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Irrigation Water Quality, Soil Transformation and Crop Growth under Organic and Textile-Effluent Irrigation in a Semi-Arid Textile Region of Rajasthan, India

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ABSTRACT:

In semi-arid regions, the quality of irrigation water is a vital bridge between industrial activity and agricultural performance. To study this relationship under field conditions at Krishi Vigyan Kendra (KVK), Agarpura Chouraha, Bhilwara, Rajasthan with three different management systems viz., groundwater without amendment (control), groundwater with vermicompost (organic management), and composite textile-effluent irrigation without amendment was taken up. A 3 × 4 × 3 experimental design with 36 experimental units was used to test four crops—wheatgrass (Triticum aestivum L.), fenugreek (Trigonella foenum-graecum L.), spinach (Spinacia oleracea L.) and spearmint (Mentha spicata L.). The groundwater had pH 7.40, EC 2.20 dS m-1 and SAR 1.79, while the composite textile-effluent water had pH 8.20, EC 4.20 dS m-1 and SAR 15.43. Post-harvest soil measurements revealed contrasting treatment trajectories. Effluent irrigation raised the soil pH to 8.50-9.00, EC to 1.60-1.90 mS cm-1, and decreased organic carbon to 0.18-0.45%, and available phosphorus to 6.34-9.57 kg ha-1. In organic treatment soil pH was 7.10-7.40, EC 0.78-0.86 mS cm-1, organic carbon increased to 0.97-1.16% and available phosphorus was 22.40-25.60 kg ha-1. Such soil differences were associated with obvious changes in crop establishment and growth. Germination or establishment under textile-effluent irrigation reduced by 31.04% in wheatgrass, 44.44% in fenugreek, 45.45% in spinach and 52.94% in spearmint as compared to the corresponding organic treatment. Under effluent irrigation, shoot height and root length decreased by 23.72–46.57% and 27.51–35.03%, respectively, compared to the unamended control. Whereas, vermicompost increased shoot height by 9.36-13.31% and root length by 7.22-30.54% over the control plants. The one-way ANOVA revealed that treatment effects on all measured shoot and root parameters were highly significant ($p < 0.001$). The results show a consistent relation between water, soil and crop in the experimental conditions and give an evaluation in field conditions that is relevant for agricultural areas suffering from textile-industrial drainage.

KEYWORDS: textile wastewater, quality of irrigation water, soil quality, electrical conductivity, sodium adsorption ratio, vermicompost, crop growth, Bhilwara, semi-arid agriculture.

INTRODUCTION:

Textile Water is extensively used in textile processing and wet processing operations like scouring, bleaching, dyeing, printing and finishing, which produce wastewater containing dissolved salts, alkaline components, surfactants and other chemicals from the processes. The concern for the environment is not just the receiving water body. The chemical properties of wastewater-affected water have an influence on the root-zone

environment and may influence the properties of the soil, the availability of nutrients and crop performance (Al-Tohamy et al., 2022; Bhagat & Tiyasha, 2013; Pokhriya et al., 2020).

The city of Bhilwara provides a good local setting for the study of this problem. Textile manufacturing and processing are well developed in the district. The Kothari and Banas river systems and their drainage channels are part of the regional hydrological set up. The textile-effluent problem of Bhilwara has been specifically reported in earlier works (Bhagat & Tiyasha, 2013; Pareek & Srivastava, 2025; Sharma, 2024). In such an industrial-agricultural interface, water quality for irrigation is more than a water supply issue, it is an agricultural management variable.
The first major compartment where irrigation water quality is translated into a plant response is the soil. The repeated use of water with high electrical conductivity can increase the loading of soluble salts. A high sodium adsorption ratio can change the soil exchange environment and cause structural deterioration. Soil reaction also affects the availability of several nutrients especially Phosphorus and micronutrients. Therefore, changes in irrigation-water chemistry may be observed in the soil before differences in crop growth are reflected (Demelash, 2013; Siddique et al., 2021; Pokhriya et al., 2020).

