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REVIEW ARTICLE

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Abstract Attaining sustainable agriculture is a key goal in many parts of the world. The increased environmental awareness and the ongoing attempts to execute agricultural practices that are economically feasible and environmentally safe promote the use of hydroponic cultivation. Hydroponics is a technology for growing plants in nutrient solutions with or without the use of artificial medium to provide mechanical support. Major problems for hydroponic cultivation are higher operational cost and the causing of pollution due to discharge of waste nutrient solution. The nutrient effluent released into the environment can have negative impacts on the surrounding ecosystems as well as the potential to contaminate the groundwater utilized by humans for drinking purposes. The reuse of non-recycled, nutrient-rich hydroponic waste solution for growing plants in greenhouses is the possible way to control environmental pollution. Many researchers have successfully grown several plant species in hydroponic waste solution with high yield. Hence, this review addresses the problems associated with the release of hydroponic waste solution into the environment and possible reuse of hydroponic waste solution as an alternative resource for agriculture development and to control environmental pollution.

Keywords Agriculture · Greenhouse · Hydroponic · Nutrient solution · Pollution · Alternative resource

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Introduction

Recently, natural resources like soil and water have become scarce; hence, opening new agricultural landscape is not feasible due to deforestation and also concern for the environment. Annually, 87 % of the freshwater is used worldwide for agricultural production (Postel 2001). In general, it is difficult to rationalize the reliable water supply because of seasonal and geographical variations (Choi et al. 2011a). Growing renewable freshwater crisis 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 (Haddad and Mizyed 2011; Al-Karaki 2011). A rapid growth of industrialization and population and their high demand per capita for water are problematic in Korea with regard to the limited water resources available (Jang et al. 2008). During the year 2000, the mean annual precipitation in Korea was 1,274 mm, which is approximately 1.3 greater than the world's mean of 973 mm (Jin et al. 2005). In Korea, the summer monsoon brings copious moisture from the ocean and approximately 75 % of the annual rainfall in Korea observed during June to August; however, the occurrence of drought has recently increased due to global climate change (Choi et al. 2011a). Hence, during the drought season, it is necessary to rationalize water consumption using alternative resources. Various studies have been recently conducted regarding the occurrence of water shortage in response to climate change or its adverse effects, and these studies have proposed the approaches for conserving the limited resources of available water by reusing reclaimed wastewater for agriculture purposes (Cooper 1991; Kang et al. 2007; Kim et al. 2009). However, regulations of water quality for using reclaimed water are very strict due to concerns of human health against pathogenic organisms and crop quality (Stanghellini and Rasmussen 1994; Ehret et al.

2001). The world population is estimated to increase by 3.7 billion by 2050, and the demand for food will increase as well, putting added strains on fresh water resources (Wallace 2000). It is becoming increasingly necessary to enhance the productivity of different edible plant species by breeding or by novel techniques such as hydroponics that promise the preservation of natural resources like water and soil and increase the productivity (Correa et al. 2012).

The high-density maximum crop yield, crop production where no suitable soil exists, a virtual indifference to ambient temperature and seasonality, more efficient use of water and fertilizers, minimal use of land area, and suitability for mechanization, disease, and pest control can be achieved through hydroponic systems. Hydroponics is a methodology to use for plant cultivation in nutrient solutions (water containing chemical fertilizers) with or without the use of an organic or inorganic inert medium such as sand, clay-expanded, gravel, vermiculite, rock wool, peat moss, perlite, coir, coco-peat, and sawdust to provide mechanical support (Castellane and Araújo 1995; Torabi et al. 2012), or other substrates were used, to which nutrient solution containing all the essential elements needed by a plant for its normal growth and development were added. Since many hydroponic methods employ some type of medium, it is often termed "soilless culture," while hydroculture with mineral nutrients alone would be true hydroponics (Resh 2013). There are six different types of hydroponic systems, they are (1) aeroponic system: one of the most high tech growing systems, (2) drip system: the most widely used type of hydroponic systems, (3) ebb and flow system: the system can be modified in many ways, (4) nutrient film technique system: the most commonly used system, (5) water culture system: a very simple-to-use hydroponic system, and (6) wick system: the simplest of all hydroponic systems. In order to provide temperature control, to reduce evaporative water loss, and to reduce disease and pest infestations, all hydroponic systems in temperate regions of the world are enclosed in greenhouse-type structures (Jensen and Malter 1995).

