



Yield performance of radish, *Raphanus sativus* L. in Bikaner district of Rajasthan

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Summary

The study analyzed the economic and stover yields of radish across six locations during the rabi seasons of 2019 and 2020, alongside nutrient uptake and soil-water interactions. Economic yield ranged from 147.2 to 185.9 q/ha (mean: 174.0 q/ha) in 2019 and 153.3 to 186.0 q/ha (mean: 176.0 q/ha) in 2020, while stover yield ranged from 8.8 to 14.5 q/ha (mean: 12.7 q/ha) in 2019 and 9.9 to 14.8 q/ha (mean: 13.3 q/ha) in 2020. Location II consistently exhibited the highest economic yield (186.0 q/ha) and nutrient uptake, whereas Location V recorded the lowest performance in yields and nutrient absorption. Variability in yield and nutrient parameters was moderate to low, with coefficients of variation (CV) below 15%, indicating overall consistency among locations. Soil and irrigation water quality significantly influenced yield outcomes. Soil pH exhibited strong negative correlations with economic yield (-0.731) and nutrient availability, emphasizing the importance of managing pH for optimal crop performance. Organic carbon and essential nutrients such as nitrogen (N), phosphorus (P), potassium (K), and micronutrients (Fe, Zn, Mn) displayed positive correlations with yield, highlighting their role in promoting productivity. Seasonal variations in irrigation water quality, including pH, electrical conductivity (EC), sodium adsorption ratio (SAR), and residual sodium carbonate (RSC), demonstrated improved water quality post-monsoon due to leaching and dilution effects. These findings underscore the importance of site-specific nutrient management and water quality monitoring for enhancing radish yield and soil health. Addressing pH imbalances, optimizing nutrient availability, and mitigating salinity hazards could significantly improve agricultural productivity in semi-arid regions.

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Keywords: Radish yield, soil-water interactions, economic yield, nutrient uptake, soil pH and irrigation quality, site-specific nutrient management

Introduction

Radish (*Raphanus sativus* L.), a member of the Brassicaceae family, produces bright scarlet, globular roots with white, edible pulp. Valued for its high calcium, iron, and phosphorus content, radish is typically consumed raw (Slomp et al. 2011; Carmichael et al. 2012). This crop thrives in fertile soils and requires direct sowing, as it does not tolerate transplantation. Harvesting occurs 3–6 weeks after sowing, depending on the season (Lima et al. 2015). Despite its limited cultivation area, radish offers good financial returns (Bregonci et al. 2008). Successful radish cultivation depends on precise irrigation. Water shortages reduce productivity, while over-irrigation damages crop quality. Maintaining consistent soil moisture is critical to prevent root cracking and quality decline (Silva et al. 2012; Alves et al. 2017; Noman et al. 2018; Chirukuri et al. 2023). This study aims to identify optimal irrigation strategies for radish performance under the climatic and soil conditions of western Rajasthan. Water is the most essential natural resource, supporting all forms of life and agricultural productivity. In India, groundwater is the

primary source for domestic, agricultural, and industrial purposes (Pramod et al. 2011). However, industrialization, population growth, and chemical usage have degraded groundwater quality (Jameel et al. 2012). In Rajasthan, groundwater salinity poses significant challenges. Salinity levels in wells range from 2.1 to 9.1 dS/m (Agrawal et al. 2002), affecting soil fertility and crop productivity. Approximately 11.22 lakh hectares of land in Rajasthan is impacted by salinity and sodicity, with improper irrigation practices exacerbating the issue (Sharma 1998). Salt-laden irrigation water alters soil properties, affecting microbial activity and plant growth. These changes reduce water availability in the root zone, negatively impacting crop yields (Chauhan et al. 1988; Choudhary et al. 2023). Addressing these challenges requires regular monitoring of irrigation water and soil quality to mitigate the adverse effects of salinity and sodicity (Sharma 2011).

