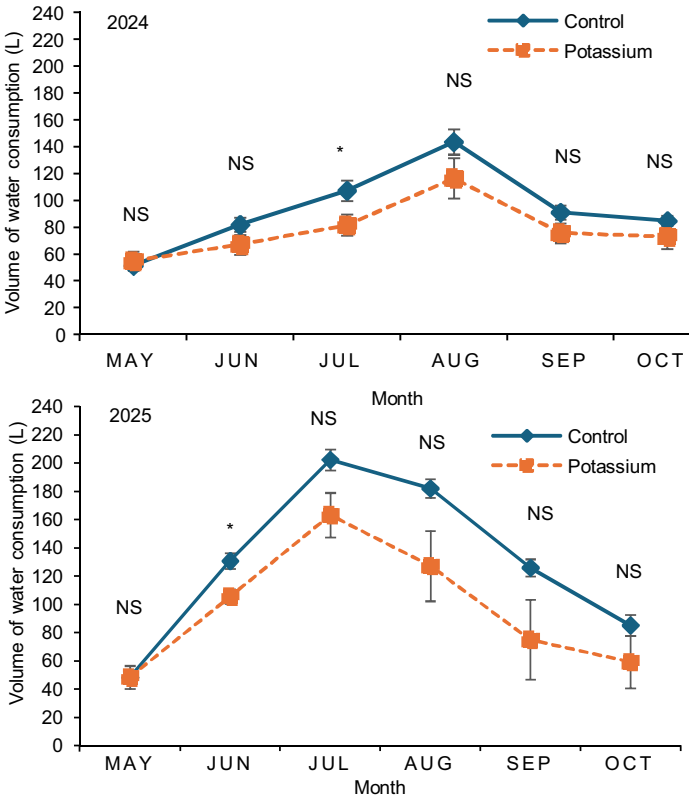


Fig. 3. Monthly volume of water consumption under 1/4-strength OAT (control) and K_2O added 1/4-strength OAT (potassium) over two consecutive years. Individual replicates for 2024, control; n=5 and potassium; n=4 and for 2025, control; n= 4 and potassium; n= 3. Error bar indicate standard error. * indicate significantly different and NS indicate not significantly different value at $P \leq 0.05$.

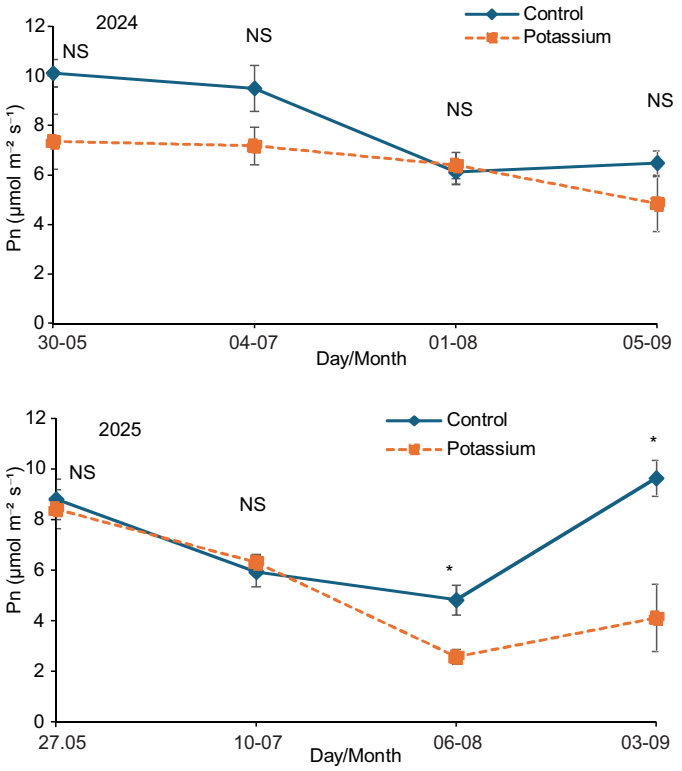


Fig. 4. Net photosynthetic rate (Pn) under 1/4-strength OAT (control) and K_2O added 1/4-strength OAT (potassium) treatments over two consecutive years. Individual replicates for 2024, control; n=5 and potassium; n=4 in 2024 and for 2025, control; n= 4 and potassium; n= 3). Error bar indicate standard error. * indicate significantly different and NS indicate not significantly different value at $P \leq 0.05$.