According to Carruthers (2002), hydroponic crop production has significantly increased in recent years worldwide, from 5,000–6,000 ha in the 1980s to 20,000–25,000 ha in 2001. In a recent publication by Hickman (2011) states that world hydroponic vegetable production is about 35,000 ha. Today, most of the hydroponic culturing facility has difficulty to control point source pollution from greenhouses. In the near future, many nurseries will have to address their runoff nutrient wastewater pollution problems, because of strict enforcement of current laws and passage of tougher new laws (Beagle and Justin 1993). Consequently, innovative approaches are required to deal socioeconomically acceptable solutions that can overcome point source pollution. One possible way is the reuse of nutrient solution discharged from hydroponic system. Hydroponic systems are commonly designed as open (i.e., once the nutrient solution is delivered to the plant roots, it is not reused) or closed (i.e., surplus solution is recovered, replenished, and recycled) systems (Raviv and Lieth 2008). In open systems, the nutrient solution is discharged into the surrounding environments after crop cultivation. Jensen and Collins (1985) insisted that the discharged solution can be recycled for irrigation purposes without secondary environmental pollutions.

Hydroponic wastewater and problems

Hydroponics culture requires large quantities of water and essential nutrients to optimize plant production (Gagnon et al. 2010). Resh (2013) recommended essential macroelements and microelements supplied to plants by dissolving fertilizer salts in water to make up the nutrient solution. A list of recommended macroelements and microelements are in Table 1. The hydroponics nutrient solution contains nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), boron (B), copper (Cu), manganese (Mn), and zinc (Zn). However, the solution that feeds the plants 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 a report, Grasselly et al. (2005) states that, the amount of nutrient solution supplied is approximately 20–30 % more than the plant that requires to account for variability of irrigation equipment and plant uptake from the substrate and to keep fertilizer salt levels from increasing in the growing media. The excess amount runoff contains high nutrient concentrations, particularly nitrate, ranging 150–500 mg L^{-1}. Park et al. (2008a) and Prystay and Lo (2001) recorded that hydroponic wastewater solution (HWS) contained highly concentrated nitrate (200–300 mg L^{-1}) and phosphorus (30–100 mg L^{-1}) but not containing organic carbon (Gagnon et al. 2010) thereby resulting in large amount of point source pollution. Though there are other nutrients also discharged from hydroponic systems, it is difficult to record as there is lack of information about the concentrations of other nutrients discharged. In hydroponics, there are two types of wastewater run-to-waste and dumped. The first run-to-waste, nutrient-loaded water comes from flow-through hydroponic systems that use a growing medium. In the second type of wastewater, residual nutrient solution in recirculating systems is periodically dumped or when a nutritional or disease problem arises (Badgery-Parker 2002).

The amount of the HWS producing everyday were 2880 L ha^{-1} day^{-1} from the greenhouse experimental facilities, and this wastewater solution could irrigate 409.86 m^2 of area to compensate for the amount of water loss by evapotranspiration (Park et al. 2005). Most of the farms discharge their effluents to lagoons, and to the River, without any

Table 1 List of general microelements and macroelements recommended for growing plants in hydroponics

