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Effect of Wastewater Irrigation on Yield, Water Productivity and Economics of Sunflower and Toria Crop

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Water scarcity is one of the most important issue affecting the global economy and human livelihoods. Climate change, rapid population growth, freshwater pollution and depletion are among the factors exacerbating the situation. Although not yet fully exploited, wastewater reclamation and reuse are considered potential mechanisms to mitigate the challenge. To evaluate the impact of wastewater on yield, economics, soil nutrient status, seed oil content and water productivity, a two-year experiment at farmers field in Angul, Odisha was taken up. The sunflower yield was found significantly higher with wastewater irrigation (10%) which was mainly contributed by higher head diameter (15.3 cm), no. of achenes per head (467) and 100 achene weight (69g). Similarly, toria crop irrigated with wastewater had higher yield by 11% resulting from higher siliquae per plant (179), no of seeds per siliqua (12.1) and test weight (4.6) compared to freshwater irrigation. Besides this soil nutrients and oil content was higher in wastewater irrigated toria and sunflower crop than freshwater crops. Benefit cost ratio was higher in wastewater irrigated sunflower (3.9) and toria (2.0) crop compared to freshwater irrigated crops (3.0 and 1.4 respectively for sunflower and toria). Water productivity under wastewater irrigation in sunflower (0.38 kg/m^3) and toria (0.21 kg/m^3) was higher than freshwater irrigated crops by 10-12%. The findings of the present study suggest that wastewater can be used as a source of irrigation for oilseed crop in Angul Odisha where water scarcity is acute during rabi season.

Keywords: Economics; freshwater; nutrient; productivity; wastewater; water productivity.

1. INTRODUCTION

With population growth, urbanisation and climate change, water is becoming an increasingly scarce resource. Agriculture accounts for 70% of all freshwater withdrawals, making it one of the largest consumers of freshwater resources. With increasing demand for water from other sectors, the provision of freshwater for agricultural purposes will be a major challenge in the future. The potential for improving agricultural production and productivity through irrigated agriculture is already well established. Globally, irrigated agriculture contributes to 34% of agricultural production, with 17% of agriculture using irrigation methods [1]. However, India is currently experiencing high levels of water stress, ranking 13th out of 17 countries worldwide, due to a significant deficit between freshwater availability and demand [2]. This situation is expected to worsen with the effects of climate change, including drought and uncontrolled groundwater pumping [2]. To reduce water stress and improve water security, wastewater reuse is a potential strategy. The use of wastewater by peri-urban or peri-industrial regions has the potential to serve as a source of irrigation water, which can effectively address water scarcity and food insecurity, provided that appropriate measures are taken [3]. In India, only 30% of the wastewater generated is treated Kaur et al. [4], with the remainder being discharged into nearby water bodies and ultimately used for irrigation.

In peri-urban and peri-industrial areas, the profitability of wastewater irrigation is higher due to year-round access to water compared to rainfall or canal water systems. In addition, nutrients such as N, P, K and S help to achieve higher yields with less fertiliser use, which can further benefit farmers [5]. Most of the available literature suggests that wastewater is primarily used to grow vegetables and fodder crops, which provide high financial returns to farmers. By using wastewater, farmers can reduce their fertiliser expenditure and achieve higher crop yields. As a result, farmers who use wastewater can earn up to a third more than those who rely solely on freshwater to grow their crops [6].

However, these vegetable and forage crops are water-intensive that require frequent irrigation. This leads to an increased accumulation of various organic matter, nutrients and heavy metals in the soil, which can damage the soil-plant system and pose a risk to human health [5]. In addition, there are concerns about the consumption of raw vegetables irrigated with wastewater and the potential health risks [5]. Therefore, it is advisable to grow crops that are not consumed raw and that require less water but offer higher profitability when using wastewater irrigation. Oilseed crops are better suited to grow under these conditions as they require less water and can grow without affecting crop yield and biomass [7]. In addition, oilseed crops, particularly sunflower and Brassica spp. have the advantage of being high-value crops that can not only generate higher income but also sustain the soil ecosystem [7].

In India, rapeseed and mustard are the most important group of edible oilseed crops and are an important source of income, especially for small and low-income farmers in rainfed areas. They rank second in the country's edible oilseed industry, accounting for about 27.8% after groundnut [8]. Similarly, sunflower (*Helianthus annuus* L.) is of great importance to the Indian oilseed sector. The seeds contain between 35 and 43% oil. Oilseed production in India reached 0.14 million tonnes in 2021-22. Both oilseed rape and sunflower can be grown during the *rabi* season due to their photosensitivity, short duration, greater adaptability, and ability to fit into any cropping system. Water availability remains a major limiting factor during the rabi season in the eastern region of India. Despite being a low water requirement crop, oilseeds still suffer from water stress as they are grown as rainfed crops. Therefore, increasing the yield of oilseeds through wastewater irrigation may be a viable option. Therefore, this study investigated the effects of wastewater irrigation on the yield and economic viability of oilseed crops in the peri-industrial region of eastern India.