Organic amendments offer an alternative management strategy. Vermicompost supplies organic matter and nutrients and can potentially modify the rhizosphere environment . Decomposition products of this material may facilitate aggregation, nutrient cycling and plant growth. The positive effects of vermicompost on soil condition and crop performance have been reported by the studies (Aslam et al., 2019; Oyege & Bhaskar, 2023; Pathma & Sakthivel, 2012; Xu & Mou, 2016). Therefore, in an agricultural landscape affected by industrial activity, the comparison of an unamended control with a vermicompost-amended treatment can be useful to distinguish the effect of soil management from the effect of the quality of irrigation water. Plant establishment is a biological early indicator of these environmental differences . Germination needs sufficient water absorption and a favorable chemical environment. The development of shoots and roots integrates conditions encountered during subsequent cultivation. The magnitude of response may also vary among crop species thus a multi-crop comparison is useful (Dadlani & Yadava, 2023; Kaur et al., 2019; Pokhriya et al., 2020).

This linkage of water–soil–crop formed the basis of the present study. Four crops with varied botanical characteristics were grown under control, organic and textile effluent irrigation in the same experimental set up. The specific objectives were to characterize the basic physicochemical quality of the irrigation waters, to assess changes in soil pH, EC, organic carbon and nutrient availability after cultivation, and to quantify germination or establishment, shoot height and primary root length.

Heavy-metal accumulation and phytochemical composition were studied separately in the broader research program and are purposely excluded from the present manuscript. The present paper intends to provide a concentrated overview of the environmental and agronomic side of the experiment.

MATERIALS AND METHODS

2.1 Study area

The experiment was conducted at the experimental farm of Krishi Vigyan Kendra (KVK), Agarpura Chouraha, Bhilwara, Rajasthan, India, in the semi-arid Eastern Plain Zone of Rajasthan. The experiment was conducted between October and March. Field soil was a clay-loam uncultivated soil with no previous history of commercial fertilizer application or industrial wastewater irrigation and provided a common starting substrate for the treatments.

2.2 Irrigation-water collection

The composite textile effluent polluted water was procured from four different locations of the Bhilwara textile industrial region. Out of these, two locations were on the Kothari river, one in Guwardi drain and one in the Banas river catchment. The collected water samples were taken in equal proportions and mixed together in clean 200-L high density polyethylene drums and transported to the experimental site. The control and organic treatment plots were irrigated using the ground water from the dedicated deep tube well at KVK.

2.3 Experimental design and crop management

The field experiment comprised three treatments, four test crops, and three replications each, summing up to 36 treatment plots. The plots were 6 ft × 8 ft (1.83 m × 2.44 m; 4.46 m 2) in size each and separated from one another by ridges to avoid contamination.

Table 1. Experimental treatment structure.

Treatment	Irrigation source	Soil amendment	Crop codes
Control	KVK groundwater	None	C1–C4
Organic	KVK groundwater	Vermicompost	OS1–OS4
Textile effluent	Composite textile-effluent water	None	TS1–TS4

The four crops were wheatgrass (Triticum aestivum L., var. Raj-4238), fenugreek (Trigonella foenum-graecum L., var. PRM-45), spinach (Spinacia oleracea L.) and spearmint (Mentha spicata L.). The organic plots were amended with 5 kg vermicompost/plot before sowing. On the 5th day, wheatgrass received one additional 5 kg application, while fenugreek, spinach and spearmint received two additional 5 kg applications at 10-day intervals. Each plot was irrigated with 20 L of water (per irrigation event) using a dedicated labeled portable sprayer. Irrigation was done daily till the emergence was complete. After that, wheatgrass was irrigated every alternate day and other three crops at fourth day intervals.

2.4 Soil sampling and analysis

Before cultivation, a composite sample was taken from the 0-15 cm root zone. After crop removal, five subsamples were collected from each plot with stainless steel hand augers and composited. The samples were then shade dried, gently crushed and sieved through 2 mm sieve and analyzed at the District Soil

Testing Laboratory, Agriculture Department, Bhilwara. The parameters measured were pH, electrical conductivity, organic carbon, available phosphorus, available potash, and available Zn, Fe, Cu and Mn.

2.5 Water Analysis

The pH, EC and sodium adsorption ratio (SAR) of irrigation water were determined for ground water and composite textile-effluent water. The parameters were utilized as the basis to characterize the main difference in salinity and sodicity of the two water sources for irrigation. Water elemental analysis is beyond the scope of this manuscript.