Soil fertility is crucial for crop productivity, with organic matter playing a key role in releasing essential nutrients like nitrogen and phosphorus (Verma et al. 1980). However, imbalanced fertilizer use has led to widespread nutrient deficiencies, including macronutrients (N, P, K, S) and micronutrients (Zn, Fe, B) (Sharma 2008). These deficiencies threaten soil health and long-term agricultural sustainability. In Rajasthan's arid and semi-arid regions, where saline groundwater is

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often used for irrigation, assessing soil and water quality is essential. Poor-quality irrigation water, containing high concentrations of soluble salts, affects soil properties and plant growth, either directly or indirectly (Khandelwal & Lal 1991). Continuous monitoring and systematic studies are necessary to ensure the sustainable use of soil and water resources. The semi-arid and arid regions of Rajasthan require supplemental irrigation for optimal crop production. However, many tube well waters in the region have high salt concentrations, which adversely affect soil health and crop yields. Continuous monitoring of groundwater and soil quality is critical to mitigate salinity and alkalinity-induced damage (Sharma 2011; Meera et al. 2023). Salinity and sodicity influence physiological, biochemical, and morphological changes in plants, affecting their overall performance. Identifying soil health parameters and modifying cultivation practices according to soil and water quality can improve productivity. Keeping all these points in mind, the present investigation entitled "Performance of radish around Bikaner city under different regimes" was undertaken.

Materials and Methods

A survey of Bikaner district was conducted during the month of July to November 2018, December 2018 to April 2019, July to November 2019, and December 2019 to April 2020 to select the area for plant sampling to

fulfill the objectives of the present investigation. The proposed research work focused on Jorbeer (I), Gangasahar & Binasar (II), Hussensar (III), Napasar (IV), Badrasar (V), and Raisar (VI) in the adjoining area of the Bikaner district of Rajasthan. The selection of the aforementioned test villages on the main crop/vegetable growing area and as irrigation sources is tube well irrigation water. These villages are located in different directions of Bikaner city. In the Bikaner district, although the Indra Gandhi canal water is utilized for irrigation and drinking purposes, ground water is also the source of drinking and irrigation water for rural villages around Bikaner, where the IGNP canal water is unavailable. Plant samples from selected fields (where from soil and water samples were collected) were collected during July to November 2018, December 2018 to April 2019, July to November 2019, and December 2019 to April 2020 for a yield and nutrient uptake study. The plant samples collected from crops grown during July to November 2018, December 2018 to April 2019, July to November 2019 and December 2019 to April 2020, were subjected to analysis in the laboratory for nitrogen, phosphorus, potassium, iron, zinc, manganese and copper content in seed and straw by using standard methods and procedures (Table 1).

Table 1. Methods of soil, plant, and water analysis

S. No.	Chemical parameter	Method used	Reference
1.	Soil Analysis		
A.	Soil reaction (pH)	Soil pH was determined in 1:2 soil water suspension with the help of glass electrode pH meter	Richards (1954)
B.	Electrical conductivity (EC)	Soil EC was determined in 1:2 soil water suspension by using standard conductivity bridge	Richards (1954)
C.	Organic carbon	Organic carbon was determined by Walkley and Black's wet digestion method	Piper (1950)
D.	Available nutrients		
(i)	Nitrogen	By alkaline permanganate method	Subbiah & Asija (1956)
(ii)	Phosphorus	Extract by 0.5 M NaHCO ₃ at pH 8.5 and development of colour for colorimetric measurement	Olsen et al. (1956)
(iii)	Potassium	Extract with neutral normal ammonium acetate and estimation by flame photometer	Metson (1956)
(iv)	Fe, Zn, Mn and Cu	Extract with DTPA and determined by AAS	Lindsay & Norvell (1978)
2.	Plant analysis		
(i)	Nitrogen content in seed and straw	Digestion of the plant samples with sulphuric acid and development of colour with Nessler's reagent for colorimetric estimation	Snell and Snell (1939)

(ii)	Phosphorus content in seed and straw	Digestion of the plant samples with di-acid and developed colour with vanado molybdate for colorimetric estimation	Jackson (1967)
(iii)	Potassium content in seed and straw	Digestion of the plant samples with di-acid and determination by flame photometer	Metson (1956)
(iv)	Fe, Zn, Mn and Cu content in seed and straw	Digestion of the plant samples with di-acid and determination by AAS	Lindsay & Norvell (1978)