Chemical formula	Chemical name	Molecular weight	Elements supplied	Solubility ratio of solute to water
Microelements				
$FeSO_4 \cdot 7H_2O$	Ferrous sulfate	278	Fe^{2+}, SO_4^{2-}	1:4
$FeCl_3 \cdot 6H_2O$	Ferric chloride	270.3	Fe^{3+}, $3Cl^-$	1:2
FeDTPA	Iron chelate	468.15	Fe^{2+}	Highly soluble
FeEDTA	Iron chelate	382.1	Fe^{2+}	Highly soluble
H_3BO_3	Boric acid	61.8	B^{3+}	1:20
$Na_2B_8O_{13} \cdot 4H_2O$	Disodium octaborate tetra hydrate	412.52	B^{3+}	Very soluble
$Na_2B_4O_7 \cdot 10H_2O$	Sodium tetraborate	381.4	B^{3+}	1:25
$CuSO_4 \cdot 5H_2O$	Copper sulfate	249.7	Cu^{2+}, SO_4^{2-}	1:5
$MnSO_4 \cdot 4H_2O$	Manganese sulfate	223.1	Mn^{2+}, SO_4^{2-}	1:2
$MnCl_2 \cdot 4H_2O$	Manganese chloride	197.9	Mn^{2+}, $2Cl^-$	1:2
$ZnSO_4 \cdot 7H_2O$	Zinc sulfate	287.6	Zn^{2+}, SO_4^{2-}	1:3
$ZnCl_2$	Zinc chloride	136.3	Zn^{2+}, 2Cl	1:1.5
$(NH_4)_6Mo_7O_{24}$	Ammonium molybdate	1,163.8	NH_4^+, Mo^{6+}	1:2.3 Highly soluble
Na_2MoO_4	Sodium molybdate	205.92	$2Na^+$, Mo^{6+}	Highly soluble
ZnEDTA	Zinc chelate	431.6	Zn^{2+}	Highly soluble
MnEDTA	Manganese chelate	381.2	Mn^{2+}	Highly soluble
Macroelements				
KNO_3	Potassium nitrate	101.1	K^+, NO_3^-	1:4
$Ca(NO_3)_2$	Calcium nitrate	164.1	Ca^{2+}, $2(NO_3^-)$	1:1
$(NH_4)_2SO_4$	Ammonium sulfate	132.2	$2NH_4^+$, SO_4^{2-}	1:2
$NH_4H_2PO_4$	Ammonium dihydrogen phosphate	115	NH_4^+,$H_2PO_4^-$	1:4
NH_4NO_3	Ammonium nitrate	80.05	$NH_4^+NO_3^-$	1:1
$(NH_4)_2HPO_4$	Ammonium monohydrogen phosphate	132.1	$2(NH_4^+)$, HPO_4^{2-}	1:2
KH_2PO_4	Monopotassium phosphate	136.1	K^+,$H_2PO_4^-$	1:3
KCl	Potassium chloride	74.55	K^+,Cl^-	1:3
K2SO4	Potassium sulfate	174.3	2 K^+,SO_4^{2-}	1:15
$Ca(H_2PO_4)_2$	Monocalcium phosphate	252.1	Ca^{2+}, $2(H_2PO_4^-)$	1:60
$CaH_4(PO_4)_2$	Triple super phosphate	Variable	Ca^{2+},$2(PO_4^{2-})$	1:300
$MgSO_4 \cdot 7H_2O$	Magnesium sulfate	246.5	Mg^{2+}, SO_4^{2-}	1:2
$CaCl_2 \cdot 2H_2O$	Calcium chloride	147	Ca^{2+}, $2Cl^-$	1:1
$CaSO_4 \cdot 2H_2O$	Calcium sulfate	172.2	Ca^{2+}, SO_4^{2-}	1:500
H_3PO_4	Phosphoric acid	98	PO_4^{3-}	Concentrated acid solution

From Resh 2013

treatment (Figueiredo et al. 2005). Rural Development Administration (RDA) of Korea stated that the total area of hydroponic cultures dramatically increased in Korea from 23 ha in 1993 to 1,107 ha in 2008 (Choi et al. 2011a). The discharged water from an open hydroponic culturing system is categorized as industrial wastewater according to the Water Quality Conservation Act of Korea, and the levels of total nitrogen (T-N) and phosphate (T-P) in the discharged water are restricted at 60 and 8 mg L^{-1}, respectively (Choi et al. 2011a). The discharge of untreated hydroponics effluent poses a significant environmental concern as it contains high amount of nitrate and phosphate, and these nutrients can induce eutrophication in the receiving waters causing algal blooms, which deplete oxygen in the water and can also release toxins that can affect animals or humans (Fig. 1). Nitrate leaching can cause several environmental problems including the loss of calcium and other cations as well as moving into surface or groundwater where it can severely impact drinking water (Prystay and Lo 2001).