2.6 Seedling Emergence and Establishment

For laboratory germination tests, Petri dishes with Whatman No. 1 filter paper were used for wheatgrass, Fenugreek, and spinach. Each treatment was tested three times with ten seeds per Petri dish. Filter papers were daily wetted with the corresponding irrigation water, and germination was determined after 96 h. Since spearmint was tested for vegetative propagation, stolons of spearmint were used instead of seeds. Healthy subterranean stolons of spearmint were cut, and one hundred stolons were tested per treatment. The establishment of spearmint plants from subterranean stolons was determined as the percentage.

2.7 Growth measurements of plants

At physiological harvest maturity, five plants were taken from each of the three field replicates as a total of 15 plants per treatment. The plants were uprooted, rinsed in tap water, and finally rinsed in double deionized water. Shoot height was measured from the base of the stem to the tip of the longest leaf, and the primary root length was measured from the rootshoot collar to the root tip.

2.8 Statistical analysis

Values are expressed as the mean ± s.d. In the experiments, shoot height and primary root length were analyzed for treatment effects by one-way ANOVA followed by Tukey's HSD for multiple comparisons. A p-value of <0.05 was considered significant.

All ANOVA p-values < 0.001, indicating highly significant morphometric treatment effects.

RESULTS AND DISCUSSION:

3.1 Irrigation-water quality

Table 2. Physicochemical characteristics of the irrigation waters.

Parameter	KVK groundwater	Composite textile effluent
pH	7.40	8.20
EC (dS m^{-1})	2.20	4.20
SAR	1.79	15.43

The two sources of irrigation were vastly different from each other in terms of their basic physicochemical properties. Groundwater had pH 7.40, EC 2.20 dS m -1 and SAR 1.79, but the composite textile-effluent water had pH 8.20, EC 4.20 dS m -1 and SAR 15.43. Hence, the textile process was a quite different ionic environment as opposed to just a different source of water. Higher EC means a greater load of soluble salts and higher SAR means markedly greater hazard from sodium. These differences serve as the environmental baseline for interpreting the soil and plant responses that were observed later in the experiment (Demelash, 2013; Siddique et al., 2021).

3.2 Post-harvest soil response

Table 3. Pre-cultivation and post-harvest soil properties.

Parameter	Initial soil	Control range	Organic range	Textile-effluent range
pH	8.20	7.80–8.10	7.10–7.40	8.50–9.00
EC (mS cm^{-1})	0.95	0.82–0.88	0.78–0.86	1.60–1.90
Organic carbon (%)	0.73	0.72–0.76	0.97–1.16	0.18–0.45
Available P (kg ha^{-1})	10.00	16.80–18.20	22.40–25.60	6.34–9.57
Available K (kg ha^{-1})	396.0	418.0–443.0	440.0–507.0	384.0–403.0
Zn (ppm)	0.59	0.98–1.12	1.20–1.61	1.41–1.66
Fe (ppm)	2.85	3.08–3.58	3.39–4.62	2.67–2.82
Cu (ppm)	0.44	0.82–0.98	1.25–1.52	0.82–1.12
Mn (ppm)	2.41	1.08–2.42	1.20–2.70	1.16–1.54

Two treatment trends were evident in the present soil analysis. Control soils were characterized by minimal intervention measures and retained near-initial pH and EC levels. The organic treatment reduced the pH to 7.10−7.40 and kept the EC at 0.78–0.86 mS cm−1. The soils subjected to textile-effluent irrigation had the highest pH (8.50–9.00) and EC (1.60–1.90 mS cm−1). The trends align with the high EC and SAR of the textile-effluent irrigation water and reported salt stress responses of soils to industrial effluents (Dhaker et al., 2025; Meena & Meena, 2020; Pokhriya et al., 2020).

The treatment effect was most visible in the trends of the organic carbon content. The initial soil content was 0.73%, and the control plots retained their organic matter levels at approximately the same. The organic plots obtained the highest content (0.97–1.16%), whereas the textile plot had the lowest (0.18–0.45%). The trends correspond to the addition of vermicompost in the OS treatment and the detrimental effect of textile-effluent irrigation on soil organic matter. Similar findings have been made for the application of vermicompost in boosting organic matter and subsequently crop productivity (Aslam et al., 2019; Oyege & Bhaskar, 2023; Pathma & Sakthivel, 2012).

