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Effect of improved land and water management strategies on crop productivity and soil fertility in wastewater irrigated eggplant (*Solanum melongena*)

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ABSTRACT

Wastewater irrigation with efficient land and water management strategies improve the marketable yield as well as reduce the pollutant threat posed by the irrigation. A field experiment was conducted for two years (2014-2016) at ICAR- IARI farm, New Delhi to study the effect of municipal wastewater irrigation along with two land configurations (ridge and furrow and basin) and two methods of irrigation (drip and flood) on the yield of eggplant (*Solanum melongena* cv. Supriya) and soil health. Wastewater irrigated eggplants resulted significantly higher yield (37.1 t/ha), fruit weight (325 g) and fruit diameter (10.02 cm) in the tune of 38, 26 and 7% higher respectively over groundwater irrigated plot. Among irrigation methods, drip irrigation increased yield, fruit weight and fruit diameter of eggplant by 10, 9 and 1% higher over flood irrigation. Significantly higher fruit weight (294 g) of eggplant was recorded with the flat bed system compared to a raised bed system (288 g) and higher yield (4%) was also recorded under a flat bed system over a raised bed system. Wastewater irrigated plots recorded higher plant height, number of branches per plant as compared to groundwater irrigated plants at 120 and 180 days after transplanting. Application of wastewater significantly enhanced available N and P content and DTPA-Pb and Fe in the soil as compared to groundwater irrigated soil. Flood irrigation led to the accumulation of DTPA-Pb and Ni in soil, compared to drip irrigation. Significantly higher dehydrogenase activity, fluorescein diacetate activity and soil microbial biomass carbon were noticed in wastewater irrigated soil as compared to groundwater plots at upper depth (0-5cm). The findings of the present investigation illustrate that wastewater applied through drip irrigation resulted in yield increment as well as reduced metal concentrations in soil.

Key words: Drip irrigation, Heavy metal, Peri-urban agriculture, Municipal wastewater, Soil health, Soil biological properties

Exponential population growth, industrialization, and climate change fueled the shortage of freshwater resources in many arid and semi arid regions of the world and affected the life style as well as development opportunities. The use of wastewater for crop production is getting attention due to inexpensive and reliable substitute for quality irrigation water. Wastewater considered a valuable source for plant nutrients and organic matter required for maintaining fertility and productivity of soils. Moreover, irrigation of crops by wastewater in periurban areas considered as an environmentally sound and economically viable option for its disposal that helps to minimize the pollution of the ecosystem subjected to contamination by direct disposal of wastewater into surface or groundwater. Since wastewater contains salts, pathogens and other toxic contaminants including heavy metals, the extensive use of untreated wastewater for urban agriculture has led to various consequences on soil quality, crop produce quality and consumer health hazard as reported by several studies (Kaur *et al.* 2014; Rosin *et al.* 2017; Khajanchi *et al.* 2020). Therefore, there is an urgent need to develop a suitable technology that can reduce the hazardous impact of wastewater on soil health, crop quality and human health.

In India, subsistence farmers use untreated wastewater through flood irrigation to cultivate vegetable crops. Since flood irrigation requires more water and cause inequality between the water demand of crop and the quantity of water supplied (Singh and Rajput 2007), it is crucial to adopt efficient irrigation methods like drip irrigation. Drip irrigation applies water both precisely and uniformly, resulting in reduced subsurface drainage, higher field-level

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application efficiency of 80–90%, control soil salinity, and increased yield of the vegetable crop (Aujla *et al.* 2007). Besides that, the pollutant threats associated with wastewater irrigation can be minimized by practicing suitable land management strategies which reduces the direct contact of pollutants and pathogens to the crops (Parany-chianakis *et al*. 2011). Besides that, land configuration plays a major important role in improving water use efficiency, availability of nutrient and provide suitable physical environment of field crops (Chiroma *et al*. 2008). Wastewater application through drip irrigation, coupled with suitable land configuration, may offer improved water and nutrient management, the potential for improved yields, and crop quality (Najafi and Tabatabaei 2008). Therefore, it is high time to explore appropriate production technologies like appropriate land configuration with suitable irrigation methods that can reduce the pollutant threat associated as well as improve the yield and quality of vegetable crops grown in peri-urban areas with reduced contamination of the natural resources.