Hydroponic waste solution treatment and reuse

In a closed hydroponic culturing system, it is difficult to evaluate the quantity of water discharge because of many

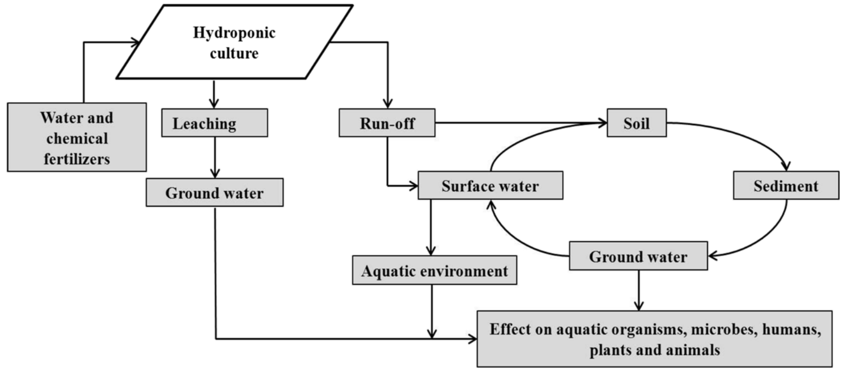

Fig. 1 Fate of hydroponic waste solution to the environment

factors including crop types, plant species, growth stages, and meteorological conditions. On the other side, in a closed hydroponic system, availability of nutrient solution is higher (Seo 1999) and the nutrients can be recycled and approximately 30 % of water can be saved (van Os 1999). Discharge of nutrient solution from open hydroponic culturing system into the agroecosystem without any purification process poses detrimental effects to the environment (Isozaki et al. 2004; Yang et al. 2005). In Korea, the open hydroponic culturing systems are more common (Seo 1999; Choi et al. 2011b), and discharged nutrient solution from open hydroponic culturing systems is categorized as industrial wastewaters according to the present Water Quality Conservation Act of Korea (WQCAK) (Choi et al. 2011b). Hence, it is essential to develop innovative technology to address the environmental risk associated with nutrient solution discharged from hydroponic culturing systems. The nutrient that loaded HWS should be treated by physical and biological methods prior to discharge into the environment. Many practices such as sedimentation, activated sludge, and filtration are employed to eliminate detrimental factors (Lazarova et al. 1999).

The applications of ultraviolet (UV), filtration, or ultrafiltration can be alternatives for disinfecting wastewater (Liberti et al. 2002; Caretti and Lubello 2003). According to the research study of Salgot et al. (2002), different filtration and disinfection processes significantly reduce the chemical oxygen demand (COD), biological oxygen demand (BOD), and fecal coliforms. They also reported that the combination of UV and ozone treatment was more effective for disinfection of wastewater than any other treatment methods. The efficient alternative methods such as settling, filtration, and UV radiation including ultrafiltration (UF) eliminated almost 100 % of the coliform bacteria. However, COD removal rate was much higher when ultrafiltration was uses in comparison with the other processes (Illueca-Muñoz et al. 2008). The use of UV and sand filtration can control total coliform bacteria in waste nutrient solution (Choi et al. 2011a) and can be used for agricultural irrigation. Ahn et al. (2005) reported that sand filter pretreatment can remove water turbidity and improve the performance of UV irradiation. The hydroponic waste solution procured by Choi et al. (2011b) from paprika (*Capsicum annuum* L.) and tomato (*Lycopersicon esculentum*) farms had a high value (2.1 dS m^{-1}) of electrical conductivity (EC) and indicated brown in color as it contained high nutrients. The EC in waste nutrient solutions decreased to 1.3 and 0.7 dS m^{-1} after one and two filtration cycles, respectively, and turned bright color when they were treated in sand filter column containing sand (0.1 to 0.5-mm grain diameters) of 5-cm diameter and 27-cm high, including 3-cm charcoal between sand layers. In a study, Takamizawa et al. (1998) recycled the nutrient solution by ultrafiltration technique. They observed the growth inhibition of plant lettuce (*Lactuca sativa* L.) by the sporangia of water mold *Pythium aphanidermatum*, a phytopathogen. They applied ultrafiltration technique and successfully removed the phytopathogen from the hydroponic culturing system. Their results suggested that ultrafiltration is an effective method to remove pathogenic microorganisms from hydroponic nutrient solution.

