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Growth and yield of sweet corn cultivated in soil using third reused nutrient solution

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Abstract Nutrient solution from growing lettuce using Nutrient Film Technique (NFT) was drained from the substrate culture to grow Chinese kale in Dynamic Root Floating Technque (DRFT) before the third usage for growing melon. The third re-used nutrient solution (UNS) was drained from the melon growing substrate, diluted with tap water, and adjusted the concentration to 2.0 mS/cm^2, pH 5.8 before irrigation on the sweet corn field. Control plants were grown under general management (manual watering and fertilizing with 15-15-15 fertilizer). Results indicated that growth parameters including shoot height, SPAD value and fresh weight per plant using the third UNS were not significantly different from the control. Yield parameters including number of ears, average weight per ear and average weight per plant using the third UNS also showed no significant differences from the control. Water consumption of sweet corn under treatment of the third UNS and the control were 35.55 and 108.23 L/plant, respectively resulted to reduced water consumption of up to 68.07% and no fertilizer was used in the UNS treatment. Thus, the UNS method reduced both water and fertilizer consumption, while minerals in the nutrient solution were completely utilized, leading to cost reduction and environmentally friendly waste production.

Keywords: Hydroponics, Re-used nutrient solution, Sweet corn

Introduction

Global population is estimated to increase by 65% (3.7 billion) by 2050; the demand for food will rise correspondingly, increasing current constrains on freshwater resources (Wallace, 2000). Natural resources like water are becoming scarce and limited availability of renewable freshwater may threaten economic development, sustainable human livelihoods, environmental quality and a host of other societal goals in arid and semiarid regions in many parts of the world such as South Africa, the Middle East, Southern Europe and South America (Al-Karaki, 2011; Haddad and Mizyed, 2011). Rapid worldwide growth of industrialization and population as well as their high demand per

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capita for water are becoming problematic. A total of 87% of the available freshwater is being used annually for global agricultural production (Postel, 2001); therefore, enhancing productivity of different edible plant species using novel techniques such as hydroponics is urgently required to preserve natural resources like water and soil (Correa *et al.*, 2012). High-density crop yield where no suitable soil exists, with virtual indifference to ambient temperature and seasonality, will promote more efficient use of water and fertilizers with minimal use of a land area. Suitability for mechanization, disease and pest control can be achieved through hydroponic systems.

Hydroponics or soilless agriculture can be divided into two groups: 1) solution culture or hydroponics where the nutrient solution is recirculated in the system. This can be achieved by various methods including nutrient film technique (NFT), deep flow technique (DFT) and dynamic root floating technique (DRFT) and 2) aggregate hydroponics or substrate culture, where the nutrient solution is usually not recirculated, using an organic or inorganic inert medium such as sand, expanded clay, gravel, vermiculite, rock wool, peat moss, perlite, coir dust or coconut peat. Hydroponics culture requires large quantities of water and essential nutrients to optimize plant production. The nutrient solution that feeds the plants also needs to be replaced periodically, generating hydroponic wastewater that is particularly rich in nitrogen and phosphorus. When these nutrients are discharged directly into the environment, they may cause contamination (Bertoldi*et al.*, 2009).

In substrate culture, the amount of nutrient solution supplied is approximately 20-30% more than the plant requires, this allows variability for irrigation equipment and plant uptake from the substrate and prevents fertilizer salt levels increase in the growing medium (Grasselly*et al.*, 2005; Park *et al*., 2008). Prystay and Lo (2001) recorded that hydroponics wastewater solution (HWS) contained highly concentrated nitrate (200-300 mg L^{-1}) and phosphorus (30-100 mg L^{-1}). HWS released into the environment can induce eutrophication, causing algal bloom and loss of oxygen in the water, while HWS may be toxic to animals and people (Park *et al.*, 2008). Developed countries are highly concerned about agricultural wasteswhich are restricted regarding release to the environment (Kumar and Cho, 2014). Detailed research in many countries has investigated the utilization of HWS in growing tomatoes (Gent and Short, 2012), Chinese cabbage (Choi *et al*., 2011a), red peppers (Park *et al.*, 2005) and musk melons (Zhang *et al.*, 2006). Recently, a report was made using used nutrient solution (UNS) from growing lettuce by NFT, growing Chinese kale by DRFT (Boonnoi*et al.*, 2017) and its subsequent reuse for growing melon in substrate culture (Boonnoi*et al.*, 2018). Here, the third usage of UNS from growing melon was utilized in substrate soil culture to grow sweet corn and hypothesized to increase the value of UNS while reducing production cost and agricultural waste release to the environment.