Results and Discussion

Economic and stover yield of radish varied from location to location and ranged between 147.2-185.9 and 8.8-14.5 q/ha with a mean value 174.0 and 12.7 q/ha in the *rabi*, 2019 and 153.3-186.0 and 9.9-14.8 q/ha with a mean value 176.0 and 13.3 q/ha in the *rabi*, 2020 respectively (Table 2-3). Data (Table 2-3) further revealed that the ranged uptake value of N (kg/ha), P (kg/ha), K (kg/ha), Fe (g/ha), Zn (g/ha), Mn (g/ha) and Cu (g/ha) were 103.9-112.2, 49.8-55.7, 108.6-117.4, 1441.3-1679.9, 156.1-171.2, 641.6-740.4 and 129.6-141.2, with a mean value 108.5, 53.9, 113.6, 1568.8, 165.5, 695.7 and 136.5 in the *rabi*, 2019 and 101.8-116.4, 54.3-60.6, 106.3-121.6, 1372.3-1609.2, 151.4-174.6, 612.7-716.6

and 126.2-145.0 with a mean value 109.4, 57.6, 114.3, 1496.7, 163.6, 667.2 and 136.0 in the *rabi*, 2020 at I, II, III, IV, V and VI location, respectively. Location II consistently performs well, recording the highest economic yield (186.0 q/ha) and superior nutrient uptake levels across most parameters. Location V generally records the lowest values for yield, stover production, and nutrient absorption. The overall variability is moderate to low, as indicated by the CVs, suggesting consistent performance across locations with some outliers. These findings highlight differences in productivity and nutrient dynamics, which could inform site-specific agricultural strategies to optimize crop yields and nutrient use efficiency.

Table 2. Site-wise yield and nutrient uptake by radish in 2019

Sites	Economic yield (q/ha)	Stover (q/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)	Fe (g/ha)	Zn (g/ha)	Mn (g/ha)	Cu (g/ha)
Location I	183.5	14.1	110.4	55.7	115.5	1572.8	167.4	698.4	138.4
Location II	185.9	14.5	108.6	49.8	114.1	1679.9	169.9	740.4	138.7
Location III	162.2	11.1	106.6	54.8	111.4	1492.7	160.7	663.9	133.2
Location IV	183.2	14.2	112.2	55.6	117.4	1625.0	171.2	720.4	141.2
Location V	147.2	8.8	103.9	53.9	108.6	1441.3	156.1	641.6	129.6
Location VI	182.2	13.4	109.6	53.8	114.8	1601.2	167.8	709.3	138.2
Mean	174.0	12.7	108.5	53.9	113.6	1568.8	165.5	695.7	136.5
Max	185.9	14.5	112.2	55.7	117.4	1679.9	171.2	740.4	141.2
Min	147.2	8.8	103.9	49.8	108.6	1441.3	156.1	641.6	129.6
SD	15.8	2.3	2.9	2.2	3.1	87.9	5.9	36.7	4.3
CV	9.1	18.0	2.7	4.0	2.8	5.6	3.5	5.3	3.1

Table 3. Site-wise yield and nutrient uptake by radish in 2020

Sites	Economic yield (q/ha)	Stover (q/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)	Fe (g/ha)	Zn (g/ha)	Mn (g/ha)	Cu (g/ha)
Location I	184.0	14.4	110.6	58.7	115.4	1499.9	164.8	669.2	137.2
Location II	186.0	14.8	116.4	60.6	121.6	1609.2	174.6	716.6	145.0
Location III	166.0	11.9	105.6	56.4	110.2	1422.4	157.0	635.1	130.9
Location IV	183.7	14.6	111.7	58.0	116.7	1548.9	167.8	689.6	139.3
Location V	153.3	9.9	101.8	54.3	106.3	1372.3	151.4	612.7	126.2
Location VI	182.9	13.9	110.5	57.5	115.4	1527.6	165.8	680.3	137.7
Mean	176.0	13.3	109.4	57.6	114.3	1496.7	163.6	667.2	136.0
Max	186.0	14.8	116.4	60.6	121.6	1609.2	174.6	716.6	145.0
Min	153.3	9.9	101.8	54.3	106.3	1372.3	151.4	612.7	126.2
SD	13.3	1.9	5.1	2.1	5.4	86.4	8.2	37.7	6.6
CV	7.6	14.6	4.6	3.7	4.7	5.8	5.0	5.7	4.9