photosynthesis rate and stomatal conductance of potassium treated vines were recorded in August and September of 2025 (Fig. 4 and 5). SPAD value of leaves showed increasing trend in early growth stage of vines in both treatments. After July of both year potassium-treated vines SPAD values started to decrease and were significantly lower in August and September of 2025 (Fig. 6).

Trunk diameter growth: The main trunk diameter increased in both treatments over the two-year experimental period. Potassium-treated vines showed slightly higher growth rates than the control vines, but result was not statistically significant (Fig. 7).

Fruit quality evaluation: Fruit quality parameters such as fruit weight, total soluble solids, titratable acidity % and total phenolic content, were not significantly different between the treatments in both experimental years (Table 3). The other parameters such as total fruit yield, fruit pulp-core colour and fruit firmness were also not significantly different (data not mentioned). The potassium content of fruit was significantly higher in potassium-treated vines in both years.

Table 2. Residual potassium ion concentration (mg L^{-1}) in growing water solution

Season	Treatment	6 June	23 July	20 August	3 September	3 October
2024	Control	0.0004±0.0001	0.001±0.0002	0.12±0.01	0.13±0.02	0.18±0.04
	Potassium	0.040±0.02	0.11±0.05	10.7±3.9	17.8±6.7	13.88±3.9
t-test		NS	NS	*	*	**
		6 June	10 July	7 August	4 September	3 October
2025	Control	1.35±1.0	0.21±0.01	0.186±0.02	0.27±0.08	0.39±0.01
	Potassium	26.93±7.9	17.78±11.5	28.53±4.1	32.86±21.2	59.23±37.2
t-test		NS	NS	*	NS	NS

Treatment control and potassium denote 1/4-strength OAT and K_2O added 1/4-strength OAT respectively. Data are shown mean ± standard error. * indicate significance and NS indicate non significance level at $P \leq 0.05$.

Table 3. Fruit quality evaluation

Season	Treatment	Fruit weight (g)	Total soluble solid (°Brix)	Titratable acidity (%)	Total polyphenol content (mgGAE g^{-1})	Potassium content (mg g^{-1} DW)
2024	Control	40.2±1.93	12.9±0.48	1.13±0.04	0.84±0.03	9.60±0.62
	Potassium	38.3±3.54	13.3±0.55	1.37±0.11	0.82±0.04	15.41±1.19
t-test		NS	NS	NS	NS	**
2025	Control	44.5±0.65	15.8±0.63	1.00±0.05	0.71±0.02	6.82±0.73
	Potassium	43.3±2.40	15.4±0.89	1.00±0.15	0.89±0.15	11.84±0.41
t-test		NS	NS	NS	NS	**

Treatment control and potassium denote 1/4-strength OAT and K_2O added 1/4-strength OAT respectively. Data are shown mean ± standard error. * indicate significance and NS indicate not significance level at $P \leq 0.05$.

