



## Depth of Water-Substrate Interface in Floating Culture and Nutrient-Enriched Substrate Effects on Green Apple Eggplant

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### ABSTRACT

A successful development of low cost floating culture system (FCS) has opened an opportunity for local farmers to cultivate vegetables during prolonged flooding at riparian wetlands. Research was aimed to identify the optimal depth of water-substrate interface (WSI) and optimal rate of NPK fertilizer application (RFA) in cultivating green apple eggplant using the FCS. Depths of WSI were adjusted to 0, 1, 3, and 6 cm and substrate was enriched with 8.4, 12.6, and 16.8 g NPK per pot. The enriched substrates were contained in pots and placed on floating rafts with variable WSI depths. Experiment was arranged in Split Plot Design. WSI was assigned as main plot and RFA was as subplot. The results exhibited that direct contact between water surface and substrate significantly increased water moisture content, enhanced shoot growth, and increased fruit yield, regardless the WSI depths. However, WSI treatments decreased SPAD value and restricted root elongation when WSI depth was more than 3 cm. The RFA treatments up to 16.8 g per pot could enhance shoot and root growth, and increased the fruit yield. This yield increase was associated with the increasing number of fruits, not the fruit size.

### INTRODUCTION

Agriculture in tropical riparian wetlands is less intensively managed, compared to those in other agro-ecosystems in Indonesia. Farmers in the riparian wetlands mostly grow one rice crop annually, due to the long and unpredictable flooding occurrence during rainy season (Lakitan et al., 2018). The duration of annual flooding in riparian wetlands may vary from less than three months (shallow wetlands) to about nine months (deep wetlands). During flooding period, local farmers do not do any agricultural activities, except preparing rice seedlings using floating seedbeds as floodwater progressing to subside towards the end of flooding period (Kartika et al., 2019).

Traditional floating seedbeds for rice seedling preparation consisted of floating rafts made of swamp sedge *Scleria poaeformis* and the growing substrate formulated from decomposed mixed biomass of local aquatic plants, predominantly *Utricularia vulgaris*.

Since they are constructed from biomaterials, these floating seedbeds deteriorate within a month. It is appropriate for producing standard three weeks old rice seedlings but it is not suitable for cultivation of vegetables with more than one month production cycle.

Cultivating annual vegetables is feasible during prolonged flooding period if longer lasting rafts are available since it can cover full production cycle of the selected vegetable. For this reason, rafts made of used plastic bottles had been developed and tested (Siaga et al., 2018). At present, used plastic bottles are mostly seen as a non-degradable solid waste. The low biodegradability of plastic waste and its presence in large quantities caused negative impact to the environment (Ilyas et al., 2018). Many suggested solutions for plastic waste are currently considered, including incorporated the solid waste into concrete for building construction (Mansour & Ali, 2015; Thorneycroft, Orr, Savoikar, &

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Ball, 2018). Used plastic bottles can also be reused for constructing low cost rafts required in the FCS. The latter option gives useful benefits in intensifying crop production at riparian wetlands.

At present, vegetables have only been grown by local farmers on limited acreage of constructed raised beds at riparian wetland ecosystem. Vegetables have never been cultivated using the FCS. The readiness of low cost FCS creates new opportunity for local farmers to cultivate vegetables during prolonged flooding period, including green apple eggplant. The demand on green apple eggplants is considerably high in Indonesia.

The objective of this research was to establish a productive FCS for green apple eggplant. Two crucial aspects in setting up the FCS will be evaluated, i.e. optimum depth of water-substrate interface and optimum rate of NPK fertilizer to be added to soil-manure mix for enhancing growth and maximizing yield in green apple eggplant.

## MATERIALS AND METHODS

This research was carried out at an of-campus research facility at Jakabaring, Palembang, Indonesia, from April to August 2018. The height of pots used was 20 cm. Upper and lower diameters of the pots were 30 cm and 20 cm, respectively. All pots were filled with soil-manure mix as growing substrate for green apple eggplants. Four holes were drilled on the base of each pot to allow water directly contact the lower part of the substrate to penetrate upward for continuously maintaining substrate moisture.

