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Optimizing AB Mix Nutrients and Wick Length in Chili Cultivated Using Nutri-Pot Method via Response Surface Methodology and Central Composite Design

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ABSTRACT

Driven by the need to address environmental issues arising from excessive fertilizer usage in agriculture activity, this study aims to determine the optimal AB mix nutrients application towards Capsicum frutescens planted using Nutri-pot system. Mathematical and statistical methods using Response Surface Methodology software have been employed to study the effect of different nutrients concentrations and wick lengths parameters towards the Capsicum frutescens growth. The parameters were measured as response variables and optimised using quadratic model of central composite design with face centered (k=1) arrangement. Results depicted that both parameters showed considerable impact on the chosen response variables with the coefficient of determination values of $R^2 < 0.9915$, P-value < 0.0001, F-value of 163.54 and the lack of fit value of 0.8608, all provided strong evidence in favour of validating the prediction models. The optimal conditions of AB mix nutrients towards Capsicum frutescens were recorded at 2.54 mS/cm of nutrients concentration and wick length of 18.15 cm. Under these conditions, the maximum plant's height simulated using Analysis of Variance and Response Surface Methodology was 38.73 cm, which was comparable with the experimental result that recorded 40.2 cm as the maximum height. Research on optimizing nutrient application is crucial, as it serves as an effective management tool for conserving resources and minimizing environmental pollution.

Keywords:

AB mix nutrients; capsicum frutescens; optimization; central composite design; response surface methodology

1. Introduction

The shortage supply of Capsicum frutescens, (C. frutescens) also known as bird's eye chili in Malaysia has been prolonged, which resulted to the need of imported chili from Thailand, China and India to fulfil the local demand. Growing the outputs with the escalating costs of the inputs is difficult therefore, highlights the importance of utilizing fertilizers and insecticides wisely to maximize the

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quality and quantity of the crops. Excessive and disproportionate use of the agrochemicals gives rise to environmental and health concerns, leading to environmental pollution and presenting dangers [1]. This encompasses the process of heavy metals building up in the soil, which has an impact on the safety of food as these contaminants make their way into the food chain [2]. Research suggests that plants utilize only a fraction of the applied fertilizers, with a substantial proportion undergoing volatilization, interacting with organic molecules, and leaking into groundwater [3,4]. The overuse of inorganic fertilizers leads to water pollution, specifically the leaking of nitrogen into lakes, rivers, and other water sources, resulting in negative consequences [5]. To prevent over application, farmers are required to follow the guidelines set by the Malaysian Department of Agriculture. This is important because there have been instances where farmers have applied more than the permitted doses [6].

This study aims to enhance the efficiency of AB mix nutrients for C. frutescens by utilizing the Nutri-pot system from week 1 to week 7. Response surface methodology (RSM) is a statistical and mathematical strategy used to identify the best circumstances for the fertilization process where it considers the cumulative impact of independent variables on the intended response [7]. The study employs AB mix nutrients, commonly used in urban farming, which comprise two solutions of A and B that consist macro- and micro-components to provide quick crop nutrient availability [8,9]. As far as we concern, there is lack of published papers specifically on optimization research for C. frutescens, as most of literatures primarily concentrate on leafy vegetables such as pakchoy, lettuce, and spinach. In this work, impact of two different factors i.e. concentration level of AB mix nutrients and wick length of the Nutri-pot were investigated by comparing the growth responses of simulated and actual plants.

2. Methodology

2.1 Experimental Design

The concentrated solution of parts A and B were initially prepared by mixing the raw materials of nutrients A and B with water in 100 L containers, separately. The solutions were mixed thoroughly using polyvinyl chloride, as shown in Figure 1. The AB mix nutrients solutions were prepared by mixing both concentrated solutions in a 5 L container filled with water, until the desired concentrated or electrical conductivity (EC) of the nutrients were achieved. The pre-determined EC levels were measured using a handheld EC meter (HANA Instruments), as shown in Figure 2 and the corresponding concentrations and volumes of AB mix nutrients prepared are outlined in Table 1.

Fig. 1. Parts A and B were diluted with water in different 100 L containers

Fig. 2. EC meter (HANA instrument) for measuring the EC level of AB mix nutrients

Table 1
EC levels and volume (mL) prepared for required concentration of AB mix nutrients

EC levels (mS/cm)	Volume (mL)
1.0	12.3 mL A + 12.3 mL B
1.2	16.6 mL A + 16.6 mL B
1.6	19.6 mL A + 19.6 mL B
1.8	22.3 mL A + 22.3 mL B
2.2	28.2 mL A + 28.2 mL B
2.6	34.4 mL A + 34.4 mL B

Next, the Nutri-pots were constructed by cutting the 5 L bottles into half, as shown in Figure 3. The upper sides of the containers were filled with coco-peat, while the bottom parts were filled with AB mix nutrients of different EC levels – 1.8, 2.2 and 2.6 mS/cm; 500 ml of AB mix nutrients were supplied to all plant samples, proportionately. Initially, the coco-peat were prepared by flushing them with water, prior to the seedlings' transplant into the containers and different length of wicks – 17, 19 and 21 cm were incorporated at the bottom of the coco – peat to absorb the AB mix nutrients. The bottom part of the containers was covered with aluminium foil to hinder algae growth, Figure 4. Literatures reported that this technique provides sufficient data in achieving the objective of the studies for the selected parameters [10]. The growth and care of C. frutescens plants were carried out in a controlled environment and away from extreme weather at Level 4, Bangunan Jauhari, Universiti Pertahanan Nasional Malaysia.

Fig. 3. Nutri-pot system

Fig. 4. Nutri-pot covered with aluminium

In the first four weeks, all seedlings were introduced with lower EC levels of AB mix nutrients at 1.0, 1.2 and 1.6 mS/cm, as shown in Table 2. The lower EC and amount (mL) of nutrients were fed to the seedlings in order to avoid any harm due to their sensitivity towards excessive nutrients and to reduce the risk of tip burn, stunted growth, nutrient imbalances and leaf scorching [11]. The heights of the plants were measured using rope or measuring tape i.e. from the ground next to the stem to the tallest stem. Mixture of organic pesticides was applied twice a week to treat and protect the plants from whiteflies and pest’s attacks.