Discussion

In hydroponic cultivation fruit trees require a low concentration of nutrient fertilizer than vegetable crops. Fruit trees absorb mineral nutrients more efficiently owing to different root distribution pattern. Fruits are the main photosynthate accumulation part in fruit trees where demand for

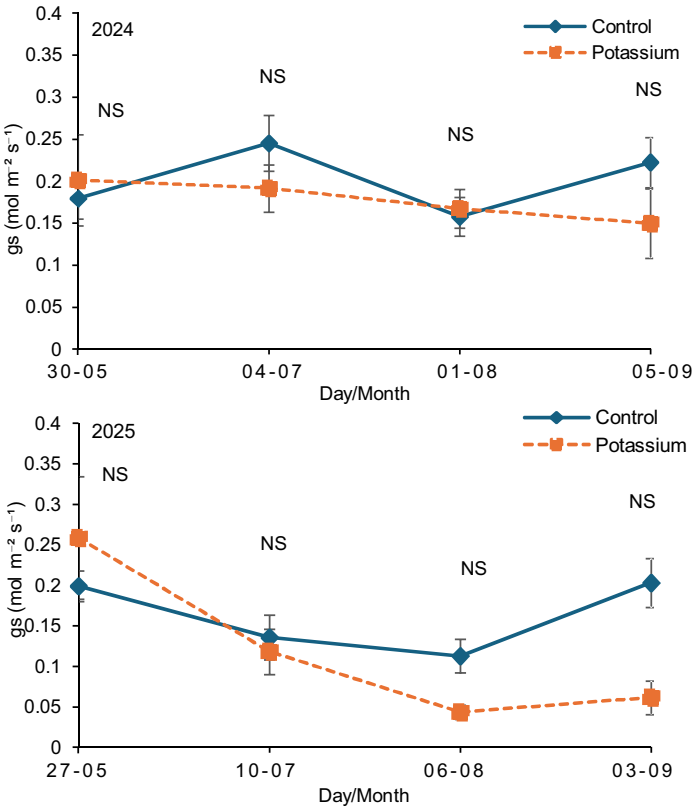


Fig. 5. Stomatal conductance rate (g_s) under 1/4-strength OAT solution(control) and K_2O added 1/4-strength OAT (potassium) treatments over two consecutive years. Individual replicates for 2024, control; n=5 and for potassium; n=4 and for 2025, control; n=4 and potassium; n=3. Error bar indicate standard error. * indicate significantly different and NS indicate not significantly different value at $P \leq 0.05$.

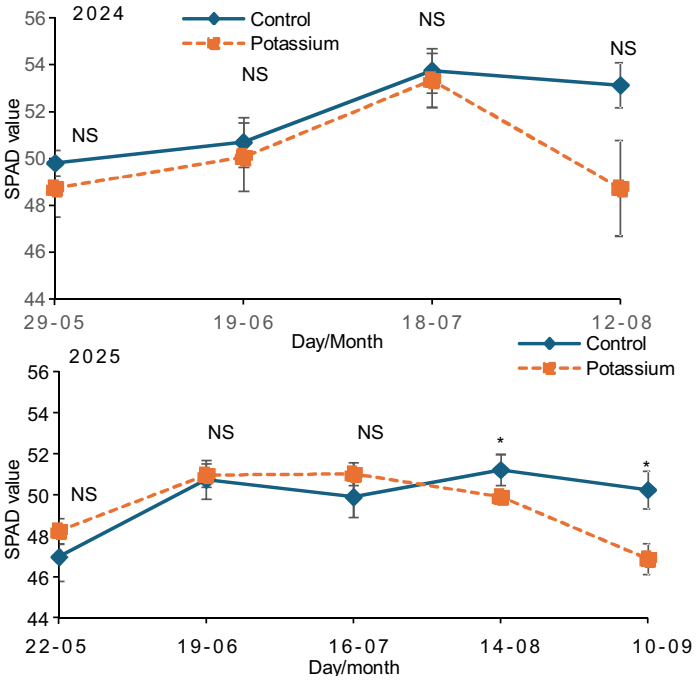


Fig. 6. SPAD value of leaves under 1/4-strength OAT solution(control) and K_2O added 1/4-strength OAT (potassium) treatments over two consecutive years. Individual replicates for 2024, control; n=5 and for potassium; n=4 and for 2025, control; n=4 and potassium; n=3. Error bar indicate standard error. * indicate significantly different and NS indicate not significantly different value at $P \leq 0.05$.