Reverse osmosis is a method through which water is purified to remove essentially all dissolved minerals and pathogens and possibly reused for irrigation purposes. That membrane is preceded in the system by sediment and charcoal filters to remove suspended (undissolved) solids and organic molecules. The ultrafiltration and reverse osmosis methods for waste solution are efficient (Koide and Satta 2004) but have high operational and maintenance costs (Gagnon et al. 2010). Reverse osmosis separation has been widely applied to sustainable industrial growth and protection of the environment (Oya 1973; Audinos et al. 1993; Andres et al. 1997; Bazinet et al. 1999; Gain et al. 2002). However, there are only a few records on reverse osmosis separation of electrolytes in discharged nutrient solution from greenhouses. In an investigation, Koide and Satta (2004) used ion-exchange membranes for treating discharged nutrient solution from a tomato cultivated commercial greenhouse. Their report suggested that reverse osmosis separation, which involves simultaneous concentration and dilution, enables the automatic control of EC in concentrated and diluted solutions without any injection of water or fertilizers. Furthermore, their study recommended that reverse osmosis would be an efficient

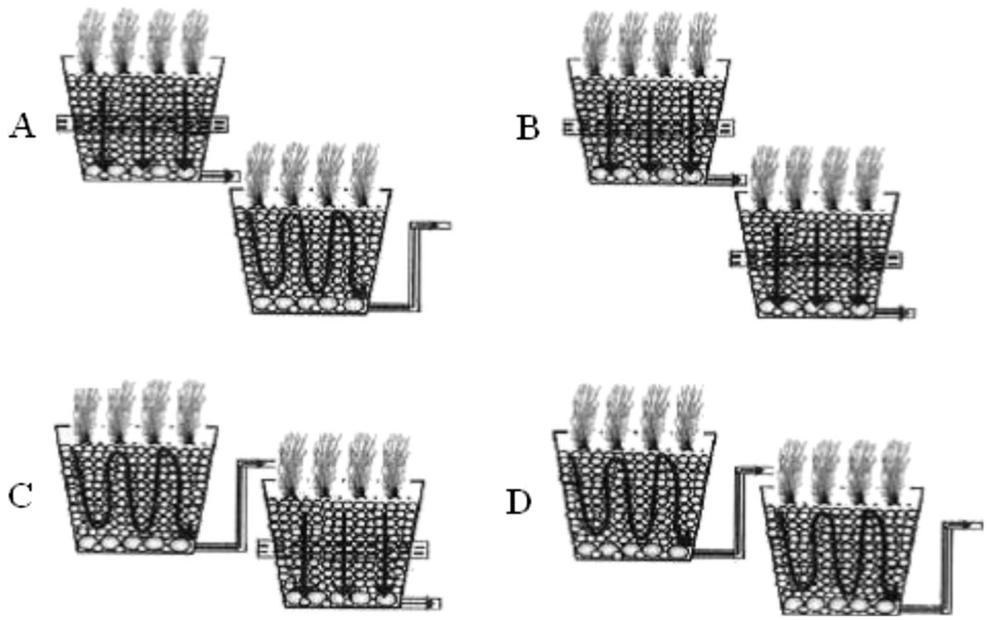

Fig. 2 Four different small-scale constructed wetland systems for hydroponic waste solution treatment (**a** vertical flow-horizontal flow system; **b** vertical flow-vertical flow system; **c** horizontal flow-vertical flow system; **d** horizontal flow-horizontal flow system) (Park et al. 2008b)

process for recycling the discharged nutrient solution containing nitrate and phosphate from greenhouses effluents.

A research on treatment of HWS in small-scale constructed wetlands was conducted by Park et al. (2008b). In order to obtain optimum configuration, depth and load of constructed wetlands (CWs) for treating of HWS discharged from cucumber-, paprika-, and strawberry-cultivated greenhouses, they used four different combined wetland systems, namely vertical flow (VF), horizontal flow (HF), VF-VF, HF-VF, and HF-HF (Fig. 2). The removal rate of pollutants under different depths of VF and HF in two-stage hybrid CWs was 50 cm<70 cm regardless of CWs configuration. The removal rate of pollutants from HWS in two-stage hybrid CWs was in the order of 150–300 L m^{-2} day^{-1}> 450 L m^{-2} day^{-1}. The optimum depth and HWS loading were 70 cm and 300 L m^{-2} day^{-1} in four configurations of CWs, respectively. Under optimum conditions, for various HWSs (cucumber, paprika, and strawberry HWS), the observed removal rate of pollutants in HF-HF CWs was higher than that in HF-VF CWs. Their study concluded that the HF-HF two-stage hybrid CWs were good for treating HWSs in greenhouses and under the optimum conditions and the observed removal rates of BOD, COD, suspended solid (SS), T-N, and T-P were 84, 81, 84, 51, and 93 %, respectively.