Table 2
Schedule of AB mix nutrients application towards C. frutescens plants from Week 1 – 7

Samples	Wick length (cm)	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
		EC level (mS/cm)						
1	19	1.0	1.2	1.6	1.6	2.2	2.2	2.2
2	17	1.0	1.2	1.6	1.6	2.2	2.2	2.2
3	21	1.0	1.2	1.6	1.6	2.2	2.2	2.2
4	17	1.0	1.2	1.6	1.6	2.6	2.6	2.6
5	19	1.0	1.2	1.6	1.6	1.8	1.8	1.8
6	19	1.0	1.2	1.6	1.6	2.2	2.2	2.2
7	19	1.0	1.2	1.6	1.6	2.6	2.6	2.6
8	21	1.0	1.2	1.6	1.6	2.6	2.6	2.6
9	19	1.0	1.2	1.6	1.6	2.2	2.2	2.2
10	19	1.0	1.2	1.6	1.6	2.2	2.2	2.2
11	17	1.0	1.2	1.6	1.6	1.8	1.8	1.8
12	21	1.0	1.2	1.6	1.6	1.8	1.8	1.8
13	19	1.0	1.2	1.6	1.6	2.2	2.2	2.2

2.2 Mathematical Model and Analysis

Response Surface Methodology software (RSM) is an experimental design tool to find the optimum condition processing parameters in a minimal experimental run [12]. Statistical methodologies in different fields of research have been used for optimization. A conventional method of RSM is useful in modelling and analyzing situations that several variables influence on a response of interest and the objective is to optimize the responses. Hence, the goal of RSM is to explore a proper approximating relationship between the input variables and the output responses, as well as to find the optimum operating conditions for a system under investigation or within which operating requirements are satisfied [13]. Eq. (1) can be expressed as follows:

$$y = f(x_1, x_2, \dots, x_k) \tag{1}$$

where, y is the response and x_k is the independent variable (factor).

Central composite design (CCD) with two (2) independent variables (X_1: EC values of AB mix nutrients and X_2: wick length) at three (3) levels were performed by applying the Design Expert software package (13.0.5 version, Stat-Ease Corp., US), whilst the crop height, Y_1 cm were studied as the response variable for the modelling. Each independent variable of three (3) levels was coded as -1, 0 and +1 for low, centre point and high points, respectively and the two (2) independent factors i.e. concentration level of AB mix nutrients, X_1: 1.8, 2.2, and 2.6 mS/cm and wick length, X_2: 17, 19, and 21 cm were considered. The standard 2^k factorial with its origin at the centre is included in determining the number of runs of the CCD. $2k$ points are fixed axially at a distance from the centre to generate the quadratic terms and replicate runs at the centre (r), where k is the number of variables. Hence, the total number of runs required for the two independent variables can be calculated using Eq. (2):

$$2^k + 2k + r = 22 + (2 \times 2) + 5 = 13 \tag{2}$$

Therefore, 13 experimental runs were required for the two (2) independent variables. Tables 3 and 4 show the variables configuration along with their coded and actual levels of the EC values and wick length; the coded value were set as -1, 0, 1 (low, medium, high). The tables also depicted the two-factor-three-level at second-order face-centred CCD that was utilized to study the individual and interaction effect of different AB mix nutrients concentrations and the length of wick used; Figure 5 shows the setup of CCD. Configuration of which model to use, the predictive models and their optimization were built by the chosen variables in Eq. (3), which expresses the equation of the second-order quadratic model:

$$Y = \beta_0\,(\beta_i \times X_1) + (\beta_j \times X_2) + (\beta_{ij} \times X_1 \times X_2) + (\beta_i \times X_1^2) + (\beta_i \times X_2^2) \qquad (3)$$

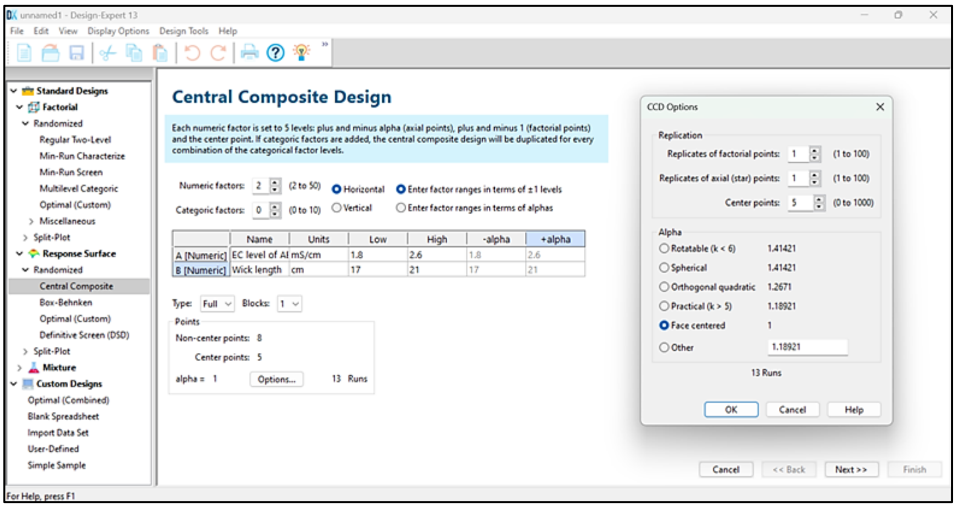
where, Y is the response in terms of predicted plant height, β_0, β_i, β_j, and β_{ij} are interactive regression coefficients, X_1 is the concentration of AB mix nutrients (mS/cm) and X_2 is the wick length (cm).

Table 3
Range of variables and their coded levels

Factors	Unit	Coded symbol	Coded levels		
			Low (−1)	Centre point (0)	High (+1)
EC levels of AB mix nutrients	mS/cm	X_1	1.8	2.2	2.6
Wick length	cm	X_2	17	19	21

Table 4
The coded and actual level of independent variables

No. of Runs	Coded label		Actual label	
	X_1	X_2	X_1	X_2
	EC levels (mS/cm)	Wick length (cm)	EC levels (mS/cm)	Wick length (cm)
1	0	0	2.2	19
2	0	-1	2.2	17
3	0	+1	2.2	21
4	+1	-1	2.6	17
5	-1	0	1.8	19
6	0	0	2.2	19
7	+1	0	2.6	19
8	+1	+1	2.6	21
9	0	0	2.2	19
10	0	0	2.2	19
11	-1	-1	1.8	17
12	-1	+1	1.8	21
13	0	0	2.2	19



Central Composite Design

Each numeric factor is set to 5 levels: plus and minus alpha (axial points), plus and minus 1 (factorial points) and the center point. If categoric factors are added, the central composite design will be duplicated for every combination of the categorical factor levels.