Relatively homogenous 3-week old eggplant seedlings were selected from nursery and transplanted into each substrate-filled pot. Pots were placed on 1 m x 2 m rafts, made of 69 used 1.5-liter plastic bottles. The bottles were previously used for mineral water. The pots were spaced at 75 cm x 75 cm such that each raft carried 18 pots.

The experimental was set up according to the split plot design. WSI treatment was the main plot and RFA treatment was the subplot. The depth of WSI treatments were 6 cm (S6), 3 cm (S3), less than 1 cm (S1), and untreated control (S0). The depths of WSI were adjusted to each specified treatment by adding extra load on each raft. NPK inorganic fertilizer was applied at 8.4 g/pot, equivalent to 150 kg/ha (F8), 12.6 g/pot, equivalent to 225 kg/ha (F12), and 16.8 g/pot, equivalent to 300 kg/ha (F16). Each combination of WSI x RFA treatments consisted of four replications.

The substrate moisture content for each pot was measured using soil moisture meter (Lutron PMS-714). The measured growth and yield traits were plant height, number of leaves, total leaf area (using digital image analyzer developed by Easton & Bloom, 2014), canopy diameter, leaf SPAD value (using Konica Minolta SPAD-502Plus), shoot dry weight, root length, root dry weight, days to flowering, days to harvest, number of fruits, total fruit weight, fruit length, and fruit diameter.

The calculated F-value generated from the analysis of variance (ANOVA) was compared to values of F-table at  $p \leq 0.05$  and  $p \leq 0.01$  for justifying significant effects of the treatments. Furthermore, if the treatment effect was significant on any measured traits, the least significant difference (LSD) test was conducted for determining significant differences among treatment levels on each of specified traits.

## RESULTS AND DISCUSSION

### Overview Effects of WSI and RFA Treatments

There was no interaction found between WSI and RFA treatments on all measured traits in floating-cultured green eggplants. Some traits, however, were separately affected by both the WSI and RFA treatments, i.e. plant height, total leaf area, root fresh weight, and total fruit yield. In contrast, there were also some traits that were not affected either by WSI or RFA treatments, i.e. days to initial flowering, days to initial fruit development, days to the first fruit was harvested, fruit/flower ratio, fruit length, and fruit diameter. Those only affected by WSI treatments were SPAD value during reproductive stages, substrate moisture content, and root length; while those only affected by RFA treatments were canopy diameter, number of leaves, shoot fresh weight, shoot dry weight, number of flowers, and number of fruits per plant (Table 1).

There was no interaction between two treatments, it indicated that each treatment worked independently. WSI affected substrate water status; meanwhile, RFA affected nutrients availability to the crop. Agricultural soil or growing substrate was hydrophilic in nature; therefore, it got easily wetted by water (Gupta et al., 2015). Growing substrate mix of soil-manure or soil with any other organic materials is also hydrophilic. Due to hydrophilic nature of substrates, water can move upward through capillary effect. The capillary rise occurs all the way from water table level to soil surface (Mikhailov, Vashlaev, Kharitonova, & Sviridova, 2018; Xing, Li, & Ma, 2019) or mixed growing

substrate surface. Capillary rise reveals the mechanism involved in groundwater evaporation. During the upward movement, water soluble minerals were carried and distributed with the growing substrate (Mikhailov, Vashlaev, Kharitonova, & Sviridova, 2018; Zhao et al., 2019). The distribution of the soluble minerals can be beneficial or toxic to crops, depending on the characteristic and concentration of the minerals. Aerial and underground organs significantly affected by both WSI and RFA were: (1) vegetative growth (plant height and average leaf area), (2) reproductive organ development (total fruit weight per individual plant or fruit yield), and (3) underground organ growth (root fresh weight). However, the nature of these effects was not analogous between the WSI

and RFA treatments.