In order to evaluate the removal rate of nitrogen and phosphorus from HWS in CWs, four different kinds of

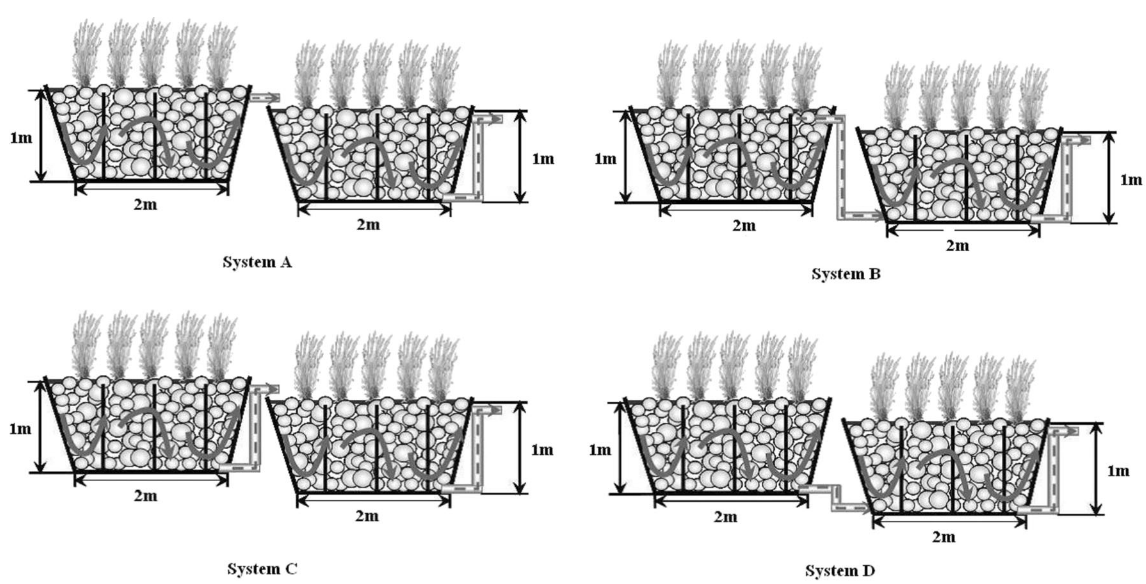

Fig. 3 Different types of constructed wetlands for hydroponic waste solution treatment. *System A* Up-Up stream; *System B* Up-Down stream; *System C* Down-Up stream; *System D* Down-Down stream (Park et al. 2012)

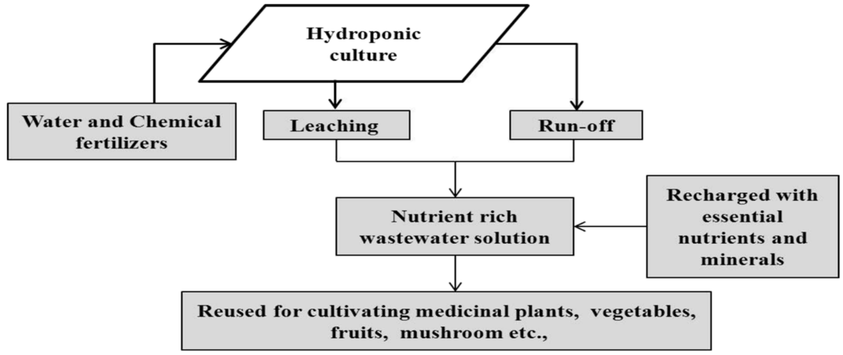

Fig. 4 Possible reuse mechanism of hydroponic waste solution

connection method of piping such as system A (UP-UP stream), system B (UP-DOWN system), system C (DOWN-UP stream), and system D (DOWN-DOWN stream) (Fig. 3) were investigated by Park et al. (2012). From their study, they observed that the removal rates of BOD, COD, SS, T-N, and T-P by the system at (UP-UP stream) connection method in actual CWs were slightly higher than their other systems. At system A, the removal rates of BOD, COD, SS, T-N, and T-P were 88, 77, 94, 54, and 94 %, respectively. Under different HWS loading, the 75 L m^{-2} day^{-1}≒150 L m^{-2} day^{-1}≧ 300 L m^{-2} day^{-1}. Their study concluded that the optimum connection method was system A for treating HWS from greenhouses.