Available phosphorus followed a similar trend pattern to that of organic matter. The initial content was 10.00 kg ha −1 , whereas organic treatment obtained the highest yield (22.40-25.60 kg ha-1), and the textile plots obtained the lowest (6.34-9.57 kg ha-1). The available phosphorus levels were lower in the textile plots

despite the high total content. The trend corresponds with the reported lower phosphorus availability in high-pH soils. Organic plots had higher available phosphorus due to the organic matter contribution and rhizosphere activity (Gao et al., 2015; Oyege & Bhaskar, 2023).

Similarly, potassium and micronutrient availability followed treatment trends. Organic plots had the highest potassium levels (440-507 kg ha −1), whereas textile plots had the lowest (384-403 kg ha −1). The available Fe content was highest in the organic plots (3.39-4.62 ppm) and lowest in the textile plots (2.67-2.82 ppm). Cu, Mn, and Zn levels followed analogous patterns. Overall, the trends suggest that organic matter and soil pH greatly influence available micronutrient content (Pokhriya et al., 2020; Oyege & Bhaskar, 2023). The study only evaluated the soil at the time of harvesting, and thus the results only represent a point in time series. Thus, the interpretation should focus on the treatment effects rather than temporal trends.

3.3 Germination and crop establishment

Table 4. Germination or vegetative establishment under organic and textile-effluent irrigation. *Spearmint was assessed by stolon establishment.

Crop	Organic (%)	Textile (%)	Change, TS vs OS
Wheatgrass	96.67 ± 5.77	66.67 ± 5.77	−31.04%
Fenugreek	90.00 ± 10.00	50.00 ± 10.00	−44.44%
Spinach	73.33 ± 5.77	40.00 ± 0.00	−45.45%
Spearmint*	85.00	40.00	−52.94%

The irrigation treatments differed in the earliest biological stage measured. Wheatgrass germination was reduced from 96.67 % under organic management to 66.67 % under textile-effluent irrigation. Fenugreek decreased from 90.00 % to 50.00 % and spinach from 73.33 % to 40.00 %. Vegetative propagation of spearmint showed 85 per cent establishment under organic management compared with 40 per cent under textile irrigation. Therefore, the reductions were 31.04 %, 44.44 %, 45.45 % and 52.94 % respectively. Similar decreases in establishment under wastewater-impacted irrigation have been reported for crop systems exposed to industrial-impacted water (Kaur et al., 2019; Pokhriya et al., 2020).

This response is consistent with the higher salinity and sodicity of the textile-effluent water. An external solution of higher salinity can reduce the effective water potential available to germinating seeds and young propagules, and the chemistry of the root-zone can be altered to further limit early development. The present experiment did not directly assess water potential, enzyme activity or oxidative stress, so these processes are taken as plausible explanations rather than directly demonstrated mechanisms (Dadlani & Yadava, 2023; Demelash, 2013; Siddique et al., 2021).

3.4 Shoot and root growth

Table 5. Shoot height and primary root length across treatments (n = 15 plants per treatment).

Crop	Treatment	Shoot height (cm)	Primary root length (cm)

Wheatgrass	Organic	25.80 ± 1.83	9.90 ± 1.28
Wheatgrass	Control	22.77 ± 1.17	8.27 ± 1.25
Wheatgrass	Textile	17.37 ± 1.34	5.90 ± 0.76
Fenugreek	Organic	34.60 ± 4.10	5.60 ± 0.69
Fenugreek	Control	30.93 ± 3.19	4.29 ± 0.62
Fenugreek	Textile	21.73 ± 1.39	3.11 ± 0.32
Spinach	Organic	23.37 ± 1.63	6.39 ± 0.39
Spinach	Control	21.37 ± 1.37	4.99 ± 0.38
Spinach	Textile	11.83 ± 1.88	3.28 ± 0.23
Spearmint	Organic	28.73 ± 1.83	9.06 ± 0.49
Spearmint	Control	26.07 ± 1.76	8.45 ± 0.52
Spearmint	Textile	13.93 ± 1.05	5.49 ± 0.53

In all four crops, the vegetative growth followed the same treatment order, that is, organic > control > textile effluent. Organic management increased shoot height compared to the corresponding control by 13.31, 11.87, 9.36 and 10.20 % in wheatgrass, fenugreek, spinach and spearmint respectively. Root length increased by 19.71%, 30.54%, 28.06% and 7.22% respectively. The positive response to vermicompost is consistent with the published observations of improved root development and plant performance following organic amendment (Aslam et al., 2019; Oyege & Bhaskar, 2023; Xu & Mou, 2016).

