Impact of Wastewater Irrigation on Nutrient Uptake and Soil Fertility in Soybean Cultivation

ABTRACT

A field experiment conducted at college farm, SR University, Warangal. Telangana to study the effect of different quality of water on nutrient uptake and soil fertility variation in soybean. The experiment was laid out in randomized block design (RBD) and replicated six times with three treatments i.e. untreated wastewater, treated wastewater and fresh water. The result of the present study indicate that untreated wastewater affects Nitrogen, phosphorus, potassium and micronutrient uptake (Fe, Zn, Cu, B, and Mn) significantly and slight variation observed in soil pH and Electric conductivity, organic carbon, available nitrogen, phosphorus, potassium and micronutrients after harvest of soybean. Highest nitrogen, phosphorus and potassium uptake in soybean at harvest was observed in untreated wastewater (158.48, 32.55, and 74.85 kg ha^{-1} *in grain and 3612, 21.25 and 67.28 kg ha*$^{-1}$ *in straw respectively) in relation to wastewater and freshwater. Higher value of micronutrient uptake was found in untreated wastewater. Highest value of soil pH, EC, organic carbon, available nitrogen, phosphorus, potassium and micronutrients after harvest of soybean was recorded in untreated wastewater treatment and lowest value in fresh water treatment. This study, it concluded untreated waste water was increase nutrient uptake (N. P. K. Fe. Zn. Cu. Mn. B) due to presence of enough amount of nutrient in untreated wastewater and made slight changes in soil physico-chemical and chemical properties.*

Key words: Nutrient uptake, Soil fertility, Soybean and Untreated wastewater.

Introduction

"Soybean (*Glycine max* (L.) is the leading oilseed crop in the world with an area of 145 M ha. In India too, it is the most important oilseed crop with an area of 10.6 M ha and a production of 10.98 M tons with an average productivity of 1017 kg ha" (FAOSTAT, 2022). "Soybean is often termed as "miracle crop" because of its nutritional value and versatile applications. It contains about 40 per cent protein well balanced in essential amino acids, 20 per cent poly unsaturated fatty acids specially omega 6 and omega 3 fatty acids, 6-7 per cent minerals, 5-6 per cent crude fiber and 17-19 per cent carbohydrates. Some of the major limiting factors for low productivity of soybean are limiting moisture conditions as this is mostly grown under rain fed conditions during *kharif*. The imbalanced and inadequate fertilization is also found to be one of the major limiting factors for its poor yield. Due to absence of better alternatives, farmers of urban and peri-urban localities are using wastewater to irrigate their crops. Wastewater from different sources not only provides water but also contains considerable amount of organic matter and plant nutrients (N, P, K, Ca, S, Cu, Mn and Zn) and has been reported to increase the crop yield" (Pathak, *et al.*, 1998 and Pathak, *et al.*, 1999). "The wastewaters are suitable for crop production provided the content of major plant nutrients are high and that if toxic elements are low. The long-term application would affect the physical, chemical and biological properties of soil" (Antil, 2012). "A long term and indiscriminate use of raw sewage water and industrial wastewater for irrigation continuously has elevated levels of available heavy metals in cultivated layer of soil" (Schirado *et al.*, 1986; Totawat, 1991, Zehra *et al.*, 2009; Doherty *et al.*, 2012 and Jhamaria and Bhatnagar, 2015). With reference to above information, the present experiment was conducted to study the nutrient uptake and soil fertility variation in soybean under wastewater use.