2. MATERIALS AND METHODS

Two field experiments were conducted at the farmers' field in the peri-industrial area of Angul district, Odisha, utilising a complete factorial design with plots measuring 15 m by 7m. The experimental crops were replicated three times. The experimental treatments comprised the irrigation of crops with groundwater/ freshwater, and wastewater. Prior to sowing, the plots were manually ploughed to a depth of 15-25 cm in order to ensure thorough soil aeration and complete weed removal, in accordance with standard agricultural practises recommended for cultivation. Toria, the PT-303 variety, and MSFH17 sunflower were selected for sowing. The sowing was carried out on 15 November 2017 and 10 November 2018, respectively.

To ensure the optimal soil moisture at the subsurface level, supplementary water was provided to the plots. This measure was implemented to prevent seed germination failure in the hot climate of Angul, Odisha. Chemical fertilizers containing nitrogen, phosphorus, and potassium were applied to the field at rates of 60-80-60 and 50-25-25 kg ha^{-1} for sunflower and toria, respectively. The full dose of P and K and N in three split doses (50% basal dose and 25% each at flowering and fruit setting) were applied through DAP, MOP and urea respectively. The soil belongs to the *Aeric Haplaquepts*. The pH of the soil was 6.4 while electrical conductivity was 0.071 dS m^{-1}. Organic carbon content was found to be 0.44%. Available nitrogen, phosphorous and potassium was 184 kg,17.6 kg and 135 kg respectively per ha. The exchangeable calcium and magnesium levels were 4.6 and 1.4 Cmole kg^{-1} respectively.

The wastewater, which was collected from a nala passing near the field in the village, was used for irrigation purpose. The wastewater exhibited a pH of 8.6, an electrical conductivity (EC) of 0.96 dS/m, a biochemical oxygen demand (BOD) of 6.37 ppm, a total dissolved solids (TDS) concentration of 384 ppm, a calcium (Ca) concentration of 40 ppm, a total hardness of 140 ppm, a sulphate concentration of 78 ppm, a soluble acidity ratio (SAR) of 2.2 meq/L, and the presence of trace elements including copper (Cu), iron (Fe), and cadmium (Cd). Following crop harvesting, the following yield variables were measured: number of siliquae, number of seeds per siliqua, number of achenes per head, test weight, head diameter, seed yield, oil content, and oil yield. The seeds were ground into a fine meal and then soaked in petroleum ether for six to seven hours in a Soxhlet extractor in order to extract the oil. The oil yield (seed yield x oil content) and oil content were calculated from the resultant oil [9]. Samples of post-harvest soil (0–15 cm) were taken in accordance with normal protocol for assessment. Available P via Bray's method [10], available K [11], available S (Williams), and available N by the alkaline KMnO4 method [12]. The total water given as irrigation was measured using flow meter in the experimental field and Water productivity was calculated following Bhushan et al. [13] as the ratio of grain yield to total water applied in a particular treatment. Economic water productivity was calculated from the ratio of net returns (Rs) to total water used (mm^3). To conduct an economic analysis, we have enlisted all inputs and operations involved in the cultivation of sunflower and toria crops, including seed, fertilization, irrigation, plant protection measures, harvesting, and threshing. We have then calculated the total cost of cultivation by summing up the prevailing market prices of these inputs and operations. Additionally, we have included the wage of human labourers required for each operation in each crop, assuming eight working hours per man-day. This allows us to accurately determine the cost of cultivation for each treatment. The Government of India's minimum support price (MSP) for toria and sunflower was used to calculate the economics. Gross returns were calculated following Dubey et al. [14], and net returns were obtained by subtracting the cost of cultivation from the gross returns. Statistical analysis of the data was performed using Excel. The treatment means were compared at a 5% level of probability using a student t-test and calculating CD values. Non-significant CD values were not reported in the paper.