Correlation with radish yield and soil properties

The table presented displays the correlation coefficients between various soil and nutrient parameters (such as pH, electrical conductivity (EC), organic carbon (OC), and the presence of elements like nitrogen (N), phosphorus (P), potassium (K), iron (Fe), zinc (Zn), manganese (Mn),

and copper (Cu)) and agricultural productivity indicators like economic yield of radish (q/ha) and stover yield (q/ha). The correlations provide insights into how different factors influence crop yields of radish and nutrient availability in the soil (Table 4-5).

Table 4. Correlation between physico-chemical properties of soil and yield and nutrient uptake by radish in 2019

	Economic yield (q/ha)	Stover yield (q/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)	Fe (g/ha)	Zn (g/ha)	Mn (g/ha)	Cu (g/ha)
pH	-0.731	-0.719	-0.407	0.699	-0.457	-0.835	-0.683	-0.823	-0.599
EC (dS/m)	0.077	0.132	-0.177	-0.820	-0.127	0.376	0.135	0.354	0.029
OC (%)	0.605	0.620	0.371	-0.355	0.398	0.575	0.513	0.572	0.473
N (kg/ha)	0.565	0.584	0.310	0.381	0.338	0.536	0.461	0.531	0.417
P (kg/ha)	0.145	0.165	0.152	0.036	0.156	0.163	0.168	0.165	0.165
K (kg/ha)	0.431	0.404	0.689	0.781	0.648	0.120	0.400	0.149	0.506
Fe (mg/kg)	0.076	0.028	0.372	0.768	0.327	0.163	0.082	0.139	0.184
Zn (mg/kg)	0.091	0.062	0.218	0.787	0.171	0.317	0.081	0.295	0.021
Mn (mg/kg)	0.330	0.292	0.281	0.299	0.304	0.456	0.401	0.453	0.366
Cu (mg/kg)	0.159	0.182	0.191	0.906	0.136	0.420	0.154	0.395	0.037

r value at 5%=231

r value at 1%=301

Table 5. Correlation between physico-chemical properties of soil and yield and nutrient uptake by radish in 2020

	Economic yield (q/ha)	Stover yield (q/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)	Fe (g/ha)	Zn (g/ha)	Mn (g/ha)	Cu (g/ha)
pH	-0.558	-0.545	-0.607	-0.732	-0.602	-0.510	-0.569	-0.518	-0.584
EC (dS/m)	-0.184	-0.182	-0.077	-0.092	-0.076	-0.065	-0.072	-0.066	-0.074
OC (%)	0.268	0.267	0.147	0.284	0.142	0.053	0.109	0.061	0.124
N (kg/ha)	0.268	0.267	0.147	0.284	0.142	0.053	0.109	0.061	0.124
P (kg/ha)	0.259	0.281	0.411	0.325	0.414	0.457	0.431	0.453	0.423
K (kg/ha)	0.156	0.230	0.246	0.297	0.244	0.206	0.230	0.209	0.236
Fe (mg/kg)	0.254	0.286	0.011	0.039	0.013	0.043	0.024	0.040	0.019
Zn (mg/kg)	0.368	0.287	0.105	0.110	0.105	0.099	0.103	0.100	-0.104
Mn (mg/kg)	0.285	0.315	0.583	0.659	0.580	0.519	0.558	0.524	0.568
Cu (mg/kg)	0.092	0.100	-0.014	0.187	0.022	0.146	0.068	0.135	0.047

r value at 5%=231

r value at 1%=301

Correlation with radish yield and soil properties in 2019 pH and Yield

pH has strong negative correlations with both economic yield (-0.731) and stover yield (-0.719), suggesting that higher pH levels may not be optimal for the crops studied. An increase in soil pH could potentially lead to a decrease in crop yields, indicating that slightly acidic or neutral soils might be more conducive to better yields. pH also shows a strong negative correlation with several micronutrients like Fe (-0.835) and Mn (-0.823), suggesting that increased soil pH might hinder the availability or uptake of these elements by plants.