In a study, the nitrogen and phosphate of nutrient waste solution were removed by using four different photosynthetic filamentous bacteria (*Anabaena* HA101, HA 701, and *Nostoc* HN601, HN701) by Yang et al. (2004). They reported that the *Nostoc* HN601 grown faster and higher uptake of N and P was observed than the other cyanobacterial strains. In the tomato grown HWS the *Nostoc* HN601 completely removed phosphate over a period of a week. The T-N and T-P removed by *Nostoc* HN601 were 63.3 mg N gram dry weight and 19.1 mg P gram dry weight, respectively. Their overall study concluded that cyanobacterial mass production under greenhouse condition might be used for recycling and cleaning of HWS.

In a research study, Bertoldi et al. (2009) subjected *Chlorella vulgaris* to remove pollutants from HWS, diluted HWS 1:1 (50 % residue and 50 % deionized water) (HWS50), and diluted HWS 1:3 (25 % residue and 75 % deionized water) (HWS25). Their study stated that growing of *C. vulgaris* in HWS could efficiently remove total inorganic nitrogen in HWS as 204.04, 109.41, and 78.65 mg L^{-1} in HWS, HWS50, and HWS25, respectively. The total removal of phosphorus in their study was 18.18, 9.01, and 4.05 mg L^{-1} in HWS, HWS50, and HWS25, respectively.

The development of technologies for reusing waste solution from open hydroponic culturing systems may provide an opportunity to reduce the quantity of wastewater or waste nutrient solution and increase water availability. For instance, approximately 57 to 67 % of nitrogen in nutrient solution supplied in a hydroponic culturing may be removed by plant uptake, and the rest of nitrogen would be discharged (Uronen 1995); therefore, recycling nutrients such as NO_3^- and PO_4^- are available for crop growth without any cost. Sonneneld and Welles (1984) suggested that reuse of the discharged waste nutrient solution for hydroponic culturing system produces the economic value by reducing fertilizer cost and environmental pollution and increasing crop yield.

Nutrient-rich waste solutions often produce higher crop yields as compared to fresh water (Sheikh et al. 1987; Chakrabarti 1995; Miranda et al. 2008). The advantages of hydroponics are that the nutrient solution is a known quantity and concentration, and it can be readily collected from the hydroponics system (Carruthers 2002). The supply of nutrient waste solution from hydroponic culturing to plant root has a direct effect on the growth of plant crops (Both et al. 1999).

Table 2 Concentration of pH, EC, and minerals in groundwater, wastewater, and organic and inorganic waste nutrient solution

Treatments	pH	EC dS/m (mg/L)	Na^+	NH_4^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	NO_3^-	PO_4^{3-}	SO_4^{2-}
GW	7.0	0.2	8.1	ND	3.9	5.6	38.3	10.1	15.4	ND	4.9
WNSO	6.0	3.0	21.7	ND	401.6	110.5	244.2	56.2	394.6	61.9	284.9
WNSI	7.0	1.0	14.7	ND	67.3	61.0	66.0	3.6	84.0	14.3	112.0
WW	7.4	0.5	52.3	9.2	12.6	6.8	48.1	63.4	21.6	1.6	8.1

From Hong et al. 2009

ND not determined, *GW* groundwater, *WNSO* waste nutrient solution from organic, *WNSI* waste nutrient solution from inorganic, *WW* wastewater

The possible reuse mechanism of HWS for plant and crop production is depicted in Fig. 4.