RFA treatments consistently increased growth of shoot and roots as rates were increased. Meanwhile, the effect of WSI treatments was split. The WSI at depths of 3 cm or less enhanced growth and development of aerial organs; however, that at depth of 6 cm significantly reduced root elongation (Table 2). These findings suggested that initial direct contact between water surface and base of substrate in FCS was beneficial to increase substrate moisture; therefore, increased water availability for crop growth. However, deeper submersion of substrate limited aerobic part of the substrate for root expansion, mainly due to oxygen deficiency in water saturated at bottom layer of the substrate.

**Table 1.** Depth of water-substrate interface and rate of NPK fertilizer application effects on growth and yield traits in floating-cultured apple-green eggplant

No.	Measured trait	Calculated F		
		WSI	RFA	WSI x RFA
1	Plant height (cm)	14.72 **	6.45 **	0.58 <sup>tn</sup>
2	Canopy diameter (cm)	2.96 <sup>tn</sup>	3.57 *	1.28 <sup>tn</sup>
3	Number of leaves	2.61 <sup>tn</sup>	18.44 **	1.64 <sup>tn</sup>
4	Total leaf area (cm <sup>2</sup> )	3.84 *	5.93 **	2.45 <sup>tn</sup>
5	SPAD value at 7 WAT	8.44 **	2.29 <sup>tn</sup>	1.10 <sup>tn</sup>
	SPAD value at 11 WAT	20.50 **	1.49 <sup>tn</sup>	1.64 <sup>tn</sup>
6	Substrate moisture (%) at 4 WAT	13.95 **	0.41 <sup>tn</sup>	0.67 <sup>tn</sup>
	Substrate moisture (%) at 5 WAT	61.03 **	1.36 <sup>tn</sup>	1.09 <sup>tn</sup>
7	Shoot fresh weight (g)	1.47 <sup>tn</sup>	15.02**	1.57 <sup>tn</sup>
8	Shoot dry weight (g)	2.62 <sup>tn</sup>	9.94 **	0.81 <sup>tn</sup>
9	Root length (cm)	35.32 **	0.40 <sup>tn</sup>	0.45 <sup>tn</sup>
10	Root fresh weight (g)	5.72 *	7.34 **	0.84 <sup>tn</sup>
11	Root dry weight (g)	2.73 <sup>tn</sup>	6.55 **	1.85 <sup>tn</sup>
12	Initial flowering (DAT)	2.13 <sup>tn</sup>	0.67 <sup>tn</sup>	0.87 <sup>tn</sup>
13	Initial fruit development (DAT)	1.53 <sup>tn</sup>	0.52 <sup>tn</sup>	1.06 <sup>tn</sup>
14	First fruit harvested (DAT)	0.58 <sup>tn</sup>	1.55 <sup>tn</sup>	1.06 <sup>tn</sup>
15	Number of flowers per plant	2.66 <sup>tn</sup>	3.75 *	0.90 <sup>tn</sup>
16	Fruit/flower ratio (%)	1.67 <sup>tn</sup>	1.73 <sup>tn</sup>	2.03 <sup>tn</sup>
17	Number of fruits per plant	2.89 <sup>tn</sup>	4.07 *	1.67 <sup>tn</sup>
18	Total fruit yield (g)	4.32 *	4.81 *	0.88 <sup>tn</sup>
19	Average fruit length (cm)	1.57 <sup>tn</sup>	0.17 <sup>tn</sup>	1.20 <sup>tn</sup>
20	Average fruit diameter (cm)	2.13 <sup>tn</sup>	0.28 <sup>tn</sup>	1.72 <sup>tn</sup>
	F Table 0.05	3.49	3.40	2.50
	F Table 0.01	5.95	5.61	3.66

Remarks: ns, \*, \*\* are not significantly different, significantly different at p ≤ 0.05 and p ≤ 0.01), respectively; WSI is basal substrate submersion treatment; and RFA is rate of fertilizer application