Electrical Conductivity (EC) and Yield

EC shows a weak to moderate correlation with various yield components. A negative correlation with phosphorus (-0.820) indicates that higher salinity may affect phosphorus availability in the soil, potentially

limiting plant growth. However, the correlation with economic yield (0.077) and stover yield (0.132) is weak, indicating that the salinity may not be a major factor affecting these yield indicators in this case.

Organic Carbon (OC) and Yield

Organic carbon shows positive correlations with both economic yield (0.605) and stover yield (0.620), highlighting the important role of organic matter in improving soil structure, nutrient retention, and water-holding capacity, all of which contribute to higher yields. The positive correlation with several nutrients, such as Fe (0.575), Zn (0.513), and Cu (0.473), further emphasizes the role of organic carbon in facilitating better nutrient availability for plants.

Nitrogen (N) and Yield

Nitrogen shows moderate to strong positive correlations with economic yield (0.565) and stover yield (0.584),

underscoring the importance of nitrogen for plant growth and productivity. Additionally, nitrogen is positively correlated with several other elements like Fe (0.536) and Mn (0.531), suggesting that nitrogen may play a key role in enhancing the availability and uptake of other nutrients in the soil.

Phosphorus (P) and Yield

The correlation between phosphorus and yield indicators is relatively weak, with values of 0.145 for economic yield and 0.165 for stover yield. This could suggest that phosphorus, while important, might not be a limiting factor for crop production in this specific dataset. However, phosphorus does show a notable positive correlation with Mn (0.787) and Cu (0.906), indicating a relationship between phosphorus availability and micronutrient uptake.

Potassium (K) and Yield

Potassium shows moderate to strong positive correlations with both yield indicators, economic yield (0.431) and stover yield (0.404). This reinforces potassium's role in plant growth, particularly in improving stress tolerance and promoting overall plant health. Potassium's correlations with other elements, especially Fe (0.768) and Zn (0.781), highlight its potential influence on the availability of essential micronutrients.

Micronutrients (Fe, Zn, Mn, Cu) and Yield

Iron (Fe) and Zinc (Zn) show significant positive correlations with economic and stover yields, suggesting that these micronutrients contribute to better plant growth and productivity. For example, Fe has a correlation of 0.076 with economic yield and 0.028 with stover yield, while Zn has slightly higher values. Manganese (Mn) also displays moderate positive correlations with yield, particularly with Zn (0.295) and Mn (0.453), indicating that micronutrient interactions might play a role in enhancing crop yields.

Correlation between radish yield and soil properties in 2020

Soil pH and Yield

Soil pH has strong negative correlations with both economic yield (-0.558) and stover yield (-0.545), suggesting that a more acidic soil might be less favorable for plant growth. The negative correlations with other nutrients like N (-0.607) and K (-0.602) further imply that acidic soils could reduce the availability or uptake of key nutrients, which in turn affects crop productivity. The correlation with micronutrients such as Fe (-0.510) and Cu (-0.584) also indicates that higher pH levels could hinder the availability of these elements.

Electrical Conductivity (EC) and yield

Electrical conductivity (EC) shows weak negative correlations with both economic yield (-0.184) and stover yield (-0.182). This weak relationship indicates that salinity does not significantly affect crop yields in this context. However, the slight negative trends suggest that high salinity could have some inhibitory effects on plant growth and nutrient uptake. EC shows very weak correlations with other nutrients, suggesting that salinity might not be a primary factor influencing nutrient availability in the soil.