Numeric factors: 2 (2 to 50) ● Horizontal ● Enter factor ranges in terms of ±1 levels
Categoric factors: 0 (0 to 10) ○ Vertical ○ Enter factor ranges in terms of alphas

	Name	Units	Low	High	-alpha	+alpha
A [Numeric]	EC level of AI	mS/cm	1.8	2.6	1.8	2.6
B [Numeric]	Wick length	cm	17	21	17	21

Type: Full Blocks: 1
Points
Non-center points: 8
Center points: 5
alpha = 1 13 Runs

CCD Options
Replication
Replicates of factorial points: 1 (1 to 100)
Replicates of axial (star) points: 1 (1 to 100)
Center points: 5 (0 to 1000)
Alpha
○ Rotatable (k < 6) 1.41421
○ Spherical 1.41421
○ Orthogonal quadratic 1.2671
○ Practical (k > 5) 1.18921
● Face centered 1
○ Other 1.18921
13 Runs

Fig. 5. Interface of CCD setup in Design Expert version 13.0.5 software

The modelling process utilizing RSM commenced with the identification of the range values for the independent variables, which included the EC of the AB mix nutrients and the length of the wick, as well as the dependent variable, represented by the change in height of C. frutescens. The experiments that have been designed using Design Expert software via CCD application were performed and the results were further analyzed using analysis of variance (ANOVA) to derive the quadratic model and study the failure analysis for prediction model. Graph model relationship between the independent variables and dependent variables were studied and finally, the suggested optimal experiment was determined and compared with the obtained and predicted results.

3. Results

3.1 Development of C. Frutescens and the Effect of Different EC Values Towards Plants' Height

As the chili seedlings were transplanted into the Nutri-pot from the cultivation tray, the seedlings' height was measured and recorded, with plant height being the sole response variable for this experiment. The growth of C. frutescens plants from Week 1 to Week 7 and the operating conditions used in this work are presented in Table 5; images of C. frutescens plants at week 7 are showed in Appendix A. The average temperature and humidity throughout the weeks were recorded at 29 °C, 79 % in the morning and 32 °C, 59 % in the evening, respectively.

Table 5
Variation of EC levels, wick lengths and the height of C. frutescens plants in seven weeks

Initial height (cm)	Weeks	1	2	3	4	5	6	7
Sample #1 Wick length: 19 cm								
28.2	EC levels (mS/cm)	1.0	1.2	1.6	1.6	2.2	2.2	2.2
	Height (cm)	28.6	29.5	31.2	31.5	39.4	56.4	68.0
Sample #2 Wick length: 17 cm								
19.4	EC levels (mS/cm)	1.0	1.2	1.6	1.6	2.2	2.2	2.2
	Height (cm)	19.8	21.6	22.1	22.8	32.8	46.6	60.4
Sample #3 Wick length: 21 cm								
36.3	EC levels (mS/cm)	1.0	1.2	1.6	1.6	2.2	2.2	2.2
	Height (cm)	36.4	37.5	37.8	39.0	53.5	60.1	70.6
Sample #4 Wick length: 17 cm								
20.7	EC levels (mS/cm)	1.0	1.2	1.6	1.6	2.6	2.6	2.6
	Height (cm)	21.9	23.6	24.6	25.1	33.9	42.8	60.6
Sample #5 Wick length: 19 cm								
26.7	EC levels (mS/cm)	1.0	1.2	1.6	1.6	1.8	1.8	1.8
	Height (cm)	27.3	28.5	29.4	30.2	49.1	52.8	63.6
Sample #6 Wick length: 19 cm								
22.5	EC levels (mS/cm)	1.0	1.2	1.6	1.6	2.2	2.2	2.2
	Height (cm)	23.1	24.2	25.2	25.6	40.6	52.8	61.7
Sample #7 Wick length: 19 cm								
29.3	EC levels (mS/cm)	1.0	1.2	1.6	1.6	2.6	2.6	2.6
	Height (cm)	29.8	30.3	31.5	31.6	43.9	51.3	62.6
Sample #8 Wick length: 21 cm								
39.5	EC levels (mS/cm)	1.0	1.2	1.6	1.6	2.6	2.6	2.6
	Height (cm)	39.8	41.9	42.4	43.0	49.3	55.7	64.6
Sample #9 Wick length: 19 cm								
22.8	EC levels (mS/cm)	1.0	1.2	1.6	1.6	2.2	2.2	2.2
	Height (cm)	23.3	24.6	26.3	28.3	43.0	54.9	63.0
Sample #10 Wick length: 19 cm								
25.4	EC levels (mS/cm)	1.0	1.2	1.6	1.6	2.2	2.2	2.2
	Height (cm)	27.1	28.7	31.9	33.6	36.6	44.9	64.4
Sample #11 Wick length: 17 cm								

Table 5
Variation of EC levels, wick lengths and the height of C. frutescens plants in seven weeks

Initial height (cm)	Weeks	1	2	3	4	5	6	7
29.9	EC levels (mS/cm)	1.0	1.2	1.6	1.6	1.8	1.8	1.8
	Height (cm)	30.5	31.6	31.8	32.6	49.8	54.4	63.8
Sample #12 Wick length: 21 cm								
24.0	EC levels (mS/cm)	1.0	1.2	1.6	1.6	1.8	1.8	1.8
	Height (cm)	24.4	25.0	25.5	26.4	38.7	43.4	59.6
Sample #13 Wick length: 19 cm								
30.3	EC levels (mS/cm)	1.0	1.2	1.6	1.6	2.2	2.2	2.2
	Height (cm)	32.3	33.6	33.7	36.2	42.4	51.9	69.5

In week 1, all seedlings were introduced with low EC level of AB mix nutrients at 1.0 mS/cm and all showed significant growth in height. All seedlings were clearly responded to the fertilizers where they began to develop stronger roots within the coco-peat medium throughout the week. For instance, the height of sample 4 increased from 20.7 cm to 21.9 cm and sample 10 increased by 1.7 cm, from 25.4 cm to 27.1 cm; sample 13 recorded the highest growth at 2 cm increased from 30.3 cm. Similarly, other samples showed the increment in growth that ranges between 0.2 cm and 0.6 cm higher, compared to their initial height.

In the following week, the EC level of AB mix nutrients were increased to 1.2 mS/cm and the C. frutescens plants began to produce longer and leaner branches. Sample 8 with 21 cm wick length depicted an increment of 41.9 cm with 2.1 cm higher compared to the previous week whilst samples 10, 4 and 2 showed the increment of 1.6 cm, 1.7 cm and 1.8 cm, respectively. There were three (3) plant samples that showed poor growth i.e. samples 7, 12 and 1 with 0.5 cm, 0.6 cm and 0.9 cm difference, respectively compared to the height recorded in week 1. In addition to that, the presence of white flies were also detected, as shown in Figure 6.