The phenomenon of WSI in limiting substrate oxygen availability is similar to those caused by shallow water table, waterlogging, and flooding. WSI is basically water saturation condition occurs at bottom layer of the substrate. Although, it occupied only a relatively thin layer of the substrate, it still effectively limited oxygen diffusion. Occurrence of restricted oxygen diffusion within water saturated substrate has been well recognized (Pedersen, Perata, & Voesenek, 2017; Voesenek, Sasidharan, Visser, & Bailey-Serres, 2016; Yamauchi, Colmer, Pedersen, & Nakazono, 2018).

Substrate moisture content, SPAD value during reproductive stage (at age 7 and 11 WAT), and root length were affected by WSI but not by RFA treatments. Substrate moisture content in WSI-treated eggplants was consistently higher than those of control plants, proving that direct contact between water surface and base of growing substrate was effective in maintaining substrate

water content in the FCS (Table 3). In this study, WSI-treated eggplants were never been watered throughout the whole growing season. Moisture content was fully relied on water absorbed at bottom part of the substrate as long as it was in a direct contact with water surface.

Length of roots in control plants were almost double compared to those of WSI-treated plants (Table 3), but root fresh weight was not significantly different, except if WSI treatment was set at depth of 6 cm (Table 2). These findings indicated that, in control plants, primary roots extension was enhanced but branching of the root system was limited. In contrast, in WSI-treated plants, extension of primary roots was restricted by the existence of water saturated layer at the bottom part of growing substrate, but the WSI treatments stimulated root branching. Similar results were reported by Ferreira, Zotarelli, Tormena, Rens, & Rowland (2017), Gérard, Blitz-Frayret, Hinsinger, & Pagès (2017), and Tron, Bodner, Laio, Ridolfi, & Leitner (2015).

**Table 2.** Plant height, average leaf area, root fresh weight, and total fruit yield as affected by depth of water-substrate interface and rate of NPK fertilizer application in floating-cultured apple-green eggplant

Rate of NPK fertilizer application	Basal substrate submersion				
	S0	S1	S3	S6	WSI mean
Plant height (cm)					
F8	45.25	56.13	55.25	52.90	52.38 a
F12	44.40	63.95	57.75	56.50	55.65 ab
F16	50.00	63.50	61.50	63.00	59.50 b
RFA mean	46.55 a	61.19 b	58.17 b	57.47 b	
Average leaf area (cm <sup>2</sup> )					
F8	303.89	309.43	341.65	243.34	299.58 a
F12	303.38	414.28	397.16	344.86	364.92 b
F16	276.37	406.34	407.71	386.84	369.32 b
RFA mean	294.55 a	376.68 b	382.17 b	325.01 ab	
Root fresh weight (g)					
F8	40.01	35.61	31.78	22.80	32.55 a
F12	48.59	65.60	60.83	36.04	52.77 b
F16	64.60	51.59	49.54	34.73	50.12 b
RFA mean	51.07 b	50.94 b	47.39 b	31.19 a	
Total fruit yield (g)					
F8	222.72	139.52	252.90	146.97	190.53 a
F12	198.28	259.58	313.22	189.29	240.09 ab
F16	209.98	326.16	365.97	265.01	291.78 b
RFA mean	210.32 ab	241.75 ab	310.70 c	200.42 a	

Remarks: Means followed by different letter within each row of RFA mean or column of WSI mean for each traits were significantly different based on LSD test at  $p \leq 0.05$

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Leaf SPAD values were significantly lower in WSI-treated eggplant (Table 3). SPAD measures chlorophyll content in standardized area of leaf, not per total area of a single leaf. Therefore, lower SPAD value in WSI-treated plants is more likely associated with 'diluting effect', i.e. chlorophyll molecules were distributed within a larger leaf area (Table 2), not because of the reduction or destruction of its chlorophyll molecules.