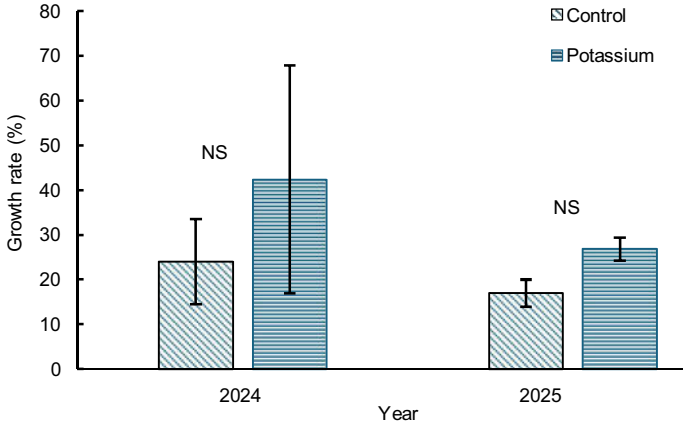


Fig. 7. Annual growth rate (%) of trunk diameter under 1/4-strength OAT solution (control) and 1/4-strength OAT + K_2O added (potassium) treatments over two consecutive years. Individual replicates for 2024, control; n=5 and potassium; n=4 for 2025, control; n=4 and potassium; n=3). Error bar indicate standard error. * indicate significantly difference and NS indicate not significantly difference value at $P \leq 0.05$.

nitrogen is relatively low (Carranca *et al.,* 2018).

The high concentration of K^+ ions in the growing water solution might be the reason for low absorption of water from root system in potassium-treated vines. When nutrient concentrations in the growing solution become high it suppresses the water absorption from roots (Nulsen and Thurtell, 1980). To regulate stomatal function K^+ acts as primary osmotic ion in guard cells through K^+ fluxes in response to vapor pressure deficit and environmental signals. Furthermore, K^+ is associated with improving osmotic balance, optimizing water use efficiency and limiting excessive transpiration from stomata during high-temperature conditions (Levitt, 1974). Song *et al* (2025) found K^+ concentration in soilless growing medium affect the uptake of water in tomato reproductive stage. The decreased photosynthesis rate and stomatal conductance in August and September of 2025 in potassium treated vines might be due to interactive effect of high temperature and cumulative EC. The low osmotic potential induced by high EC during high temperature condition causes earlier closing of stomata. Additionally, high K^+ in growing solution also causes antagonism to Ca^{+2} and Mg^{+2}. Unavailability of sufficient Mg^{+2} impairs chlorophyll formation and subsequently decline in photosynthesis rate. The decreased SPAD value of leaves in potassium-treated vines in late growth stage might be due to less absorption of NO^-_3 and NH^+_4. The SPAD value of leaf explain the chlorophyll content which is associated to leaf nitrogen content. Weak root activity resulting from high EC of growing water solution might be responsible for lower SPAD values of leaves after August of both years in potassium-treated vines.

Additional K_2O (OAT House No. 10) sourced from K_2SO_4 supply K^+ and SO_4^{-2} in the growing solution which increases EC and K^+ concentration. The low value of EC in 2025 compared to 2024 indicates higher absorption of mineral nutrients soluble in growing water solution. In 2025, application of 1/4-strength OAT (Prescription A; OAT House No. 1 and 2) and 200 ppm OAT House No. 10 at two-week intervals enhanced absorption of mineral nutrition in potassium-treated vines. Low EC of the growing water solution causes nutrient deficiency whereas high EC suppresses the absorption of water due to weak root activity. An EC range of 0.8-3.5 $mS \cdot cm^{-1}$ and pH 5-7.5 are suitable for vegetable crop species in hydroponic cultivation (Umar *et al.,*

2024). Beppu *et al* (2024) reported EC ranges from 0.2-0.9 $mS \cdot cm^{-1}$ and pH 6.2-7.3 in deep-water hydroponic culture of kiwifruit in vegetative stage when 1/4-strength OAT solution was exchanged monthly.