Materials and Methods

The present investigation was carried out at college farm, SR University, Warangal. Telangana to assess the effect of wastewater irrigation on soybean crop and soil fertility during *kharif* 2022-23. The experiment was laid out in randomized block design (RBD) and replicated six times with three treatments. The treatments based on irrigation water quality *i.e.* fresh water (FW) from open well, treated wastewater (TWW) untreated wastewater (UTWW). Untreated wastewater collected from SR university hostels and mess. Aquatic macrophytes grown in constructed wetpond to treat wastewater and then collected in separate pond. The experimental field was ploughed with bullock drawn disc plough followed by two ploughings with cultivator and the clods were broken. The field was uniformly leveled, broad bed and furrows were prepared and divided into plots.JS-335 variety of soybean was used in this experiment. Sowing were carried out though bullock drown seed drill at a depth of 5 cm by adopting an inter-row spacing of 30cm for Soybean and plant to plant distance of 10 cm to achieve desired plant population ha^{-1}. The recommended dose of Soybean was 30 kg N + 60 P_2O_5 + 0 kg K_2O ha^{-1}. Full dose of nitrogen, phosphorus and potassium were applied as a basal dose for soybean. Soil samples were collected prior to layout of the experiment at 0-30 cm depth. The present experimental soil was sandy loam, dark reddish brown colour, low in organic carbon (0.22 %), slight alkaline in reaction (7.8), non-saline (0.11 dS m^{-1}), low in available nitrogen (180 kg ha^{-1}), medium in available phosphorus (16 kg ha^{-1}), medium in available potassium (230 kg ha $^{-1}$) and low in CEC (11.8 C mol (p+) kg^{-1}). Secondary nutrient content in experimental soil was 2014 ppm of Ca, 256 ppm of Mg and 4.5 ppm of S. Micronutrient in sandy loam soil were in the order of Fe>B>Mn>Cu>Zn. Heavy metal content in experimental soil was below the permissible limit of soil in the order of Cr>Pd>As>Cd. The irrigated water was analyzed to ascertain the quality of water by following standard methods (Dhyan Singh *et al.,* 2000) (Table 1). The data obtained on the different growth and yield components and yield were analyzed statistically as per the procedure given by Gomez and Gomez (1984).

Table 1. Water quality analysis data used for irrigation

Sr. No.	Parameters	Fresh water	Treated waste water	Untreated waste water
1	pH	7.2	7.6	8.2
2	EC (dS m^{-1})	0.76	1.7	2.5
3	Carbonate (mg L^{-1})	Traces	Traces	Traces
4	Bicarbonate (mg L^{-1})	84.36	141.23	247.63
5	Chloride (me L^{-1})	78	153	258
6	Sulphate (mg L^{-1})	7.36	16.36	32.33
7	Calcium (mg L^{-1})	56	84	152
8	Magnesium (mg L^{-1})	23	45	68
9	Sodium (mg L^{-1})	29	52	94
10	Phosphorus (mg L^{-1})	Traces	0.78	5.63
11	Potassium (mg L^{-1})	1.98	14.36	38.55
12	Ammonical-Nitrogen (mg L^{-1})	2.02	19.33	65.36
13	Nitrate-Nitrogen (mg L^{-1})	0.39	3.69	9.25
14	Chemical Oxygen Demand (COD)	45.3	175.5	458.3
15	Biochemical Oxygen Demand (BOD)	15.9	125.3	156.2
16	Residual Sodium Carbonate (RSC)	5.36	12.23	27.63
17	Sodium Adsorption Ratio (SAR)	4.61	6.47	8.96
18	Boron (µg lit $^{-1}$)	0.11	0.56	1.02
19	Cadmium (µg lit $^{-1}$)	Traces	Traces	Traces

20	Chromium (µg lit $^{-1}$)	Traces	Traces	Traces
21	Cobalt (µg lit $^{-1}$)	Traces	Traces	Traces
22	Arsenic (µg lit $^{-1}$)	Traces	Traces	Traces
23	Lead (µg lit $^{-1}$)	Traces	Traces	Traces
24	Copper (mg lit $^{-1}$)	0.11	0.36	0.65
25	Manganese (mg lit $^{-1}$)	0.23	0.69	1.32
26	Iron (mg lit $^{-1}$)	1.02	2.36	5.36
27	Zinc (mg lit $^{-1}$)	2.36	4.36	8.36
28	Nickel (mg lit $^{-1}$)	Traces	Traces	Traces