Canopy diameter, number of leaves, shoot fresh and dry weights, number of flowers and fruits per plant were affected by RFA treatment. NPK fertilizer application at rates up to 16.8 g per pot consistently increased growth and yield in eggplants (Table 4). Enhanced uptake of these essential elements was associated with the increase of their solubility at higher substrate water content (Zhang & Marschner, 2018).

#### Significance and Precaution of Direct Contact Between Water and Substrate

The FCS is not just growing crops on a raft. It is also designed to take advantage of available water and hygroscopic nature of growing substrate. For this reason, direct contact between water surface and bottom part of substrate has to be maintained throughout the growing season. In principle, FCS is

a simplified hydroponic system (Sharma, Acharya, Kumar, Singh, & Chaurasia, 2018). However, in spite of using wicks for transferring water to growing substrate, FCS continuously maintains direct contact between water surface and substrate.

The need of establishing direct contact between substrate and water surface in FCS has not been fully comprehended. An optimal depth of WSI for vegetable crop cultivation using FCS has not been systematically studied. The result of this experiment revealed that substrate moisture content significantly increased as a direct contact between water surface and substrate were established at any depth (Table 3). In this study, the increase in substrate moisture content enhanced growth of aerial vegetative organs and increased fruit yield at depth of WSI around 1 to 3 cm (Table 2). However, WSI at depth of 6 cm restricted root elongation (Table 3). However, it did not significantly affect root biomass (Table 2), due to the increase in root branching to compensate for shorter primary root. The presence of water saturated layer at bottom part of substrate prevented roots of eggplant to penetrate deeper but the saturated layer induced branching of the root system within aerobic zone at upper part of the substrate.

**Table 3.** Traits significantly affected by depth of water-substrate interface in floating-cultured apple-green eggplant

Trait measured	Depth of water-substrate interface			
	S0	S1	S3	S6
Substrate moisture (%) at 4 WAT	10.35 a	14.09 b	16.84 bc	18.49 c
Substrate moisture (%) at 5 WAT	2.69 a	22.95 b	22.33 b	28.61 c
Root length (cm)	61.93 a	34.44 b	32.07 b	32.70 b
SPAD value at 7 WAT	50.21 a	47.75 a	42.88 b	42.40 b
SPAD value at 11 WAT	38.55 a	35.83 b	33.43 c	33.93 c

Remarks: Means within each row followed by different letter were significantly different based on LSD test at  $p \leq 0.05$ .

**Table 4.** Traits significantly affected by rate of NPK fertilizer application in floating-cultured apple-green eggplant

Trait measured	Rate of NPK fertilizer application		
	F8	F12	F16
Canopy diameter (cm)	62.26 a	65.75 ab	70.63 b
Number of leaves	31.00 a	43.94 b	47.88 b
Shoot fresh weight (g)	122.30 a	158.56 b	181.37 c
Shoot dry weight (g)	26.97 a	32.88 a	42.01 b
Root dry weight (g)	10.04 a	16.04 b	14.97 b
Number of flower per plant	9.38 a	10.06 ab	11.38 b
Number of fruit per plant	1.88 a	2.50 ab	3.00 b

Remarks: Means within each row followed by different letter were significantly different based on LSD test at  $p \leq 0.05$

Leaf expansion and stem elongation have been associated with water content of the aerial organs which directly associated with internal hydraulic pressure (Turc, Bouteillé, Fuad-Hassan, Welcker, & Tardieu, 2016). The increase in leaf area frequently caused a lower SPAD value; reversely, restricted leaf expansion was compensated with a higher SPAD value. However, the relationship between water-induced leaf expansion and chlorophyll development has not been clear.