The absorption of K^+ after August in potassium-treated vines was low compared to period before August in both years. Kiwifruits require more potassium during vegetative growth, fruit development and fruit enlargement stages than during fruit maturation phase (Zhao *et al.,* 2013). In 2024, slightly higher absorption of K^+ in potassium-treated vines might be due to availability of K^+ rich growing water solution for longer period of time as additional K_2O was applied with 1/4-strength OAT in potassium-treated vines. The low absorption of K^+ by plant system associated with high EC condition of growing water solution. The variation of K^+ in residual growing water solution of potassium treated vines was closely corelated to water consumption (Fig. 3). This indicates, K^+ absorption is mainly governed by transpiration induced mass flow which varies with stomatal conductance under high temperature condition. Xu *et al* (2020) reported reduce root activity of young apple trees cultivated in high potassium concentration than normal concentration in hydroponic culture.

The limited water absorption causes reduce leaf water potential, loss of guard cell turgor and leads to stomatal closure. Due to decreased stomatal conductance and intercellular CO_2 concentration, Rubisco activity and carbon assimilation supresses which finally decrease photosynthesis rate. Munns and Tester (2008) and Chaves *et al* (2009) mentioned the result of suppress photosynthesis activity under high EC growing condition in cereal crops.

In fact, K fertilizers are positively correlated with vegetative growth parameters including trunk diameter of fruit trees. K fertilization promotes trunk diameter growth by cellular osmotic regulation, maintaining turgor pressure which leads to cell elongation and cambium expansion (Wind *et al.,* 2004). Sharma *et al* (2024) reported balance nutrient with adequate potassium supply significantly increases trunk diameter in apple trees when compared to low potassium supply.

The high EC of growing water solution and reduced Mg^{2+} uptake due to K^+ - Mg^{2+} antagonism causes impaired photosynthesis rate and inhibit sugar transport in potassium-treated vines, might be the primary reasons for not improving fruit total soluble solid as expected. Additionally, High K^+ content in the fruit tissue increased water influx which causes dilution of total soluble solid content. Despite this physiological condition, fruit tissues maintain high potassium concentrations suggesting robust sink strength for potassium which might also reduce toxicity of potassium in leaves. Cui *et al* (2023) explained water-potassium coupling response differently in different stage of vine growth to enhance the quality of fruits in 11 years old 'Jinan' kiwifruit. The ratio of nitrogen to potassium fertilization is important factor to improve the quality of fruits, potassium fertilization dose increases from 50 g per tree to 250 g per tree alone did not have any effect in quality of sweet cherry (Ucgun, 2018).

In conclusion, the robust growth of vines and recorded vegetative and fruit related parameters clearly explained the possibility of deep-water hydroponic cultivation of Sanuki Kiwicco® kiwifruit. Fruit yield and quality parameters were comparable between the treatments. Total soluble solid content of fruit was not improved as expected in potassium rich growing solution, but potassium fortified Sanuki Kiwicco® kiwifruit can be produced under K_2O added 1/4-strength OAT nutrient solution.

Acknowledgement

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References

Beppu, K., Y. Ogihara, M. Ohtani and I. Kataoka, 2022. Comparison of waterlogging tolerance between *Actinidia macrosperma* and *Actinidia deliciosa*. *Acta Hortic.,* 1332: 219-226.