Results and Discussions

Nutrient uptake (NPK) by soybean grain and straw (kg ha^{-1})

The uptake of nitrogen (N), phosphorus (P), and potassium (K) by soybean grain at harvest was significantly influenced by the quality of irrigation water (Table 2). The highest uptake of N, P, and K in soybean grain was observed under untreated wastewater (TWW) irrigation, with values of 158.48, 32.55, and 74.85 kg ha^{-1}, respectively. In contrast, significantly lower NPK uptake was recorded with freshwater (FW) irrigation, with values of 125.56, 19.28, and 51.59 kg ha^{-1}, respectively. The uptake of N, P, and K in soybean grain under treated wastewater (TWW) irrigation was intermediate, recorded at 142.25, 23.59, and 63.87 kg ha^{-1}, respectively.

A similar trend was observed in the uptake of N, P, and K by soybean straw at harvest (Table 3). The higher uptake of these nutrients in both soybean grain and straw under untreated wastewater irrigation could be attributed to the additional nutrient load contributed by untreated wastewater compared to treated wastewater and freshwater irrigation. These findings align with the results of previous studies by Manjunath and Thippeswamy (2015), Asangi et al. (2018), , Gassama et al. (2015) in rice, Wang et al. (2022), Almeida et al. (2018), Kanwal et al. (2020).

Table 2. Effect of different irrigation water treatments on nutrient uptake (kg ha^{-1}) by Soybean grain

Treatment	Nitrogen	Phosphorus	Potassium
FW	125.56	19.28	51.59
TWW	142.25	23.59	63.87

UTWW	158.48	32.55	74.85
SE.m (±)	3.54	0.42	1.53
CD (P=0.05)	9.52	1.74	3.56

Table 3. Effect of different irrigation water treatments on nutrient uptake (kg ha^{-1}) by Soybean straw

Treatment	Nitrogen	Phosphorus	Potassium
FW	21.56	10.25	53.74
TWW	30.25	15.36	62.53
UTWW	36.12	21.25	67.28
SE.m (±)	1.23	0.58	1.57
CD (P=0.05)	5.86	2.54	9.56

Micronutrient uptake by soybean grain (ppm)

Micronutrient uptake (Fe, Zn, B, Cu, and Mn) in soybean grain showed significant variation among treatments (Table 4). Iron (Fe) uptake was highest under untreated wastewater (UTWW) irrigation at 125.22 ppm, followed by treated wastewater (TWW) irrigation at 104.69 ppm. The lowest Fe uptake (92.36 ppm) was observed with freshwater (FW) irrigation. A similar trend was recorded for other micronutrients (Zn, B, Cu, and Mn), with higher uptake observed under UTWW irrigation, followed by TWW irrigation, and the lowest uptake under FW irrigation. Specifically, the uptake of Zn, B, Cu, and Mn under UTWW irrigation was 71.05, 35.36, 29.62, and 42.18 ppm, respectively. Corresponding values for TWW irrigation were 65.59, 33.47, 25.69, and 39.55 ppm, respectively. The increased micronutrient uptake with UTWW irrigation can be attributed to the higher availability of these nutrients in untreated wastewater. Furthermore, enhanced nitrogen uptake in plants likely contributed to the improved uptake of micronutrients in both grain and straw. These findings are consistent with the results reported by Asangi et al. (2018) and Mohammad and Ayadi (2004).