Subsequently in week 3, as the EC level were increased to 1.6 mS/cm, it can be observed that the C. frutescens began to develop flower buds and produced darker green leaves where all plants showed positive response towards the AB mix nutrients application. For instance, sample 8 recorded huge height difference of 8.5 cm of 42.4 cm height, sample 10 showed significant increase of 3.2 cm from 28.7 cm at week 2 and sample 9 depicted the rise of 1.7 cm to 26.3 cm. So far, all plants attained satisfactory growth with time, which indicated that the concentration and amount of AB mix nutrients applied were appropriate with the plants' need. However, burnt sign at the tip of several plant leaves were observed as depicted in Figure 7, where it may be due to the rapid increased in the EC level of AB mix nutrients.

In week 4, the height of the plant samples 3, 9, 10 and 13 were prominently increased by 1.8 cm, 2 cm, 1.7 cm and 2.5 cm, respectively, compared to other plants that showed less noticeable change in height. Due to the curling and burnt effects of leaves in week 3, the EC level of AB mix nutrients was maintained at 1.6 mS/cm throughout week 4 and it can be observed that the growth patterns for most of the plants required adequate dosage and concentration of fertilizer to ensure sufficient nutrient uptake. Therefore, in week 5, the EC level of AB mix nutrients were varied according to the parameters designed by Design Expert software as shown in Table 4. All plants exhibited substantial growth in height for example, sample 5 showed the most proficient growth at 49.1 cm after 1.8 mS/cm of AB mix nutrients was introduced, which indicated the increase of 18.9 cm compared to previous week. Similarly, sample 3 showed the increment of 53.5 cm with 2.2 mS/cm of AB mix nutrients, sample 11 exhibited 17.2 cm difference, from 32.6 cm to 49.8 cm with the increasing EC level to 1.8 mS/cm.

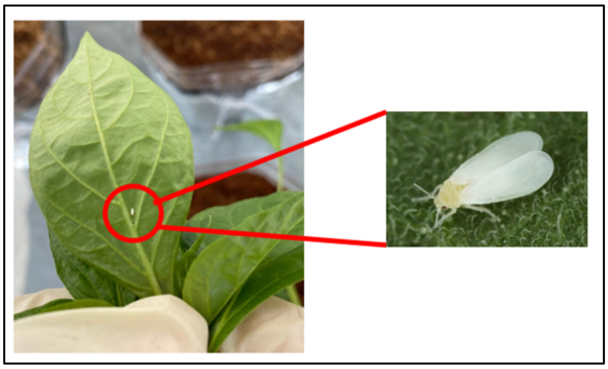


Fig. 6. White flies found under several leaves of C. frutescens plant [14]

Fig. 7. Burnt and curling effects on the leaves observed in one of the plant sample

Starting week 6, it can be observed that several of the plants began to produce chilies where some of the flowers have turned into small chilies; the leaves produced were smaller and thicker, as well as proliferated branches. With the raised of EC level to 2.2 mS/cm, the plants continued to grow higher where sample 3 recorded the tallest height of 60.1 cm, increased by 6.6 cm from week 5 and sample 2 showed the largest difference in height by 13.8 cm, from 32.8 cm to 46.6 cm. In the final week 7, number of chilies produced increased significantly, as the plants grew taller and larger, as shown in Figure 8.

Fig. 8. Chilies production in Week 7

In general, all plants grew to the final height of more than 60 cm, regardless of variations in EC level and wick length except for sample 12 that reached 59.6 cm using 21 cm wick length of 1.8 mS/cm. At 2.2 mS/cm, samples 1 and 2 showed height increment of 11.6 cm and 13.8 cm difference even though using shorter wick length of 17 cm and 19 cm, respectively. In contrast to sample 3 that recorded small height difference by 10.5 cm, even by using the longest wick of 21 cm, the height of sample 3 plant yielded at 70.6 cm. This occurrence may be due to the longer time required for the long wick to absorb nutrients as the length of the wick plays a critical role in influencing the nutrient uptake efficiency of plants.

In conclusion, the data suggest that the parameters of wick length and EC level of AB mix nutrients play important roles in the growth of C. frutescens using Nutri-pot system. While moderate increased in the EC levels can support the growth and development of the plants, there appears to be a nuanced interaction with the wick length factor, that too long of wick might delay the nutrient absorption process by the root [15]. The optimal wick length seems to be around 19 cm for this specific plant species and nutrient mix, which consistently supported substantial growth across varying EC levels. This indicates a synergistic effect where the right combination of wick length and nutrient concentration can maximize growth and deviation from the optimal condition may result in less efficient nutrient uptake and reduced plants growth. In wick fertigation system, wicks serve as conduits for transporting water and essential nutrients from a fertilizer source to the plant's root zone [15]. Contrarily, if the wick is excessively long, it may transport an excess of moisture, potentially leading to overwatering and nutrient imbalances, which can negatively affect plant growth [16,17].

3.2 Optimization Study via Response Surface Methodology (RSM)

In this study, RSM was used to obtain the optimum conditions of AB mix nutrients application towards C. frutescens with two (2) factors employed i.e. the concentration of AB mix nutrients and wick length. Response variable was determined by second-order quadratic equation as shown in Eq. (3) and all experimental data were evaluated using Design Expert (Version 13) software. As shown in Table 6, various mathematical models can be used to predict the response, however the results show that for this work, quadratic model is the most appropriate mathematical equation to be used. Quadratic model can effectively determine the optimal conditions for the response variable where it predicts the curvature of the response surface, allowing for precise determination of the optimum condition. Regression model describing the height of C. frutescens was established and the equation obtained in terms of quadratic model is shown in Eq. (4).

$$Y = -401.703 + 208.301A + 24.2917B + -5.03125AB + -26.3254A^2 + -0.390517B^2 \tag{4}$$

where, *Y* is the height of C. frutescens, *A* is the EC value of *AB* mix nutrients and *B* is the wick length.