MATERIALS AND METHODS

A field experiment was conducted at the research farm of ICAR- Indian Agricultural Research Institute, New Delhi, India (latitude of 28° 64 17" N and longitude of 77°14 98" E from September to April in 2014-2015 and 2015-2016 (two years). The experimental soil was sandy loam in texture, having pH (7.83), EC (0.54 dS/m), organic carbon (7.5 g/kg), available N (260 kg/ha), available P (29.6 kg/ha) available K (280 kg/ha), DTPA- extractable Zn (1.89 mg/kg), Fe (5.06 mg/kg), Mn (2.55 mg/kg), Cu (1.59 mg/kg), Pb (1.87 mg/kg), Cr (0.36 mg/kg), while Ni and Cd were present in soil as traces amount.Wastewater for irrigation of the crop was collected from the drain passing through the Indian Agricultural Research Institute, New Delhi. Wastewater had pH (7.9), EC (1.9 dS/m), RSC (1.6 meq/L), SAR (6.8 meq/L), BOD (240 ppm), Zn (1.03 ppm), Ni (0.26 ppm), Cr (0.08 ppm), Pb (1.03 ppm), while Cu and Cd were in trace amount. A drip irrigation system was installed for wastewater and groundwater separately. An in-line lateral (J-Turbo Line) with 40 cm spaced emitting units were placed on the ground for surface drip. The experiment was conducted with a split-split plot design with three replications. The experiment having two sources of water for irrigation (groundwater and wastewater) as the main plot, sub-plots were two methods of irrigation (drip and flood) and sub-sub plots with two land configurations (ridge & furrow and basin). For conducting the experiment seedlings of eggplants (cv. Supriya) were grown and four weeks old seedlings were transplanted as per standard procedure in the fourth week of September in each year. The recommended dose of N, P and K (120:85:50 kg/ha) was applied to the crop. The full dose of P & K as basal and N in three split doses (50% as basal and 25% each before flowering and fruit development stage) were applied through diammonium phosphate, murate of potash and urea, respectively.

The growth parameters of the crop, *viz.* plant length, number of branches per plant, number of leaves per plant were recorded at 60, 120 and 180 days after transplanting of the crop as per the standard procedure. Matured eggplant fruit was harvested manually six times at intervals of 8–10 days for calculating the yield of eggplants. After harvesting, fruit weight and fruit diameter (by Vernier Caliper) were recorded for each treatment separately. The post-harvest soil samples from treated plots were collected for biological properties (0-5 & 5-15 cm) and other chemical analysis (0-15 cm) during each year. The samples were analyzed for pH, electrical conductivity, potassium dichromate oxidizable