Micronutrient uptake by soybean straw (ppm)

Micronutrient uptake (Fe, Zn, Cu, and Mn) showed significant differences among treatments, while boron (B) uptake did not vary significantly (Table 5). Iron (Fe) uptake was highest under untreated wastewater (UTWW) irrigation, at 315.36 ppm, followed by treated wastewater (TWW) irrigation, at 261.2 ppm. The lowest Fe uptake (222.08 ppm) was observed with freshwater (FW) irrigation. A similar trend was observed for Zn, Cu, B, and Mn, with higher uptake recorded under UTWW irrigation, followed by TWW irrigation, and the lowest uptake with FW irrigation. Specifically, the uptake of Zn, B, Cu, and Mn under UTWW irrigation was 30.98, 27.05, 20.58, and 46.89 ppm, respectively. In contrast, uptake values under FW irrigation were 18.59, 24.30, 10.12, and 28.25 ppm, respectively. The increased micronutrient uptake under UTWW irrigation can be attributed to the higher nutrient content in untreated wastewater, enhancing availability in the soil.

Table 4. Effect of different irrigation water treatments on micronutrients (ppm) uptake by Soybean grain at harvest

Treatment	Fe	Zn	B	Cu	Mn
FW	92.36	61.25	30.25	21.36	35.63
TWW	104.69	65.59	33.47	25.69	39.55
UTWW	125.22	71.05	35.36	29..62	42.18
SE.m (±)	4.25	0.94	0.51	0.22	0.78
CD (P=0.05)	14.29	2.21	NS	1.52	NS

Table 5. Effect of different irrigation water treatments on micronutrients (ppm) uptake by Soybean Straw at harvest

Treatment	Fe	Zn	B	Cu	Mn
FW	222.08	18.59	24.30	10.12	28.25
TWW	261.20	25.36	25.90	14.26	38.59
UTWW	315.36	30.98	27.05	20.58	46.89

SE.m (±)	10.53	0.98	0.53	0.25	2.07
CD (P=0.05)	36.52	3.51	NS	1.08	5.46

Post-harvest status of soil

Post-harvest status of soil pH, electrical conductivity (dS m^{-1}) and organic carbon (%) after harvest of Soybean

The soil pH, electrical conductivity (EC, dS m^{-1}), and organic carbon content (%) varied significantly across the irrigation treatments (Table 6). The lowest soil pH values were recorded under FW irrigation (7.71) and UTWW irrigation (7.88), whereas the highest pH was observed with TWW irrigation (8.15). A similar trend was observed for EC and organic carbon content, both of which increased significantly from FW irrigation (0.18 dS m^{-1} and 0.28%, respectively) to UTWW irrigation (0.23 dS m^{-1} and 0.37%, respectively). The increase in soil pH, EC, and organic carbon content under different irrigation treatments can be attributed to the nutrient and chemical composition of the irrigation water. The highest values of these parameters were observed in UTWW-irrigated soil, likely due to the greater concentrations of salts, organic matter, and nutrients in untreated wastewater compared to treated wastewater and freshwater. As a result, the application of untreated wastewater enriched the soil with these constituents more effectively. These results are consistent with findings reported by Prasad and Gajbhiye (2005), Tiwari et al. (2003), Sharma et al. (2004), Hussain et al. (2006), and Dutta et al. (2000), who demonstrated similar impacts of irrigation water quality on soil properties.

Post-harvest status of soil available nitrogen, phosphorus and exchangeable potassium nutrient (kg ha^{-1}) after harvest of Soybean