Table 6
Analysis of various models for predicting the response variable

Source	Sum of squares	DF	Mean square	*F*-value	*P*-value	Remarks
Mean	17546.29	1	17546.29			
Linear	72.10	2	36.05	2.43	0.1376	
2FI	64.80	1	64.80	7.00	0.0266	
Quadratic	81.40	2	40.70	152.45	< 0.0001	Suggested
Cubic	0.6483	2	0.3242	1.33	0.3447	Aliased
Residual	1.22	5	0.2441			
Total	17766.46	13	1366.65			

Several attempts have been carried out to optimize the data using RSM, as shown in Table 7, where initially the alpha value of rotatable *k* was set to ± 1.41421 and the center points was set to 9. The mathematical model obtained for the first attempt was the mean model, which did not fit the quadratic model and results of the goodness-of-fit, R^2 value was 0.3829. This contributes to the negative value of adjusted and predicted R^2 values, which indicated that the model has no predictive value. The model was re-run where the alpha value was set to ± 1.41421 and the center points was set to 5. The obtained R^2 value increased to 0.6139 and the regression model suggested quadratic model. Plonsky and Ghanbar [18] reported that the increased of adjusted R^2 may be due to the decreased in the center points that improves the model more than would be expected by chance and the decreased in the adjusted R^2 value occured if the additional variables do not contribute to the model's explanatory power.

The data were re-run until the 13th attempt where the alpha value and center points were set new to face-centred (*k* = 1) and 9, respectively and a better value of R^2 was obtained at 0.9811. The increasing R^2 values were due to the random sequence of parameters in each sample where it served to test the robustness of experimental designs by introducing variations and assessing system responses, reducing the potential for bias in results [18,19]. However, negative values of the predicted R^2 from 4th to 13th attempts were contradict with the linear regression model, where the predicted R^2 value should be near to R^2 value. Thus, the data were re-evaluated and several attempts have been carried out in order to obtain the best value of R^2, adjusted R^2 and predicted R^2, as shown in Table 7; significant lack of fit indicated that it was necessary to determine better R^2, adjusted R^2 and predicted R^2 values [19].

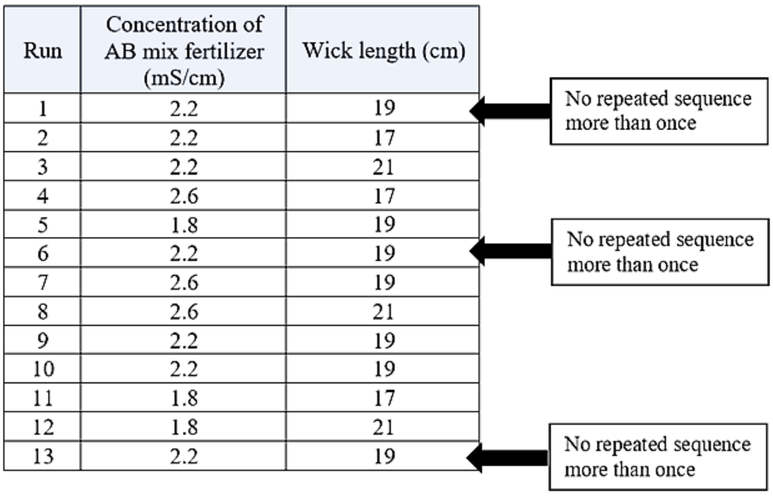
Table 7
Details of the attempts run using central composite design

Parameters	Attempts									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Model	NS	NS	NS	NS	NS	NS	NS	NS	NS	S
Lack of Fit	NS	NS	NS	NS	NS	NS	NS	NS	NS	S
R^2	0.3829	0.6139	0.6895	0.6925	0.6361	0.5824	0.5615	0.6999	0.596	0.9811
Adj. R^2	-0.0578	0.3381	0.4677	0.4729	0.3761	0.2842	0.2997	0.4856	0.3074	0.9654
Pred. R^2	-1.9809	-0.3403	-0.5953	-1.3167	0.0244	-0.695	0.5477	-1.046	-0.6999	0.7399
Parameters	Attempts									
	11th	12th	13th	14th	15th	16th	17th	18th	19th	20th
Model	S	NS	NS	S	S	S	S	S	S	S
Lack of Fit	S	NS	NS	NS	NS	S	S	NS	NS	NS
R^2	0.8424	0.6916	0.6902	0.8549	0.9736	0.8407	0.9738	0.9889	0.9710	0.9915
Adj. R^2	0.7298	0.4713	0.4689	0.7512	0.9516	0.7079	0.955	0.9796	0.9502	0.9854
Pred. R^2	-0.5031	-1.3432	-0.6656	0.6392	0.7551	-0.5651	0.765	0.8154	0.7563	0.9568

NS: Non-significant; *S*: Significant; R^2: *R*-squared; Adj. R^2: Adjusted R-squared; Pred. R^2: Predicted R-squared

To ensure the consistency of the regression model, the alpha value was set as face-centred (k = 1) and the center points was changed to 5. The model showed significant lack of fit in the 16th and 17th attempts therefore, the data were further evaluated and re-runs again until reasonable values of R^2, predicted and adjusted R^2 were achieved. The final R^2 value obtained was 0.9915, i.e. close to 1, along with the adjusted and predicted R^2 values of 0.9854 and 0.9568, respectively. Ideally, the value of R^2 should be near to 1, as low R^2 indicates that the selected model is inadequately explains the variability in the response variable and this can occur due to several factors such as an unsuitable model, noisy data or missing variables [20]. As for the adjusted R^2 value typically, it should be positive and the value is lower than the R^2 value. The high randomness distribution of parameter sequence, shown in Figure 9 enhances the reliability, validity and practicality of the RSM experiments. Randomness helps validate mathematical models by ensuring they are applicable across a broader range of conditions. Additionally, it efficiently explores the entire design space, leading to a more comprehensive understanding of the system and the potential for statistical significance in data analysis. Furthermore, randomization aligns experiments with real-world variability, making results adaptable to practical applications and optimizing processes under varying conditions [21].

Statistical analysis of model terms has been carried out using ANOVA to study the relevancy of the designed models and determined the most important and significant factor. The best results and relevancy of AB mix nutrients condition are presented in Table 8. It can be observed that the independent factors in the proposed equation i.e. A, B, AB, A^2 and B^2 expressed in quadratic model in Eq. (4) were significant by obtaining the probability of error value (P-value) < 0.05. The model achieved high F-value of 163.54 and small P-value < 0.0001 indicated that the model terms are significant.