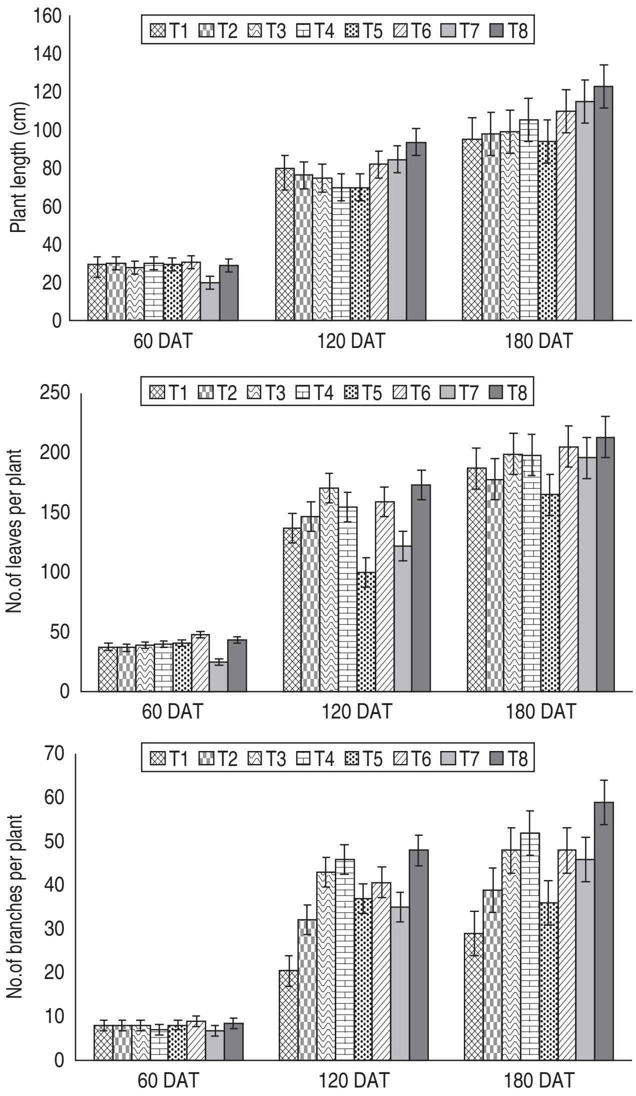

Fig 1 Effect of water quality, irrigation method and land configuration on growth (a) plant length (b) number of leaves per plant and (c) number of branches per plant of eggplant. T1-Groudwater with drip irrigation and ridge & furrow; T2-Groudwater with drip irrigation and basin; T3- Groudwater with flood irrigation and ridge & furrow; T4- Groudwater with flood irrigation and basin; T5- Wastewater with drip irrigation and ridge & furrow; T6- Wastewater with drip irrigation and basin; T7- Wastewater with flood irrigation and ridge & furrow; T8- Wastewater with flood irrigation and basin.

Table 1 Effect of water quality and irrigation method on yield and yield attributes of eggplant (means of two-year data)

Treatment	Yield (t/ha)	Fruit weight (g)	Fruit diameter (cm)
Water quality (WQ)			
Groundwater	26.9^{B}	257^{B}	9.36^{B}
Wastewater	37.1^{A}	325^{A}	10.02^{A}
LSD (P≥0.05)	8.0	6.0	0.59
Irrigation method (IM)			
Drip	35.5	303^{A}	9.73
Flood	32.3	279^{B}	9.65
LSD (P≥0.05)	NS	3	NS
Land configuration (LC)			
Raised Bed	31.3	288^{B}	9.53^{B}
Flat Bed	32.6	294^{A}	9.85^{A}
LSD (P≥0.05)	NS	2	0.23
Interactions			
WQ × IM	NS	6.18	0.56
WQ × LC	NS	5.86	0.49
IM × LC	2.2	3.22	NS
WQ × IM x LC	11.7	6.08	0.55

Table 2 Effect of water quality and irrigation method on fertility status of post-harvest soil (means of two-year data)

Treatment	pH	EC (dS/m)	Avil-N (kg/ha)	Avil-P (kg/ha)	Avil-K (kg/ha)
Water quality					
Groundwater	7.76	0.60	280^{B}	35.2^{B}	289
Wastewater	7.80	0.59	292^{A}	37.7^{A}	293
LSD (P≥0.05)	NS	NS	10	1.2	NS
Irrigation Method					
Drip	7.75	0.59	271	35.0	290
Flood	7.81	0.60	301	37.8	292
LSD (P≥0.05)	NS	NS	NS	NS	NS
Land configuration					
Raised Bed	7.74	0.60	284	35.8	292
Flat Bed	7.82	0.60	288	37.1	290
LSD (P≥0.05)	NS	NS	NS	NS	NS
Interactions	NS	NS	NS	NS	NS

organic carbon as per the standard procedure. Soil samples were also analyzed for available N (Subbiah and Asija 1956), available P (Olsen *et al.* 1954), and available K (Hanway and Heidal 1952). The available micronutrients (Zn, Fe, Cu and Mn) and heavy metals (Pb, Cr, Ni, Cd) in soil were extracted by DTPA method (Lindsay and Norvell 1978) and determined using atomic absorption spectrophotometer. Dehydrogenase activity (DHA) was determined using the reduction of 2, 3, 5 triphenyl tetrazolium chloride (3%) method (Klein *et al.* 1971), Fluorescein diacetate activity (FDA) hydrolysis was measured by the fluorescein production from fluorescein diacetate as per the protocol of Green *et al.* (2006), soil microbial biomass carbon (SMBC) was estimated through chloroform fumigation method (Vance *et al.* 1987). For statistical analysis, data were analyzed by the general linear model (glm) procedure of the SAS statistical software (Version 9.1) (SAS Institute Inc., 2008). All main effects were compared by Fisher's least significant difference (LSD) test using the MEANS statement under proc glm with mean at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Yield and yield attributes

Two years of pooled yield data of eggplant revealed that there was a significant impact of water quality on yield of crop. The significantly highest yield (37.1 t/ha) was recorded with the application of wastewater compared to groundwater (26.9 t/ha). No significant impact of irrigation methods and land configuration was observed on eggplant yield. The yield under different treatments ranges from 32.3 - 35.5 t/ha and 31.3 - 32.6 t/ha respectively. Significantly higher fruit weight of eggplant 325, 303 and 294 g/fruit was recorded in wastewater, drip irrigation and flat-bed system respectively over other management practices. In case of fruit diameter, the wastewater (10.02cm) and flat bed system (9.58 cm) recorded significantly higher fruit diameter compared to groundwater and raised bed system respectively. Nevertheless, no significant impact on the fruit diameter of produce was noticed with the irrigation methods. Significant positive interaction between water quality, irrigation method and land configuration on yield, fruit weight as well as fruit diameter were observed. Irrigation methods and land configurations also had positive and significant interaction to yield and fruit weight of eggplant, while non-significant interaction observed in case of fruit diameter. Significant interaction between water quality and irrigation methods as well as water quality and land configurations to fruit weight and fruit diameter were noticed, while these interactions were non-significant for yield.