SPAD value has been reliably used for predicting or estimating leaf chlorophyll content (Jiang, Johkan, Hohjo, Tsukagoshi, & Maruo, 2017; Vesali, Omid, Kaleita, & Mobli, 2015). Chu et al. (2015) had identified 443 photosynthetic proteins related to chlorophyll deficiency that showed differential accumulations between chlorophyll-deficient mutant and its corresponding wild-type in *Brassica napus* leaves. The decreased in chlorophyll biosynthetic enzymes and photosynthetic proteins reduced chlorophyll contents and impaired photosynthetic capacity in the mutant plant. Shen et al. (2017) reported that wheat leaf chlorosis was caused by accelerated chlorophyll degradation and elevated leaf moisture under stress condition. However, there was no attempt to relate increase in leaf moisture to chlorophyll degradation or vice versa. Chlorophyll biosynthesis or degradation is very complex process.

At water saturation condition, substrate pores were filled with water, restricting oxygen diffusion and causing reduction in oxygen availability. Most of terrestrial plants suffer physiological stress under root-zone oxygen deficiency condition (Munir, Konnerup, Khan, Siddique, & Colmer, 2019). Most of commercial vegetables had been reported as sensitive crops to substrate hypoxia (He, Yu, Li, Du, & Guo, 2018; Mariani & Ferrante, 2017; Yasin & Andreasen, 2016).

#### **Inorganic NPK for Complementing Soil-Manure Mixed Substrate**

Shoot and root growth significantly increased in green apple eggplants as rates of NPK fertilizer application were increased up to 16.8 g/plant (Table 4). Similarly, fruit yield also significantly increased (Table 2). These findings signified that the availability of these three macro nutrients in soil-manure mixed substrate used in this study were at suboptimal level. Therefore, the macro nutrients have to be added to increase fruit yield.

The increase in fruit yield was associated with higher number of fruit per plant (Table 4) whereas fruit size (length and diameter) was not significantly affected by NPK fertilizer application rates (Table 1). However, Khalifezadeh Koureh, Bakhshi, Pourghayoumi, & Majidian (2019) reported that higher yield was observed in grape plant fertilized with inorganic fertilizers; however, highest nutritional quality, improved antioxidant capacity, and some other biochemical characteristics were obtained in plant nourished with organic fertilizer.

These current findings suggested that the combination of organic and inorganic fertilizers could potentially be beneficial to increase yield and nutritional quality in fruit of eggplant. Maghfoer, Soelistyono, & Herlina, 2013; 2014) also found that, at the same nitrogen application rate, mixing organic (goat manure) and inorganic nitrogen (urea) produced higher yield in eggplant than those fertilized solely with inorganic nitrogen. The application of organic fertilizer was not only as source of multiple elements but also improved hydraulic properties of soil or growing substrate, i.e. moisture content, water holding capacity, and substrate conductivity (Khairuddin, Md. Isa, Zakaria, & Rani, 2018). Biochar as ameliorant also provided similar benefits such as improving soil properties and availability of existing nutrients (Maftu'ah & Nursyamsi, 2019); however, it did not provide additional nutrients

Using soil-manure mix as growing substrate and application of NPK fertilizer at an appropriate rate can be recommended to local farmers in growing vegetables using floating culture system.

#### **CONCLUSION AND SUGGESTION**

In floating culture system, a direct contact between water surface and bottom part of substrate has to be established. The depth of WSI in less than 3 cm significantly increased substrate water content, enhanced shoot growth, and increased fruit yield; however, if the depth was more than 3 cm, it lowered the SPAD value and restricted root elongation. Therefore, a continuous contact has to be established but the depth of contact should be kept as thin as possible. The lower SPAD value was more associated with the increase of leaf area, not because of the decrease in chlorophyll content. NPK fertilizer application up to 16.8 g/pot (equivalent to 300 kg/ha) enhanced shoot and root growth and increased fruit yield. This increase was associated with the increase in number of fruits,

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not the increase of fruit size, since both fruit length and diameter were not significantly affected. The significant increase in fruit yield of RFA-treated plants suggested that soil-manure mixed substrate was still need to be complemented with inorganic NPK fertilizer.

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