Run	Concentration of AB mix fertilizer (mS/cm)	Wick length (cm)
1	2.2	19
2	2.2	17
3	2.2	21
4	2.6	17
5	1.8	19
6	2.2	19
7	2.6	19
8	2.6	21
9	2.2	19
10	2.2	19
11	1.8	17
12	1.8	21
13	2.2	19

Fig. 9. Random sequence of runs

The large *F*-value and small *P*-value interpreted the independent variable give significant impact on response variable [22,23]. There is only a 0.01 % chance model of *F*-value implies this large could occur due to noise. The lack of fit *F*-value with 1.14 indicated that the lack of fit is not significantly different from pure error. The model, which explains the best fit with a chance of 43.45 %, suggests that such large *F*-value could be attributed to noise. The *P*-value induces the R^2 value to be relatively high at 0.9915, as shown in Table 8. The value of 0.9915 denoted that approximately, 99.15 % of the variability observed in the target was explained by the regression model. The predicted R^2 value of 0.9568 was in reasonable agreement with the adjusted R^2 of 0.9854, where the difference is less than 0.2. As for Adequate Precision value, it measures the signal-to-noise ratio where a ratio greater than 4 is desirable. As denoted in Table 8, the value of 45.450 indicated an acceptable signal and 0.14 % of Residual Standard Error indicates that the experimental data has smaller error percentage between the actual and predicted values.

Table 8
Analysis of Variance (ANOVA) for regression model to optimize AB mix nutrients condition

Sources	Sum of squares	*DF*	Mean square	*F*-value	*P*-value	Remarks
Model	218.30	5	43.66	163.54	< 0.0001	Significant
A (EC value of AB mix)	9.38	1	9.38	35.12	0.0006	Significant
B (Wick length)	62.73	1	62.73	234.96	< 0.0001	Significant
AB	64.80	1	68.40	242.74	< 0.0001	Significant
A^2	49.00	1	49.00	183.55	< 0.0001	Significant
B^2	6.74	1	6.74	25.24	0.0015	Significant
Residual	1.87	7	0.2670			
Lack of fit	0.8608	3	0.2869	1.14	0.4345	Not significant
Pure error	1.01	4	0.2520			
Cor total	220.17	12				
Std. dev. (vRSE)	0.5167		RSE (%)	0.14		
R^2	0.9915		Predicted R^2	0.9568		
Adjusted R^2	0.9854		Adequate precision	45.4496		

The experimental data on the height of the plant were analyzed in comparison to the predicted values derived from RSM and ANOVA and it is evident that the actual measurements align closely with the predicted values, demonstrating a strong correlation between the observed and anticipated data. The fitting is relatively good, which demonstrated that the CCD model with an experimental design can be effectively applied for optimization [20]. In this study, ANOVA analysis confirmed that the second order quadratic model formulated in the optimization of AB mix nutrients condition is reliable, stable and provides good predictions. Prior to ANOVA analysis, it was essential to verify the normality of the residuals by plotting normal probability graph, as illustrated in Figure 10. The graph shows that the data points follow a near-linear trend along the reference line, suggesting that the residuals are approximately normally distributed. This supports the assumption of normality, which is a crucial prerequisite for the validity of ANOVA [24,25]. The normal distribution of the residuals enhances the credibility of the statistical analysis, thereby affirming that the second-order quadratic model established for this study is robust, dependable, and offers precise predictive capabilities [26].

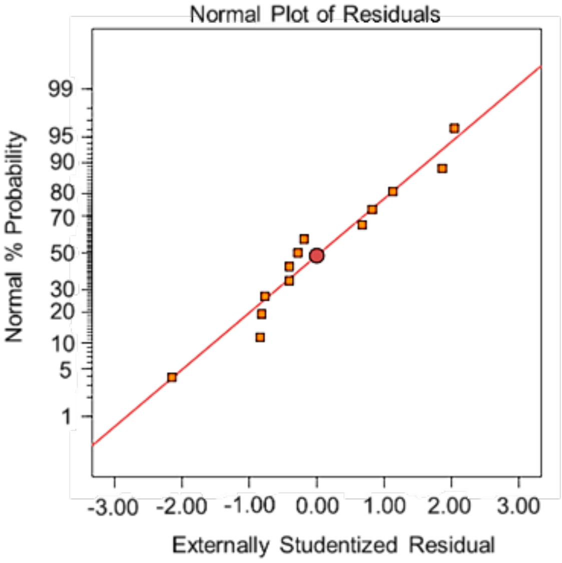
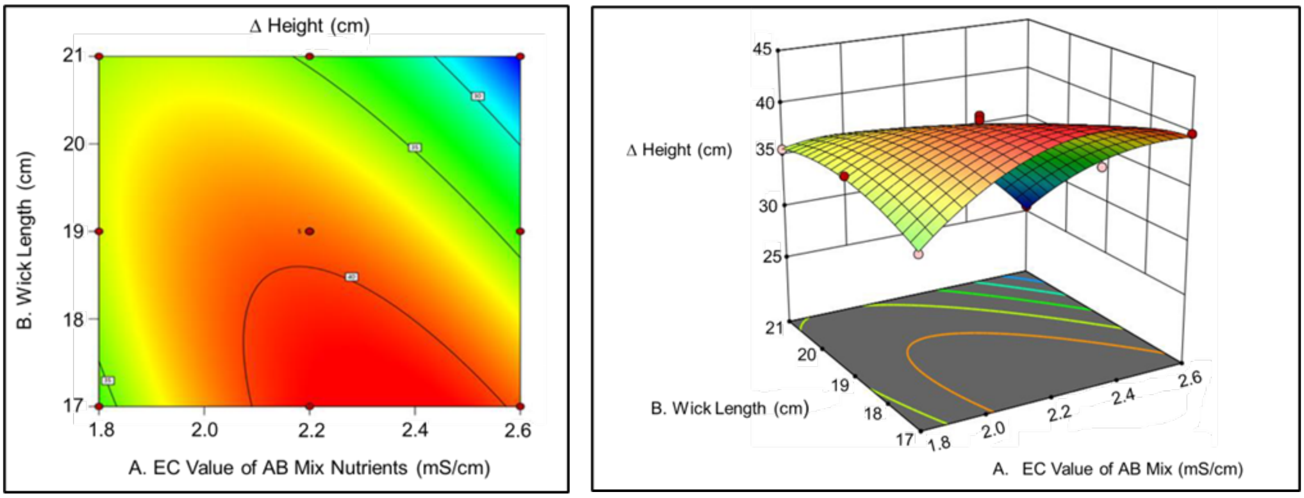


Fig. 10. Normal probability plot of actual data

3.3 Graphical Interpretation of RSM and Interaction between Experimental Parameters

Relationship between the dependent and independent variables can be expressed by three-dimensional (3D) model graphs where the 3D model graphs also interpret the optimum level of producing optimal height of C. frutescens. Interaction between the EC value of AB mix nutrients (1.8-2.6 mS/cm) and wick length (17-21 cm) is shown in Figure 11. The graphs demonstrated that the height of C. frutescens was likely to be higher as the EC value and wick length were set at the midpoint, specifically at 2.2 mS/cm and 19 cm. This can be attributed to an adequate supply of nutrients that supports plant growth, along with an optimal wick length that facilitates the absorption and transportation of fertilizer to the roots and other areas of the plant.