3. RESULTS AND DISCUSSION

3.1 Yield Attributes and Yield

Yield (two years pooled data) attributes and yield of toria and sunflower were found to be significantly higher with wastewater irrigation. Wastewater irrigated sunflower crop had 6.3% significantly higher yield compared to freshwater irrigated crop (Table 1). Similarly, the number of achenes per head and seed weight were 19% and 13% higher respectively in the wastewater irrigated crop compared to the freshwater crop. Wastewater irrigation (532 kg/ha) in toria crop showed significantly higher yield by 12.2% compared to freshwater (474) irrigated crop (Table 1). Although the number of siliquae per plant (179) and number of seeds per siliquae (12.1) were higher in wastewater irrigated toria crop, they were found to be statistically insignificant. The results agreed with Sahay et al. [9] who showed that with wastewater irrigation, crop production increased. Furthermore, in our study, wastewater contains sulphur, which is one of the essential nutrients for oilseed production. Oilseeds require sulphur to produce specific amino acids and various S-containing metabolites necessary for protein synthesis Patel et al. [15], which contributed to the increase in yield.

3.2 Soil Nutrient Status

The percentage change in soil nutrient status before and after irrigation is shown in Fig. 1. Soil available nitrogen increased by 46.1 and 25.0% in the sunflower and toria fields, respectively. Available phosphorus increased by 60.6% and 29.9% in the sunflower and toria plots, respectively. Similarly, available potassium increased by 52.3 and 36.2 in sunflower and toria field, respectively. Soil available sulphur increased by 58.8% in sunflower and 56.3% in toria field. All the increases in nutrient availability are due to the presence of these nutrients in the effluent that reaches the soil through irrigation. Some amount is used by the crop, therefore depending on the nutrient uptake by sunflower and toria crop the difference in soil nutrient status is seen.

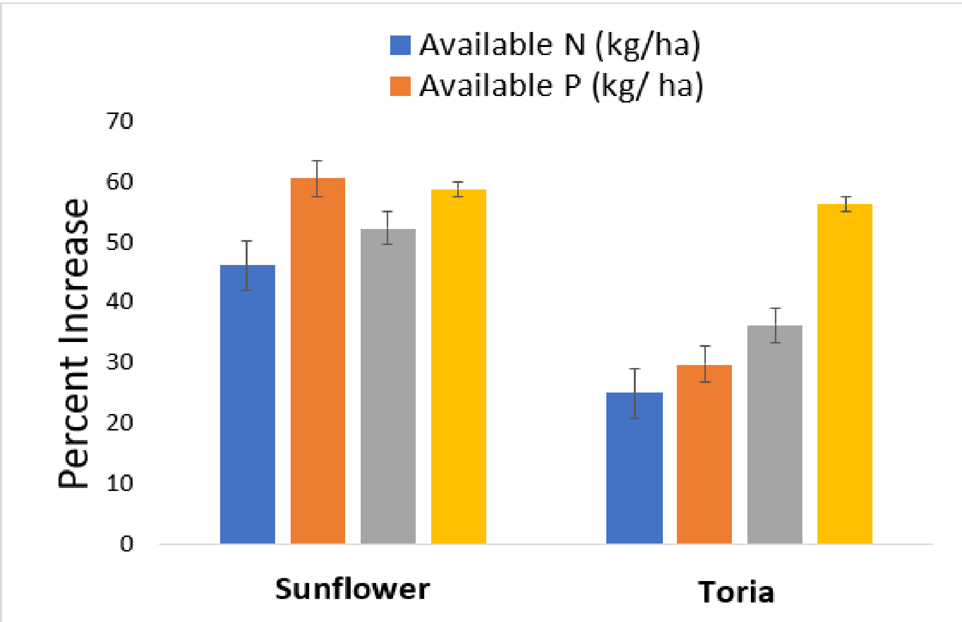

Fig. 1. Percent increase in soil nutrient status after wastewater irrigation compared with freshwater irrigation for sunflower and toria crop

Table 1. Seed yield and yield attributes of sunflower and toria as influenced by wastewater irrigation under field trial

Yield/Yield attributes	Sunflower Crop		LSD (0.05)	Toria		LSD (0.05)
	Freshwater	Wastewater		Freshwater	Wastewater	
Seed yield (kg ha^{-1})	1205	1320	14			
Head diameter (cm)	14.4	15.3	3.2			
Number of achenes/head	392	467	6.7			
Number of silique/plant		-	-	162	179	3.8
Number of seeds/siliquae				10.6	12.1	5.8
Test Weight (g)	61	69	4	4.2	4.6	1.4

Table 2. Nutrient concentration in seeds of sunflower and toria crops

Concentration (%)	Sunflower		LSD (0.05)	Toria		LSD (0.05)
	Freshwater	Wastewater		Freshwater	Wastewater	
N	2.71	2.98	0.16	2.88	3.08	NS
P	0.53	1.01	0.48	0.41	0.54	0.11
K	1.45	1.68	0.47	0.89	1.40	0.41
Oil	28.6	33.3	2.6	35.0	45.6	4.8