Park et al. (2005) demonstrated the reuse of waste nutrient solution by growing paprika (*C. annuum* L.). Their experiment suggested that the introduction of HWS increased the pH and EC of the soils, coupled with the increases in the concentrations of exchangeable cations (Ca, Mg, and K), T-N, NH_4-N, and NO_3-N. Their study suggested that the growth and yield of red pepper were higher when they were combined with 70 % of chemical fertilizer and 30 % of HWS. Yang et al. (2005) applied the HWS to the upland soils by column leaching and field experiment by growing paprika (*C. annuum* L.). The soil pH and EC were increased when the amount of HWS was increased. Their results suggested that the HWS can be recycled and reused as plant nutrients to enhance soil fertility and maintain environmental quality. In another study, Zhang et al. (2010) used non-recycled HWS for growing paprika. The paprika decreased nitrous concentration as the plants grew. The cultivated paprika showed a thicker stem diameter and higher leaf area index. The chlorophyll, potassium, magnesium, and calcium contents were higher. Their study concluded that the growth, total yield, and number of paprika fruits were higher in the plants grown in HWS.

A study conducted by Choi et al. (2011b) reported that nutrient solution discharged from hydroponic culturing systems can be reused for the cultivation of Chinese cabbage (*Brassica campestris* L.). Their study concluded that the leaf width, fresh weight, and dry weight of the cabbage plants irrigated with waste nutrient solution were similar or greater than those of plants irrigated with a conventional groundwater cultivation method. In another study when Choi et al. (2011c) introduced the waste nutrient solution with 10 g m^{-2} of NO_3^-, K^+, SO_4^{2-}, and Ca^{2+}, it increased the pH and EC values of the nutrient solution by 6.3 and 1.5 dS m^{-1}, respectively, and thereby enhanced the Chinese cabbage growth. A similar study by Hong et al. (2009) found that the concentrations of K^+, NH_4^+, Mg^{2+}, Ca^{2+}, Cl^-, NO_3^-, PO_4^{3-}, and SO_4^{2-} were higher in waste nutrient solution than wastewater, and the growth of Chinese cabbage seedlings irrigated with waste nutrient solution was similar to those irrigated with groundwater (Table 2). Their study added that, the T-N uptake in Chinese cabbage seedling irrigated with groundwater (GW), waste nutrient solution from organic (WNSO) and inorganic (WNSI) hydroponic cultures and wastewater (WW) were 5.47, 10.02, 5.20, and 4.59 mg/plant, respectively. Their overall study suggested that the waste nutrient solution can be used as an alternate water resource for cultivating Chinese cabbage.

Bertoldi et al. (2009) had proven the reuse of hydroponics waste solution for the successful cultivation of single-cell protein *C. vulgaris*. In their study, they subjected Bold's basal medium (BBM), HWS, diluted HWS 1:1 (50 % residue and 50 % deionized water) (HWS50), and diluted HWS 1:3 (25 % residue and 75 % deionized water) (HWS25). Their results suggested that *C. vulgaris* cultivated in HWS has potential to obtain single-cell protein of good quality, due to its composition and balanced amino acid distribution, as well as high protein content that presented values of 52.40, 50.51, 43.96, and 39.98 g/100 g for BBM, HWS, HWS50, and HWS25, respectively.

The study of Zhang et al. (2006) had shown good yield and marketable fruit percentage of melon and cucumber grown in a non-recycled hydroponics waste solution. The study of Yang et al. (2004) revealed that cyanobacterial strains can be grown on HWS and possibly used for agriculture as a biofertilizer. Leaf lettuce (*L. sativa* L) was successfully cultivated in discharged nutrient solution by Lee et al. (1999). The germination rate of lettuce showed no difference when Choi et al. (2011b) conducted a comparative test with wastewater and waste nutrient solution, and twice sand-filtered waste nutrition solution promoted the radicle growth. Kim et al. (2000) also found that the reuse of waste nutrient solution from rose hydroponic cultures promoted the growth of commercially important plant species poinsettias (*Euphorbia pulcherrima*).

Conclusion

The reason behind the drive to the reuse of HWS was to overcome water crisis in arid and semiarid areas of the world and to control point source pollution. More attention should be given as the hydroponics runoff from greenhouse contains rich nutrients such as nitrous, phosphorus, potassium, calcium, and magnesium, so it is important to monitor the concentration of nutrients before discharging into the environment. Instead of discharging HWS into the environment, it could be reused for cultivation of popular choice of fruits, vegetables, medicinally important plants, and high protein-rich mushrooms. Recently, around the world, many researchers are showing interest and investigating the possibility of growing various commercial plants using HWS. Recharge and reuse of HWS may be valuable as economic, control environmental pollution and could contribute to reduce the consumption of irrigation water.

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