The textile treatment showed an opposite response. Compared to the control, wheatgrass shoot height was decreased by 23.72%, fenugreek 29.74%, spinach 44.64% and spearmint 46.57%. The length of the primary root was reduced by 28.66, 27.51, 34.27 and 35.03% respectively. The larger reductions in spinach and spearmint suggest that these crops are more sensitive to the experimental irrigation environment, a pattern previously seen for growth suppression in leafy crops due to wastewater (Kaur et al., 2019; Pokhriya et al., 2020).

This greater root response is important because roots are the plant organ in direct contact with the treated soil. The higher EC and pH and lower organic carbon and phosphorus in the textile irrigation soils produced a substantially different rooting environment than that which was produced by the groundwater plus vermicompost. Conversely, the organic treatment resulted in a soil environment with more available carbon and phosphorus and was correlated with longer roots. Likewise, systems based on vermicompost have also shown similar relationships between the improvement of the rhizosphere induced by the amendment and root development (Aslam et al., 2019; Oyege & Bhaskar, 2023).

3.5 Statistical validation

Table 6. One-way ANOVA for treatment effects on morphometric parameters.

Crop	Parameter	F-value	p-value
Wheatgrass	Shoot height	121.35	<0.001
Wheatgrass	Root length	47.28	<0.001
Fenugreek	Shoot height	69.83	<0.001
Fenugreek	Root length	72.31	<0.001
Spinach	Shoot height	223.18	<0.001

Spinach	Root length	334.40	<0.001
Spearmint	Shoot height	372.46	<0.001
Spearmint	Root length	217.21	<0.001

All comparisons of shoot height and root length showed highly significant treatment effects. The highest F value was for spearmint shoot length (372.46) and the lowest was for wheat grass root length (47.28) but each comparison was significant at $p < 0.001$. These results support the interpretation that differences in vegetative growth are systematic responses to treatment and not just random variation among plants.

3.6 Integrated interpretation

The results make up a coherent sequence. The EC and SAR the of textile-effluent water were observed to be higher than groundwater. After cultivation, soil pH and EC increased, while soil organic carbon and available phosphorus decreased in respective plots. The same treatment was associated with reduced germination or establishment and reduced shoot and root growth. While organic treatment had the opposite effect, with increased soil organic carbon and phosphorus and increased plant establishment and growth . This water-soil-crop nexus is in line with the broader environmental literature on industrial wastewater reuse in agriculture (Al-Tohamy et al., 2022; Pokhriya et al., 2020).

The experiment does not identify one mechanistic causal because multiple water-quality characteristics and management factors changed at once, but it does provide for a controlled field comparison with the same soil, crop framework and volumes of irrigation used across treatments. The consistency of the response for four crops and a number of independent soil and growth variables support the interpretation that irrigation-water quality was an important determinant of the soil and plant responses observed.

CONCLUSIONS:

The present study demonstrates the clear connection of water–soil–crop under experimental condition at KVK Bhilwara. The EC and SAS of composite textile effluent water were significantly different from the groundwater used as a control and organic treatments. The cultivation of crops after irrigation with textile-effluent leads to an increase in soil pH and EC, decrease in organic carbon, available phosphorus. Adding vermicompost to groundwater resulted in a different soil response, an increase in organic carbon and phosphorus, a decrease in pH and EC.

Plant responses were in the same general direction. Germination or establishment declined in all four crops and both shoot height and primary root length were reduced under textile-effluent irrigation. Organic management increased shoot and root growth compared to the unamended control. Across the morphometric measurements we found a general pattern of organic > control > textile and very significant ANOVA results showing a systematic treatment response.

Therefore, the routine monitoring of irrigation-water EC and sodicity, along with soil pH, EC, organic carbon and nutrient status is warranted for agricultural areas affected by industrial drainage. The present single season experiment revealed some beneficial effects of vermicompost based soil management and

deserves further field evaluation. Studies are needed over multiple seasons and in multiple locations to determine if these treatment differences persist or grow stronger with repeated irrigation.

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