Materials and Methods

Collection of UNS from melon grown in substrate culture

The experiment was conducted in a greenhouse located in NakhonRatchasima Province, Thailand. Melon was grown in a substrate culture using coconut coir dust as an organic medium. The nutrient solution was the UNS that has already been reused twice, from lettuce grown in NFT and subsequently from Chinese kale grown in DRFT, following Boonnoi *et al.* (2018). The UNS was drained from the substrate during cultivation, collected and finally used to grow sweet corn in field soil.

Soil preparation

Physicochemical properties of the field soil were determined at the Soil Science Laboratory, King Mongkut's Institute of Technology Ladkrabang before planting. Soil pH and electrical conductivity (EC) were measured (1:1 soil:water) using a pH meter and an EC meter, respectively. Exchangeable cations were analyzed using the 1 N ammonium acetate method, while organic matter (OM) was measured following the Walkley-Black method, available phosphorus pentoxide (P_2O_5) was measured using the BrayII method and Fe, Mn, Cu, and Zn were analyzed following the diisopropanolamine (DIPA) method.

UNS management for growing sweet corn in soil

UNS drained from the substrate culture was collected, analyzed and managed prior to application for growing sweet corn in field soil. The UNS was diluted with tap water and the concentration was adjusted to 2.0 mS/cm^2 and a pH of 5.8. Fertigation for growing sweet corn was done using a drip irrigation system. By comparison, the control was cultivated by N-P-K chemical fertilizer (15-15-15) application with watering twice a day by surface irrigation.

The two treatments were arranged in a randomized complete block design with three replications. Each block was comprised of two plots. Experimental growing space was determined at inter and intra-plant spacing of 20×25 cm with inter-row spacing of 120 cm. Seedlings were grown in peat moss until two weeks of age, then transplanted in soil and harvested at 20 days after ear silks has turned to a brown color (Figure 1).

Figure 1. UNS management for growing sweet corn in soil

Determination of growth and yield parameters

The growth parameters measured included plant height using a meter ruler (4, 5 and 6 weeks after transplanting), SPAD value using a chlorophyll meter SPAD-502 (4 and 8 weeks after transplanting) and fresh weight per plant (at day of harvest). Yield parameters were measured as number of ears, average weight per ear, and average weight per plant at harvest time.

Data regarding UNS management were recorded for water consumption, fertilizer and nitric acid amendment.

Data analysis

Results were subjected to analysis of variance and means were compared for two sample t-test at P = 0.05.

Results

Physical and chemical properties of experimental sites

The soil properties of the experimental areawere medium alkaline soil, slightly saline, low organic matter, very high phosphorus, medium potassium, high calcium, high magnesium, low in iron, manganese and copper as well as very low zinc (Table 1).

Table1. Physical and chemical properties of experimental sites before experimentation

Description	**pH**	**EC**	**OM**	**P_2O_5**	**K**	**Ca**	**Mg**	**Fe**	**Mn**	**Cu**	**Zn**
		µS/cm	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
Soil	8.20	228	0.62	288	68.9	2,058	448	3.97	6.58	0.48	0.49

Components of nutrient solution in UNS for sweet corn grown in soil

The UNS drained from the substrate was collected for growing sweet corn in soil. The drained UNS concentration was 4.2 mS/cm^2 with high minerals, especially NO_3^- and K at concentrations of 482 and 692 ppm, respectively. For growing sweet corn, UNS was diluted with water and the concentration was adjusted to 2.0 mS/cm^2. Analysis in ppm of the diluted UNS for sweet corn growth gave NH_4^+ (11.5), NO_3^-(196), P (6.66), K (193), Ca (114), Mg (52.6), Fe (0.05), Mn (0.00), Cu (0.01), Zn (0.01), and Na (73.1) (Table 2).

Table 2. Components of UNS supplied to sweet corn

Component	**pH**	**EC**	**NH_4^+**	**NO_3^-**	**P**	**K**	**Ca**	**Mg**	**Fe**	**Mn**	**Cu**	**Zn**	**Na**
	-	(mS/cm)						(ppm)					
UNS[1/]	6.6	4.18	18.5	482	61.8	692	244	89.6	0.23	0.14	0.02	0.15	71.7
UNS[2/]	7.7	2.12	115.	196	6.66	193	144	52.6	0.05	0.00	0.01	0.01	73.1

[1/] UNS original drained from the substrate

[2/] UNS adjusted before supplying to sweet corn field

Growth parameters of sweet corn cultivated in soil under general management as control and using UNS

The UNS drained from the substrate was reused for growing sweet corn in soil. It was compared with the control, as general management grown using chemical fertilizer (15-15-15) application, results showed that growth parameters such as stem height at 2, 4 and 6 weeks of age did not significantly differ with 37.7-39.3, 111.1-118.9 and 243.0-246.3 cm, respectively. SPAD values at 3 and 8 weeks grown by UNS were also not significantly different compared with the control at 42.5-42.9 and 51.9-54.6, respectively. Fresh weight per plant grown by UNS did not significantly differ compared with control at 0.375-0.553 kg (Table 3).