Morphological traits

In general, the plant height was higher in wastewater irrigated plots than groundwater irrigated plots, but its effect was only visible at 120 and 180 DAT. At 120 DAT, maximum plant height (94 cm) was observed when the crop was irrigated by wastewater through flood irrigation under the flat-bed system, while minimum (70 cm) was recorded under a drip-irrigated crop grown on the raised-bed system with groundwater. At 180 DAT, the plant height of eggplant ranged from 92 cm to 138 cm among different treatments. The wastewater irrigated plants height ranged from 100 to 138 cm under different land configurations and methods of irrigation at 180 DAT.

The average leaf numbers of wastewater irrigated plots were 44, 160, and 212 at 60, 120 & 180 DAT, respectively

Table 3 Effect of water quality and irrigation method on soil micronutrient and heavy metal content of post-harvest soil (means of two-year data)

Treatment	Metal concentration (mg/kg)						
	Zn	Cu	Fe	Mn	Cr	Pb	Ni
Water quality							
Groundwater	1.91	1.82	5.09^{B}	2.40	0.38	2.16^{B}	0.88^{B}
Wastewater	2.10	1.84	6.28^{A}	2.97	0.63	3.03^{A}	1.17^{A}
LSD (P≥0.05)	NS	NS	0.36	NS	NS	0.37	0.18
Irrigation method							
Drip	1.94	1.71	5.59	2.53	0.45	2.42^{B}	0.89^{B}
Flood	2.07	1.95	5.78	2.84	0.57	2.68^{A}	1.16^{A}
LSD (P≥0.05)	NS	NS	NS	NS	NS	0.16	0.18
Land configuration							
Raised bed	1.98	2.00	5.14	2.76	0.42	2.63	0.94
Flat bed	2.03	1.66	6.23	2.60	0.60	2.57	1.11
LSD (P≥0.05)	NS	NS	NS	NS	NS	NS	NS
Interactions	NS	NS	NS	NS	NS	NS	NS

Table 4 Effect of water quality, irrigation methods and land configuration on microbial activity of soil (means of two-year data)

Treatment	DHA (µg TPF/g soil/24 hr)		FDA (µg FDA/g soil/ hr)		MBC (µg C/g soil)	
	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm
Irrigation water						
Groundwater	113^{B}	76.3	155^{B}	141	461	482
Wastewater	130^{A}	78.7	170^{A}	143	732^{A}	515
LSD (P≥0.05)	10	NS	11	NS	174	NS
Irrigation method						
Drip	111^{B}	78.5	164	136	585	511
Flood	132^{A}	76.4	161	148	608	486
LSD (P≥0.05)	14	NS	NS	NS	NS	NS
Land configuration						
Raised bed	122	75.0	163	143	527	467
Flat bed	121	80.0	161	141	666	529
LSD (P≥0.05)	NS	NS	NS	NS	NS	NS
Interactions	NS	NS	NS	NS	NS	NS

DHA- Dehydrogenase activity; FDA-Fluorescein diacetate activity; MBC-microbial biomass carbon.

and it was significantly higher over groundwater irrigated plots. In general, the drip-irrigated plots had less number of leaves as compared to plant irrigated through flood irrigation method. Plant growth vigour was measured through the number of branches per plant. At 60 DAT, similar number of branches per plant (8 branches/plant) was recorded under wastewater and groundwater irrigated plots. At 120 DAT, the branches/plant were increased to 41 branches/plant with wastewater compared to groundwater irrigated plots (36 branches/plant). Moreover, 52 and 48 branches/plant were noticed in wastewater and groundwater irrigated plots respectively at 180 DAT. Wastewater irrigation increased the available nitrogen (discussed in next section), which increases the plant growth and development since nitrogen is a part of plant metabolism through enzymes, amino acids, proteins, pigments and nucleic acids, fundamental constituents of protoplasm and chlorophyll, essential for photosynthesis (Medeiros *et al.* 2018).