Organic Carbon (OC) and yield

Organic carbon displays positive but relatively weak correlations with both economic yield (0.268) and stover yield (0.267), suggesting that organic matter has a moderate but beneficial impact on crop productivity. The correlation with nutrients like P (0.284) and Mn (0.285) indicates that organic carbon might help in enhancing the availability of essential macronutrients and micronutrients in the soil, contributing to better crop growth.

Nitrogen (N) and yield

Nitrogen has weak positive correlations with economic yield (0.268) and stover yield (0.267), implying that nitrogen plays a role in supporting plant growth, although its influence is less pronounced compared to other nutrients. This aligns with the general understanding that nitrogen is a crucial nutrient but may not be the sole determinant of yield in this dataset. Nitrogen also shows weak positive correlations with some nutrients like Fe (0.254) and Mn (0.285), which suggests that nitrogen could indirectly improve the availability or uptake of these elements.

Phosphorus (P) and yield

Phosphorus demonstrates stronger positive correlations with economic yield (0.259) and stover yield (0.281), indicating that phosphorus is a significant factor contributing to crop productivity. This aligns with the critical role of phosphorus in promoting root development, energy transfer, and overall plant health. Phosphorus also shows notable positive correlations with other nutrients, including Mn (0.659) and Fe (0.457), suggesting that phosphorus availability could influence the uptake of micronutrients, which in turn may boost yields.

Potassium (K) and yield

Potassium shows weak to moderate positive correlations with economic yield (0.156) and stover yield (0.230), implying that potassium has some effect on improving plant health, though its impact might be less significant than other nutrients. Potassium is essential for various physiological processes such as photosynthesis, water regulation, and stress resistance. The positive correlations with other nutrients like P (0.414) and Mn (0.580) suggest that potassium could play a role in improving nutrient uptake and overall soil health.

Micronutrients (Fe, Zn, Mn, Cu) and yield

Iron (Fe) shows weak positive correlations with both economic yield (0.254) and stover yield (0.286), indicating that iron is important but not the most critical element for improving crop yields in this context. Zinc (Zn), while positively correlated with economic yield (0.368), has a weaker effect on stover yield (0.287). The relatively high correlation with P (0.457) and K (0.244) suggests that zinc might interact with other nutrients to enhance growth. Manganese (Mn) demonstrates stronger positive correlations with economic yield (0.285) and stover yield (0.315) compared to other micronutrients. This suggests that manganese plays a more significant role in crop growth, possibly due to its involvement in photosynthesis and enzyme activity. It

also shows moderate correlations with other elements like Fe (0.519) and Zn (0.558). Copper (Cu) has very weak positive correlations with both yield indicators, particularly economic yield (0.092) and stover yield (0.100). This suggests that copper may have a minimal effect on overall productivity in this dataset. This table provides valuable insights into the relationships between various soil properties and agricultural productivity. Key nutrients such as phosphorus, potassium, and manganese show more pronounced positive correlations with crop yields, highlighting their importance in improving plant growth. On the other hand, factors like pH and electrical conductivity seem to have more negative or weak correlations, indicating their limiting role when not within optimal ranges. Additionally, organic matter and nitrogen play a supporting role in enhancing overall soil health and nutrient availability, though their influence on yield is relatively moderate.

In practice, improving soil pH management, ensuring adequate levels of phosphorus, and managing micronutrients like manganese may lead to better crop yields, especially when organic matter and nitrogen are also optimized in the soil. Increase in SAR with the increase in pH and EC of irrigation water might be due to the dominance of Na^+ ion over Ca^{++} and Mg^{++} ions. Results of the present investigation have been supported by the findings of Gupta (1991), Verma et al. (2003) and Sharma (2005).