Nevertheless, the minimum height of C. frutescens was observed when the EC value of AB mix nutrients and the wick length reached their maximum levels of 2.6 mS/cm and 21 cm, respectively. This phenomenon can be attributed to the fact that an overabundance of nutrients provided to the plant resulted in stunted growth. Excessive application of fertilizers to plants can lead to harmful outcomes, such as nutrient imbalances, inhibited growth, leaf scorch, diminished production of fruits or flowers, heightened vulnerability to pests and diseases, as well as adverse environmental impacts. [27]. The overuse of fertilizers can disturb the essential nutrient equilibrium necessary for optimal plant development, resulting in multiple problems, including diminished crop yields and environmental contamination due to nutrient runoff. Therefore, it is crucial to apply fertilizers responsibly and accurately, guided by soil analysis and the specific needs of the plants, to alleviate these adverse effects and support sustainable agricultural practices. Effective nutrient management strategies, combined with sustainable agricultural methods, contribute to the preservation of soil health, minimize the necessity for excessive fertilization, and promote the well-being of both plants and the environment.



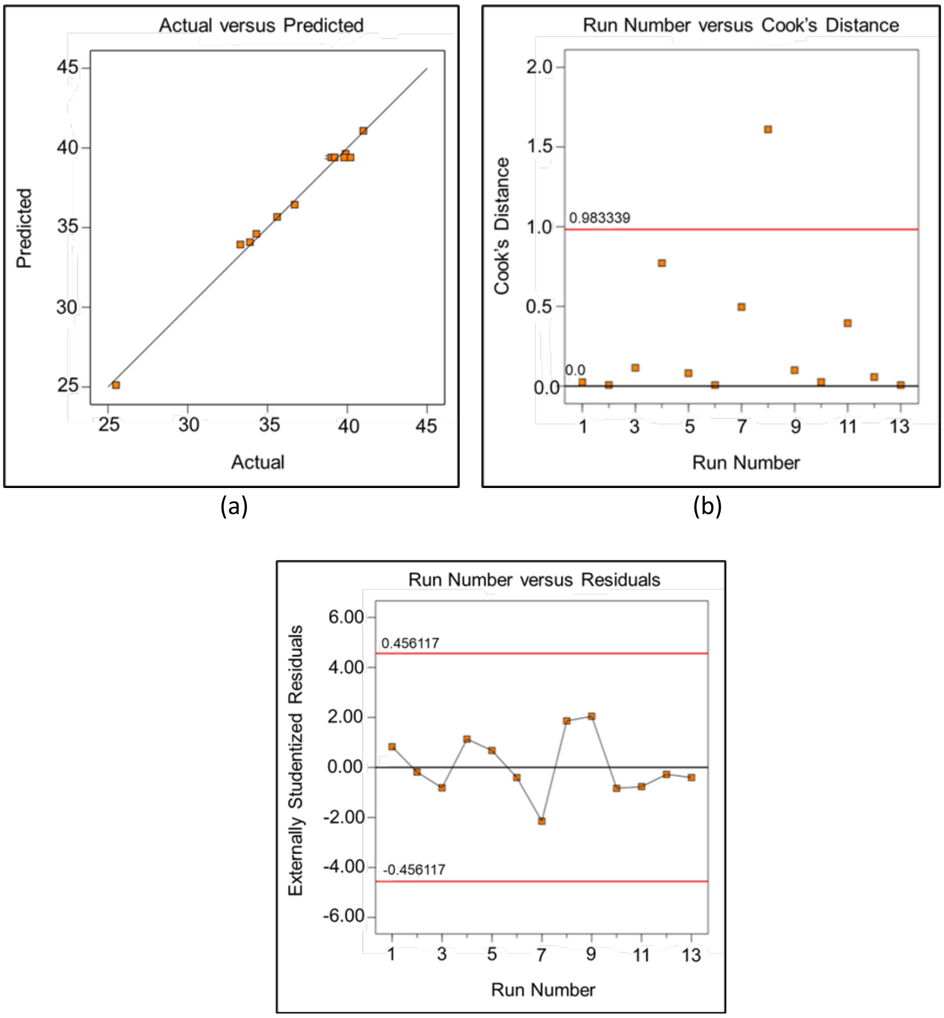
(a) (b)

Fig. 11. (a) Response contour plot (b) 3D surface plot for interactive effects of EC level of AB mix nutrients and wick length on C. frutescens' height

3.4 The Developed Model Adequacy

Developed model adequacy by RSM to explain the behaviour of parameters that influenced the height of C. frutescens has been described in Figure 12. A developed model should align closely with both the predicted and experimental data, as shown in Table 9. It can be observed that the experimental and predicted data are comparable with each other; slight difference between both values ranged 0.07 to 0.4 indicated that the accuracy of the model is high, suggesting a strong predictive capability and close match between theoretical expectations and observed outcomes. Such minimal discrepancies are often regarded as indicative of effective model performance in various fields, where differences below 1 are frequently accepted as signs of reliable predictions [28,29]. Residual analysis ensures that differences between experimental and predicted values are randomly distributed, indicating no systematic patterns missed by the model. In addition, Korbahti and Rauf [29] stated that a good adequate model performance exhibits consistency in both predicted and experimental values or otherwise, it may yield to misleading results [30].

The diagnostic plots of model adequacy for this work are shown in Figure 12. Figure 12(a) illustrates the relationship between the actual and predicted heights of C. frutescens, demonstrating that the data points closely align with a straight line. This alignment indicates a normal distribution, implying that the model accurately represents the response surface [31,32]. Figure 12(b) shows the graph of run number against Cook's distance data where the data depicted < 1 value, which conclude that there is no potential influence of points on the fitted model in experimental data [33]. Figure 12(c) depicts the graph of residuals across observation runs: externally studentized data which shows the points are scattered randomly and does not exceed the range ± 3.00, which indicates a good fit to the model developed [34,35].