Beppu, K., Y. Shirakawa, K. Ono and I. Kataoka, 2024. Suitable conditions for deep-water hydroponic kiwifruit culture with wet-tolerant rootstock. *Hort. Res. (Jpn.),* 23: 195-203. (In Japanese with English abstract)

Carranca, C., G. Brunetto and M. Tagliavini, 2018. Nitrogen nutrition of fruit trees to reconcile productivity and environmental concerns. *Plants,* 7: 4. https://doi.org/10.3390/plants7010004

Chaves, M.M., J. Flexas and C. Pinheiro, 2009. Photosynthesis under drought and salt stress: regulation mechanisms from whole plant to cell. *Ann. Bot.*, 103: 551-560.

Cui N., M. Wang, Q. Zou, Z. Wang, S. Jiang, X. Chen, Y. Zha, L. Xiang and L. Zhao, 2023. Water-potassium coupling at different growth stages improved kiwifruit (*Actinidia* spp.) quality and water/potassium productivity without yield loss in the humid areas of south China. *Agr. Water Manag.,* 289: 108552.

Kataoka, I., M. Matsuoka, K. Beppu and M. Ohtani, 2022. High temperature tolerance of Sanuki Kiwicco® kiwifruit interspecific hybrid *Actinidia rufa* × *A. chinensis* var. *chinensis. Acta Hortic.,* 1332: 25-30.

Kataoka, I., T. Yamada, T. Fukuda, M. Ohtani, K. Suezawa and K. Beppu, 2021. Waterlogging tolerance of *Actinidia macrospserma* and its application to kiwifruit by grafting. *Hort. Res., (Jpn.),* 20: 265-271. (In Japanese with English abstract)

Khanal, S.R., R. Mochioka, K. Ono and K. Beppu, 2024. Effects of foliar spraying of potassium sulfate on fruit growth and quality of the low-chill early ripening peach 'KU-PP1'. *Trop. Agr. Dev.,* 68: 17-23.

Levitt, J., 1974. The mechanism of stomatal movement. *Protoplasma,* 82: 1-17.

Marcellán, O., M. Briguglio, J. Irastorza, C. Godoy and M. Murcia, 2022. *Actinidia* interspecific hybrids: Valuable resources for the selection and breeding of kiwifruit rootstocks. *J. Appl. Hortic.,* 24: 3-8. https://doi.org/10.37855/jah.2022.v24i01.01

Mian, G., G. Cipriani, S. Saro, M. Martini and P. Ermacora, 2022. Potential of different *Actinidia* genotypes as resistant rootstocks for preventing kiwifruit vine decline syndrome. *Horticulturae,* 8: 627. https://doi.org/10.3390/horticulturae8070627

Motosugi, H., K. Beppu and A. Sugiura, 1995. Studies on NFT culture of 'Koyoho' grapes: Water stress symptoms and fruit quality of grapevines supplied ammonium nitrogen at low pH after veraison. *Acta Hortic.,* 396: 227-234.

Munns, R. and M. Tester, 2008. Mechanisms of salinity tolerance. *Annu. Rev. Plant Biol.*, 59: 651-681. https://doi.org/10.1146/annurev.arplant.59.032607.092911

Nulsen R. and G. Thurtell,1980. Effects of osmotica around the roots on water uptake by maize plants. *Aust. J. Plant Physiol.,* 7: 27-34.

Okuda, T., K. Ono, I. Kataoka and K. Beppu, 2024. Investigation of nutrient solution concentrations suitable for flooded, non-flowing hydroponics of kiwifruit 'Kagawa UP-Ki5'grafted on *Actinidia macrosperma. Hort. Res. (Jpn.),* 23 *(Suppl. 2)*: 338. (In Japanese)

Ono, K., K. Beppu, R. Shimomura, Y. Tokaji and I. Kataoka, 2025.Trial of hydroponic cultivation of kiwifruit using wet tolerant rootstock, *Actinidia macrosperma. Acta Hortic.,* 1431: 111-118.