Soil fertility

There was no significant difference in pH and soluble salt content of soil (electrical conductivity) due to the application of different quality of irrigation water, land configurations and irrigation methods. The soil pH was recorded in the range of 7.76 to 7.82 among different treatments, while electrical conductivity ranged from 0.59 to 0.60 dS/m. However, available N and P content exhibited marked difference with the application of different sources of water. Significantly higher available N was noticed in the soil of wastewater irrigated plots (292 kg/ha) as compared to groundwater (280 kg/ha) irrigated plots. Application of water through flood irrigation method (301 kg/ha) increased the available nitrogen content of the soil as compared to the drip (271 kg/ha) irrigation method. The significant highest available P in soil (37.7 kg/ha) was recorded with wastewater irrigation over groundwater irrigation (35.2 kg/ha). No significant impact of irrigation method and land configuration was noticed on available P content of the soil. Build up of available potassium content was also not observed irrespective of water quality, irrigation method and land configuration, although it ranged from 289 to 293 kg/ha under different treatments. No significant interaction effect among different treatments was noticed with the fertility status of the soil.

DTPA extractable Zn, Cu and Mn of soil were not significantly affected by water quality, irrigation method and land configuration. The DTPA extractable Zn, Cu and Mn content ranged from 1.91 to 2.10, 1.66 to 2.00 and 2.40 to 2.97 mg/kg respectively, among different treatments. Significantly higher DTPA extractable Fe was recorded with the application of wastewater as compared to groundwater irrigated plots but no significant build-up of Fe was noticed with different irrigation methods and land configuration. Continuous two-year application of wastewater led to significantly higher DTPA extractable Pb (3.03 mg/kg) and Ni (1.17 mg/kg) in the soil as compared to groundwater irrigated plots, however, no significant difference was noticed in DTPA-Cr of post-harvest soil. The DTPA extractable Cr, Pb and Ni ranged from 0.38 to 0.63, 2.16 to 3.03 and 0.88 to 1.17 mg/kg respectively in soil irrigated with different quality water. Most importantly, flood irrigation led to the accumulation of DTPA extractable Pb and Ni in soil, compared to drip irrigation, whereas no significant impact on DTPA extractable Cr was recorded. No significant effect on DTPA extractable metal concentration was noticed under different land configurations practised in post-harvest soil samples.

Biological properties

The DHA, FDA, and SMBC of soil ranged from 113-130 (µg TPF g^{-1}soil 24 hr^{-1}), 155-170 (µg FDA g^{-1}soil hr^{-1}) and 461-732 (µg C g^{-1} soil) respectively at upper depth (0-5cm). Soil irrigated with wastewater had significantly higher DHA, FDA activities and SMBC as compared to groundwater at 0-5 cm depth of soil, whereas no significant difference was observed at lower depth (5-15cm) of soil. Factors such as oxygen availability, organic carbon availability and soil nutrients could influence the soil enzyme activities in the wastewater treated plots, as wastewater having a high amount of nutrient and organic matter load as compared to groundwater. Secondly, the metal concentration of wastewater treated plots was under the range of safe limit (discussed in the previous section); therefore, the negative effect of metal on microbial properties was not observed in wastewater treated plots. The decrease in microbial activity and SMBC was recorded with increasing depth of soil irrespective of the treatments. The decrease in the enzyme activities in deeper layers could be due to the changes in the microbial population, decrease in the synthesis of enzymes, low organic matter content, and or increase of inhibitors such as metal ions under the reduced condition as also attributed by Freeman *et al.* (1997). Soil enzymes and microbial biomass carbon are susceptible to changes due to the nutrient loading, land-water management practices, soil organic matter addition through FYM (Kumar *et al.* 2014; 2018). Irrigation methods had a significant effect on DHA of soil (0-5 cm), but no significant improvement was noticed in the FDA and SMBC of soil irrespective of soil depth. Different land configurations used for the growth of crops had not affected the microbial activity as well as the SMBC of soil.

From the results, it may be concluded that short-term use of wastewater for irrigation in eggplant enhanced plant growth attributes, productivity and also increased enzymatic activities, microbial biomass C, available N and P content of the soil. Moreover, no significant accumulation of heavy metals noticed except Pb and Ni in post-harvest soil. However, the application of wastewater through drip irrigation reduced the heavy metal accumulation in soil. Therefore, municipal wastewater through drip irrigation could be used as an alternative water resource for short-term to enhance vegetable crop productivity without deteriorating the soil health in peri-urban agriculture.

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