(a) (b)

(c)

Fig. 12. Diagnostic plots of developed model adequacy (a) Actual vs. predicted (b) Run number vs. Cook's distance (c) Residuals across observation runs: externally studentized data

Table 9
Experimental and predicted data of C. frutescens height with number of runs

No. of runs	Response Y_1	
	Δ height of C. frutescens (cm)	
	Experimental data	Predicted data
1	39.80	39.40
2	41.00	41.07
3	34.30	34.61
4	39.90	39.64
5	36.70	36.44
6	39.20	39.40
7	33.30	33.94
8	25.50	25.12
9	40.20	39.40
10	39.00	39.40
11	33.90	34.09
12	35.60	35.67
13	39.20	39.40

3.5 Optimized Condition of AB Mix Nutrients

The minor discrepancy observed between the predicted and experimental values of the response presented in Table 10 has successfully verified the optimum point identified by the RSM. The optimum values were found at EC value and wick length of 2.54 mS/cm and 18.15 cm, respectively where under the optimal conditions, the height of C. frutescens plant was expected to be 38.73 cm, which fitted well to the corresponding experimental value. The optimized value derived from RSM has a desirability of 1, signifying an ideal or nearly perfect solution. This indicates that the optimization parameters are in close alignment with the model's maximum capabilities. The comparison of variables for the experimental, predicted and model-optimized values, are shown in Table 10 and similarly, Figure 13 depicts the optimum condition of independent variables and the optimum response outcome computed by RSM. The experimental data indicated that the tallest plant measured was 40.20 cm, surpassing the predicted value of 39.40 cm and this discrepancy occurred under similar operating parameters of EC 2.2 mS/cm and a wick length of 19 cm.

Table 10
Comparison data between actual, predicted and optimized values using RSM for C. frutescens plant

Variables	Experimental value	Predicted value	Optimized value using RSM
EC value (mS/cm)	2.2	2.2	2.54
Wick length (cm)	19	19	18.15
Plant height (cm)	40.20	39.40	38.73
Plant height deviation (%)	–	2.03	3.80

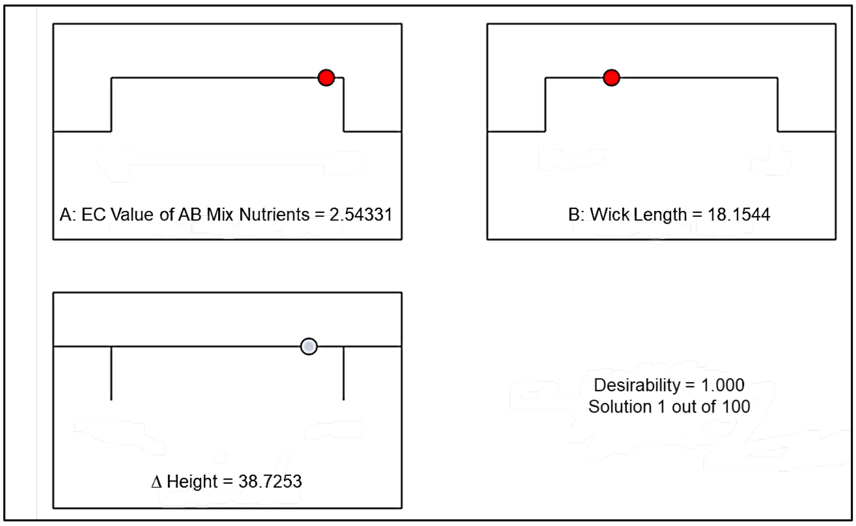


Fig. 13. Optimum condition of independent variables and the optimum response outcome computed by RSM

4. Conclusions

Studies on the optimum condition of AB mix nutrients for the growth of C. frutescens has been successfully carried out using Nutri-pot method and Response Surface Methodology (RSM), which highlighted the critical role of nutrient concentration and wick length of the Nutri-pot in promoting optimal C. frutescens growth. The optimal simulated conditions growth of C. frutescens were determined at EC 2.54 mS/cm and wick length 18.15 cm. Under these conditions, the expected height of the plant predicted to be at 38.73 cm, closely matched with the experimental data. The quadratic regression model used in RSM was found to be the most suitable, with a high R^2 value of 0.9915, indicating that 99.15 % of the variability in plant height is fitted to the model. The lack of fit was not significant, confirming the model's adequacy in predicting the response variable. In this work, it was found that the optimization of the EC value and wick length is crucial to ensure the well growth of C. frutescens via Nutri-pot systems. Steady supply of AB mix nutrients as well as the optimum length of wick used are essential to prevent nutrient imbalances, overwatering and to ensure efficient nutrient uptake, thereby supporting plant development. By using RSM, this research identified the key factors that contribute to maximum plant height, emphasizing the need for precise nutrient management to enhance growth without compromising environmental effect. The findings offer valuable insights into sustainable fertilization practices, suggesting that optimization of fertilizers in Nutri-pot system can achieve sustainable agricultural practices that strengthen plant growth while maintaining environmental sustainability. The growth and development of the C. frutescens plant samples in the Nutri-pot systems at Week 7 is provided in the Appendix for reference.

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Appendix A:

(a) Sample 1

Wick length: 19 cm
EC level: 2.2 mS/cm
Height: 68.0 cm

(b) Sample 2

Wick length: 17 cm
EC level: 2.2 mS/cm
Height: 60.4 cm

(c) Sample 3

Wick length: 21 cm
EC level: 2.2 mS/cm
Height: 70.6 cm

(d) Sample 4

Wick length: 17 cm
EC level: 2.6 mS/cm
Height: 60.6 cm

(e) Sample 5

Wick length: 19 cm
EC level: 1.8 mS/cm
Height: 63.6 cm

(f) Sample 6

Wick length: 19 cm
EC level: 2.2 mS/cm
Height: 61.7 cm

(g) Sample 7

Wick length: 19 cm
EC level: 2.6 mS/cm
Height: 62.6 cm

(h) Sample 8

Wick length: 21 cm
EC level: 2.6 mS/cm
Height: 64.6 cm

(i) Sample 9

Wick length: 19 cm
EC level: 2.2 mS/cm
Height: 63.0 cm

(j) Sample 10

(k) Sample 11

Wick length: 19 cm
EC level: 2.2 mS/cm
Height: 64.4 cm

Wick length: 17 cm
EC level: 1.8 mS/cm
Height: 63.8 cm

(l) Sample 12

(m) Sample 13

Wick length: 21 cm
EC level: 1.8 mS/cm
Height: 59.6 cm

Wick length: 19 cm
EC level: 2.2 mS/cm
Height: 69.5 cm

Appendix A. Images for all plant samples at week 7 with their respective height, EC level and wick length used