Table 3. Economics of sunflower and toria crop in field experiment

Parameter	Sunflower		Toria	
	Freshwater	Wastewater	Freshwater	Wastewater
Input cost (Rs/ha)	15953	13453	8508.2	6868.2
Gross Income (Rs/ha)	48200	52800	12093	13482
Net return (Rs/ha)	22018	29118	3584.8	6613.8
B:C ratio (Rs/per Rs invested)	3.0	3.9	1.42	2.0

Table 4. Water productivity of sunflower and toria crop under field experiment

Parameter	Sunflower		Toria	
	Freshwater	Wastewater	Freshwater	Wastewater
Water productivity (kg m^{-3})	0.34	0.38	0.19	0.21
Economic Water productivity (Rs m^{-3})	6.64	8.69	4.86	6.33

3.2.1 Nutrient content in seeds of sunflower and toria crops

To know if there is any nutrient enrichment in the seeds due to wastewater irrigation, we analysed the seeds of sunflower and toria crops. The percentage of nitrogen in sunflower seeds under wastewater (2.98%) and freshwater (2.71%) was significantly different. However, in toria, percent nitrogen was statistically different in wastewater (3.08%) and freshwater (2.88%). The P concentration was significantly higher in the effluent irrigated sunflower and toria crops by 91 and 32% respectively (Table 2). Potassium content in wastewater irrigated sunflower (1.68%) and toria (1.40%) seeds was 16 and 57% higher than in freshwater irrigated crops, respectively. The oil content, which is the most important output of oilseed crops, showed statistically significant differences in wastewater and freshwater irrigated crops, where the oil content in sunflower seeds was 16% and in toria seeds 30% higher than in freshwater irrigated crops. Similar results were found by Tsoutsos et al. [16], where biodiesel oil content was higher in wastewater irrigated seeds.

3.2.2 Economics of sunflower and toria crops

Economics of sunflower and toria crops was calculated by calculating the total input cost (including ploughing, labour, fertilizers, pesticides, electricity charges etc.) and gross income (grain and straw yield). Net return was calculated by subtracting gross income and input cost. Finally, benefit: cost ratio was calculated from the ratio of gross income to total cost of cultivation (Table 3). Input cost in sunflower crop in freshwater and wastewater irrigation was found to be Rs. 15953 and 13453 respectively. While gross income was Rs. 48200 and Rs. 52800 from freshwater and wastewater irrigated sunflower crop. When benefit cost was calculated wastewater irrigated sunflower showed 3.9 ratio compared to freshwater irrigated crops (3.0).

In case of toria similar trend was seen. Input cost was Rs. 8508 and Rs.6868 in freshwater and wastewater irrigation. While gross return was Rs. 12093 and Rs. 13482 in freshwater and wastewater irrigated toria crop. Net return was higher in wastewater (Rs. 6613.8) than freshwater (Rs.3584.8) irrigated crop. Similarly, B:C ratio was higher by 43% in wastewater (2.0) than freshwater (1.4) irrigated toria crop. The major difference was due to two reasons: one is reduced irrigation cost in wastewater and higher yield.

3.2.3 Water productivity

Water productivity is the ratio of yield and total water used by the crops. Since the yield was found higher under wastewater irrigated crops, similar trend was observed in water productivity. Water productivity under wastewater irrigation in sunflower (0.38 kg/m^3) and toria (0.21 kg/m^3) was higher than freshwater irrigated crops by 10-12% (Table 4). We calculated the economic water productivity as the ratio of net returns (Rs) to the total water supplied for irrigation (m^3). Net return under wastewater irrigated sunflower and toria crop was Rs. 30,438 and 15,298 respectively compared to freshwater irrigated crops (Sunflower: Rs. 23223 and Rs. toria: 11193). Quantity of water used was same for both the crops irrespective of source of water. The economic water productivity was 6.64 and 8.69 in sunflower crop under freshwater and wastewater irrigation. Similarly, in toria the economic water productivity was 30% higher from wastewater (6.33 Rs m^{-3}) than freshwater irrigation (4.86 Rs m^{-3}) (Table 4) [17].

4. CONCLUSION

Wastewater is abundant in peri industrial area of Angul, Odisha where farmers do not attempt second crop after rice due to water scarcity and mostly the land remains fallow. From this study, it can be said that wastewater can aid in solving irrigation water problem during *rabi* season. In-fact use of wastewater proved to be beneficial for oilseed crop (toria and sunflower) in terms of yield, economics, soil nutrients status, seed oil content and water productivity. No significant heavy metal build up was found during the study. Therefore, the short-term use of WW may have safe disposal and may contribute to filling the gap between water availability and water demand. However, as wastewater composition changes with time and season, we need to go for long term studies to ensure for any clinical disorders to human health and animal wellbeing besides soil health.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares 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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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