The application of untreated wastewater irrigation (UTWW) significantly increased soil nutrient levels of available nitrogen (N), available phosphorus (P), and available potassium (K) after harvest (Table 7). The highest soil nutrient levels were observed under UTWW irrigation, with available nitrogen at 270.84 kg ha^{-1}, available phosphorus at 23.57 kg ha^{-1}, and available potassium at 262.55 kg ha^{-1}. In contrast, freshwater (FW) irrigation resulted in the lowest nutrient levels, with available nitrogen at 211.56 kg ha^{-1}, available phosphorus at 15.27 kg ha^{-1}, and available potassium at 208.18 kg ha^{-1}. The significant increase in soil available nitrogen under UTWW irrigation can be attributed to the higher nitrogen content in untreated wastewater, which augmented the soil nitrogen pool. Similarly, soil available phosphorus levels were highest under UTWW irrigation, followed by treated wastewater (TWW) irrigation, and lowest under FW irrigation. This increase in phosphorus availability is likely due to enhanced mineralization of organic matter in untreated wastewater and the greater phosphorus content it supplies compared to other treatments. Unlike nitrogen and phosphorus, soil potassium levels after harvest showed a reduction across all treatments compared to the initial levels. This decrease may be attributed to the luxury uptake of potassium by plants, which led to its depletion in the soil. These results align with findings from earlier studies, including those by Rajhi (1995), Mitra and Gupta (1999), Reddy and Rao (2000), Tiwari et al. (2003), Rangaraj et al. (2007), Abd El-Kader et al. (2009), Al Zabir et al. (2016), Chauhan et al. (2025) and Muscarella et al. (2024), which reported similar effects of irrigation water quality on soil nutrient status.

Post-harvest status of soil micronutrients (ppm) after harvest of Soybean

The post-harvest concentrations of micronutrients (Fe, Zn, B, Cu, and Mn) in the soil exhibited significant differences across the irrigation treatments using different water qualities (Table 8). The highest concentrations of micronutrients were observed under untreated wastewater irrigation (UTWW), followed by treated wastewater irrigation (TWW), with significantly lower concentrations found under freshwater irrigation (FW). The concentrations of Fe, Zn, B, Cu, and Mn in the soil under UTWW irrigation were 28.14, 1.99, 0.67, 2.36, and 15.69 ppm, respectively, while under FW irrigation, they were 12.36, 1.87, 0.58, 1.74, and 10.63 ppm, respectively. The increase in Fe, Zn, and Mn concentrations in the soil after UTWW irrigation compared to initial levels can be attributed to the higher concentrations of these micronutrients in untreated wastewater. However, the concentrations of B and Cu showed a decrease after harvest, likely due to their lower initial levels in untreated wastewater. These findings are consistent with studies by Abdul Ghafoor et al. (1996), Bansal (1998), Samaras et al. (1999), Yadav et al. (2003), Sharma et al. (2004), Saraswat et al. (2005), and Bigdeli and Seilsepour (2008), which reported similar trends in the impact of irrigation water quality on soil micronutrient status.

Table 6. Effect of different irrigation water treatments on soil pH, electrical conductivity ($dS\ m^{-1}$) and organic carbon (%) after harvest of Soybean

Treatment	pH	EC ($dS\ m^{-1}$)	Organic carbon (%)
FW	7.71	0.18	0.28
TWW	7.88	0.21	0.34
UTWW	8.15	0.23	0.37
SE.m (±)	0.04	0.01	0.01
CD (P=0.05)	0.21	NS	0.04

Table 7. Effect of different irrigation water treatments on soil available nitrogen, phosphorus and exchangeable potassium nutrient status ($kg\ ha^{-1}$) after harvest of Soybean

Treatment	Nitrogen	Phosphorus	Potassium
FW	211.56	15.27	208.18
TWW	232.45	19.81	221.53
UTWW	270.87	23.57	262.55
SE.m (±)	5.38	0.85	4.54
CD (P=0.05)	16.51	2.49	14.56

Table 8. Effect of different irrigation water treatments on soil micronutrients status(ppm) after harvest of Soybean

Treatment	Fe	Zn	B	Cu	Mn
FW	12.36	1.87	0.58	1.74	10.63
TWW	20.96	1.95	0.63	1.86	12.74
UTWW	28.14	1.99	0.67	2.36	15.69
SE.m (±)	2.25	0.09	0.03	0.11	0.45
CD (P=0.05)	7.87	NS	NS	0.36	1.25

CONCLUSION

From present study, it revealed that untreated wastewater treatment is an alternative water resource has increases nutrient uptake in soybean compare to fresh water. Untreated wastewater treatment enhanced available nutrient content in soil compared to treated wastewater and fresh water.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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