Pomoni, D.I., M.K. Koukou, M.G. Vrachopoulos and L. Vasiliadis, 2023. A review of hydroponics and conventional agriculture based on energy and water consumption, environmental impact, and land use. *Energies*, 16: 1690. https://doi.org/10.3390/en16041690

Rajan, P., P. Natraj, M. Kim, M. Lee, Y.J. Jang, Y.J. Lee and S.C. Kim, 2024. Climate change impacts on and response strategies for kiwifruit production: A comprehensive review. *Plants*, 13 : 2354. https://doi.org/10.3390/plants13172354

Rosen, C.J. and D.L. Allan, 1990. Nitrogen form and solution pH influence growth and nutrition of two vaccinium clones. *J. Amer. Soc. Hort. Sci.*, 115: 83-89.

Sathyanarayana, S., W.V. Gangadhar, M.G. Badrinath, R. Ravindra and A.U. Shriramrao, 2022. Hydroponics: An intensified agriculture practice to improve food production. *Rev. Agr. Sci.,* 10: 101-114.

Sharma K. J.C. Sharma, S. Sharma, N. Sharma, R. Sharma, S. Ananthakrishnan, A. Hashem, K.F. Almutairi and E.F. Allah, 2024. Optimizing leaf nutrient status, growth, and yield parameters in high-density apple orchards (cv. Super Chief) via integrated drip irrigation and fertigation techniques. *Heliyon,* 10: e36136. https://doi.org/10.1016/j.heliyon.2024.e36136

Singleton V.L. and J.A. Rossi, 1965. Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *Am. J. Enol. Viticult.,* 16: 144–158.

Song, J., R. Zhang, B. Fu, H. Chen, X. Song, G. Lv and R. Zhang, 2025. Effects of potassium supply in nutrient solution on water and nutrient absorption of substrate-grown tomato plants. *Horticulturae,* 11: 629. https://doi.org/10.3390/horticulturae11060629

Teragishi, A., Y. Kanbara and H. Ono, 1998. Effects of the nutrient solution concentrations on growth of fig plant and fruit quality. *J. Japan. Soc. Hort. Sci.*, 67: 391-395. (In Japanese with English abstract)

Ucgun, K., 2018. Effects of nitrogen and potassium fertilization on nutrient content and quality attributes of sweet cherry fruits. *Not. Bot. Hort. Agrobo.,* 47: 114-118.

Wang, F., J. Li, K. Ye, P. Liu, H. Gong, Q. Jiang, B. Qi and Q. Mo, 2019. An invitro *Actinidia* bioassay to evaluate the resistance to *Pseudomonas syringae* pv. *actinidiae. Plant Pathol. J.* 35: 372-380.

Wind, C., M. Arend, and J. Fromm, 2004. Potassium-dependent cambial growth in poplar. *Plant Biol.,* 6: 30-37.

Wu. K., C. Hu, P. Liao, Y. Hu, X. Sun, Q. Tan, Z. Pan, S. Xu, Z. Dong, S. Wu, 2024. Potassium stimulates fruit sugar accumulation by increasing carbon flow in *Citrus sinensis*. *Hortic. Res.*, 11: uhae240.

Xu, X., X. Du, F. Wang, J. Sha, Q. Chen, T. Ge, Z. Zhu, S. Ge and Y. Jiang, 2020. Effects of potassium levels on plant growth, accumulation and distribution of carbon, and nitrate metabolism in apple dwarf rootstock seedlings. *Front. Plant Sci.,* 11: 904. https://doi.org/10.3389/fpls.2020.00904

Yamashita, T., K. Suezawa, M. Otan, S. Ono, T. Sakashita, T. Fukuda, K. Beppu and I. Kataoka, 2021. Breeding of kiwifruit cultivars 'Kagawa UP-Ki 1 to 5 Go'. *Bul. Kagawa Agr. Exp. Stn. 72.* Kagawa Jpn. (In Japanese with English abstract)

Zhao, Z., Y. Tong and J. Wang, 2013. Nutrient uptake and distribution in field-grown kiwifruit vines. *Acta Hortic.,* 984: 219-227.

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