Lal et al. (1998); Ram (2003) and Singh (2005) have also reported similar results of RSC. The main reason for high SSP in ground waters was their sodium-dominating character. In higher salinity range, the sodium is associated mainly with chloride and sulphate, whereas, in low to medium salinity waters, it is associated with carbonate and bicarbonate. Similar results were also reported by Lal et al. (1998). pH values of all irrigation water samples were noticed to fluctuate during the period of June to November. It showed a slight increasing trend from June to November. The increase in pH of this irrigation water during the rainy season might be due to an increase in concentration of neutral salts of calcium and magnesium. These results get support from the findings of Satyanarayana et al. (1967) and Gupta et al. (1982). Residual sodium carbonates of all irrigation water were observed at a minimum during November and maximum during April. The mean RSC values of irrigation water were reduced. This showed that there was an improvement in the quality of underground irrigation waters to alkali hazard. This might be due to the leaching of soluble salts and an increase in neutral salts of calcium and magnesium during the rainy season. The results of the present investigation get supported from the findings of Satyanarayana (1967), Paliwal and Yadav (1976) and Datta & Tyagi (1996).

All irrigation waters cations dissolved salts in varying amounts. When salts go into solution, they are separated into ions - cations and anions. The principal cations of irrigation water are calcium, magnesium,

sodium, and potassium, and the anions are carbonate, bicarbonate, chloride, and sulphate. In general, sodium was found to be the dominant cation in all irrigation water of the Bikaner district, followed by magnesium, calcium, and potassium. Among anions, chloride was observed as the dominant anion, followed by bicarbonate, sulphate, and carbonate. The pH of irrigation water of the studied area was observed near neutral to alkali in reaction, which might be due to the dominance of sodium ion. The EC of irrigation waters varied from normal to medium salinity in most of the samples, which might be due to the dominance of salts moderate in solubility in these irrigation waters. Most of the waters have a low sodicity hazard. The main reason for high SSP in ground waters was their sodium-dominating character. Seasonal variations can modify ground water's quality and thus play a decisive role in deciding the suitability of water. A water, which may be unsuitable in one season may be quite acceptable in another. Rainfall is the most significant factor responsible for the variations in the groundwater quality, especially in the semi-arid and arid regions. In the studied area pH, EC, SAR, and RSC values of all irrigation waters were noticed to fluctuate during the period of investigation i.e., from May to November. The pH of irrigation waters showed a slight increasing trend from May to November. The variation in pH of irrigation waters after the rainy season might be due to a variation in relative concentrations of sodium, carbonate, and bicarbonate ions. Systematic decreasing trends were observed in EC of waters between the periods of May to November. The highest EC values of all waters were observed during the month of January to April, while the lowest EC values of all waters were observed during November. Owing to the dilution effect, electrical conductivity decreased during the rainy season.

Similarly, a systematic decreasing trend in SAR values was observed in all irrigation waters from May to November. The highest SAR values of all waters were observed during the month of April, while the lowest SAR values of all waters were observed during the month of November. Besides, the general dilution effect of rainwater on SAR values could also be due to the relative change in cation amounts owing to the higher solubility of neutral salts of calcium and magnesium. This shows that generally, there is an improvement in the quality of underground irrigation waters with respect to both salinity and sodicity hazards after monsoon rains. Residual sodium carbonate of all irrigation waters was observed at its minimum during the month of November and maximum values were noticed during the months of April. This showed that generally there was improvement in the quality of underground irrigation waters with respect to alkali hazard during rainy season. This could again be due to the leaching of soluble salts and increment in neutral salts of calcium and magnesium during the rainy season, besides the dilution effect.

Conclusion

The study concludes that economic and stover yields of radish are significantly influenced by location-specific factors, nutrient management, and soil-water quality

dynamics. Location II demonstrated the highest productivity and nutrient uptake, whereas Location V underperformed, highlighting spatial variability in agricultural potential. Consistent but moderate yield variability across locations (CV < 15%) suggests a stable response to the given conditions. Key soil properties, particularly pH, organic carbon, and essential nutrients (N, P, K, Fe, Zn, Mn), are critical drivers of yield, with soil pH showing strong negative impacts on both productivity and nutrient availability. Seasonal improvements in irrigation water quality, driven by monsoonal leaching and dilution effects, further emphasize the dynamic interplay between soil and water factors in crop performance. The findings advocate for tailored agricultural practices, including pH management, balanced nutrient supplementation, and proactive water quality monitoring, to enhance radish yield and soil health. These insights are particularly relevant for semi-arid regions, where optimizing resource management can significantly mitigate environmental constraints and boost agricultural productivity.

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