Yield parameters of sweet corn grown in soil under general management and using UNS

Using UNS for growing sweet corn revealed that yield parameters at the first time of harvest including number of ears, total weight of ears, average weight per ear and yield per plant grown under UNS treatment were not significantly different compared with the control at17.0-17.3, 3.67-4.53, 0.214-0.264, and 0.217-0.333, respectively. Total yield and average weight per plant under UNS treatment were also not significantly different compared with the control at11.0-13.6 and 0.215-0.261, respectively (Table 4).

Table 3. Growth parameters of sweet corn cultivated in soil under general management and using UNS

Treatment	Growth parameter					
	High (cm)			SPAD		Fresh weight per plant(kg)
	Week2	Week4	Week6	Week3	Week8	
Control	37.7	111.1	243.0	42.5	51.9	0.375
UNS	39.3	118.9	246.3	42.9	54.6	0.553
	ns[1/]	ns	ns	ns	ns	ns

ns= not significantly different at a 0.05 significance level.

Table 4. Yield parameters of sweet corn grown in soil with general management and using UNS

treatment	The first time of harvested					End crop		
	Number of plants	Aveage number of ears	Total ears weight(kg)	average weight per ear (kg)	yield per plant (kg)	Number of plants	weight(kg)	yield per plant (kg)
Control	51	17.0	3.67	0.214	0.217	51	11.0	0.215
UNS	52	17.3	4.53	0.264	0.333	52	13.6	0.261
		ns[1/]	ns	Ns	ns			

ns= not significantly different at a 0.05 significance level.

Water and fertilizer consumption

General management for sweet corn growth was manually done by watering and fertilizer application with a 15-15-15 fertilizer. The water consumption was 108.23 L/plant. UNS treatment involved automatic fertigation (watering and fertilizer application) controlled by a drip irrigation system. Water consumption was 34.55 L/plant. Using UNS reduced water consumption by 68.07% and fertilizer consumption by100% (Table 5).

Table 5. Water and fertilizer consumption of sweet corn grown in soil

Treatment	Number of plants	Water(L)	UNS drained from substrate(L)	Fertilizer	Nitric acid(L)
Control[2/]	51	5520	-	900 g	-
		average/plant 108.23	-	average/plant 17.64g	-
UNS[1/]	52	1796.6	657.6	-	5.225
		average/plant 34.55	average/plant 12.64	-	
%saving		68.07		100	-

Discussion

Final utilization of the third reused nutrient solution was assessed for growing plants. The first UNS from growing lettuces in NFT was reused for growing Chinese kale in DRFT. The second UNS from growing Chinese kale in DRFT was then reused for growing melon in substrate culture as previously reported by Boonnoi *et al*. (2017, 2018). Finally, the third UNS was drained from the substrate and used for irrigating sweet corn in soil. Substrate culture systems must be drained out of the nutrient solution by 20-30% to reduce accumulation of Na and gain optimal yield (Singandhupe *et al.*, 2003). A sample of drained UNS was collected and analyzed for the remaining elements. Results showed that the concentrations of NO_3^- and K were still high at 482 and 692 ppm, respectively and could still be utilized for other crops instead of being drained off. Grasselly *et al.* (2005) stated that excess runoff contains high nutrient concentrations, particularly nitrate, ranging 150-500 mg L^{-1},while Park *et al.* (2008a) and Prystay and Lo (2001) reported that HWS contained highly concentrated nitrate (200-300 mg L^{-1}) and phosphorus (30-100 mg L^{-1}).

In our experiment, UNS drained from the substrate was diluted with water and the concentration was adjusted to 2.0 mS/cm^2 and with pH 5.8 before application to soil for sweet corn growth. Compared with the control of general management using a chemical fertilizer 15-15-15, results showed that growth and yield of corn using UNS were not significantly different. Our findings concurred with several previous researchers, who reported that using HWS or UNS resulted in no significant differences compared with the control for growth and yield of Chinese cabbage (Choi *et al.*, 2011b; Hong *et al.*, 2009), tomatoes (Gent and Short, 2012) and gerbera (Savvas and Gizas, 2002). Moreover, using UNS gave significantly higher growth and yield than the control in musk melon (Zhang *et al.*, 2006) and Chinese cabbage (Choi *et al.*, 2011a).

Our findings also demonstrated that using UNS reduced water and fertilizer consumption for sweet corn production at around 68 and 100% respectively. Gent and Short (2012) showed that recycled nutrient solution reduced average water consumption by 14-17%. Thus UNS, reused three times from previous growing systems, can still be utilized for cultivating sweet corn in soil without significant differences from control. UNS can be utilized to reduce water consumption and total use of fertilizer as a zero waste in planting production system.

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