



Integrated nutrient management using compost and canal silt improves nutrient uptake and nutrient use efficiency of onion seed crop in arid sandy soils

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ABSTRACT

Sandy soils of arid and semi-arid regions are characterized by poor fertility, low organic matter content, weak nutrient retention capacity, and low nutrient use efficiency, which limit onion seed productivity. Organic amendments and fine-textured materials such as canal silt have the potential to improve soil fertility and nutrient utilization in these soils. Therefore, a field experiment was conducted during the *Rabi* season of 2021–22 at the Agricultural Research Station, Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan, India, to evaluate the effect of compost, canal silt, and fertilizer levels on nutrient concentration, nutrient uptake, and nutrient use efficiency of onion (*Allium cepa* L.) seed crop. The experiment was laid out in a split-plot design with four soil amendment treatments [Control, canal silt @ 2%, compost @ 30 t ha⁻¹, and canal silt @ 2% + compost @ 30 t ha⁻¹] and four fertilizer levels [0, 75, 100 and 125% recommended dose of fertilizers (RDF)]. The combined application of compost @ 30 t ha⁻¹ and canal silt @ 2% significantly enhanced nitrogen, phosphorus, potassium, iron, zinc, manganese and copper concentrations in seed and dry matter. The highest uptake of N, P and K by seed (12.59, 1.73 and 12.15 kg ha⁻¹, respectively) and dry matter (12.33, 4.08 and 48.81 kg ha⁻¹, respectively) was recorded under the integrated application of compost and canal silt. Similarly, micronutrient uptake was significantly improved. Nutrient use efficiencies were also markedly enhanced, with maximum NUE (14.09%), PUE (7.20%) and KUE (34.59%) recorded under compost @ 30 t ha⁻¹ + canal silt @ 2%. The findings suggest that integration of compost and canal silt with balanced fertilization improves nutrient availability, nutrient uptake, and nutrient use efficiency, thereby offering a sustainable strategy for onion seed production in hyper-arid sandy soils.

Keywords: Compost, Canal silt, Nutrient uptake, Nutrient use efficiency, Sandy soil

INTRODUCTION

Onion (*Allium cepa* L.) is one of the most important vegetable crops cultivated worldwide and plays a significant role in human nutrition, food security, and agricultural economies. It is valued not only for its culinary uses but also for its nutritional and medicinal properties owing to the presence of vitamins, minerals, flavonoids, and sulfur-containing

compounds (Brewster, 2008). India is the second-largest producer of onion in the world; however, the productivity of onion seed crop remains relatively low in several arid and semi-arid regions due to poor soil fertility and suboptimal nutrient management practices. Production of high-quality onion seed requires adequate nutrient availability throughout the crop growth period because nutrient deficiencies

adversely affect flowering, seed set, seed yield, and seed quality. The soils of western Rajasthan are predominantly sandy in texture and are characterized by low organic carbon content, poor aggregation, low water-holding capacity, and limited nutrient retention ability (Yadav *et al.*, 2019). These inherent constraints often result in poor nutrient availability and low fertilizer use efficiency, thereby restricting crop productivity. Furthermore, continuous reliance on inorganic fertilizers alone may lead to nutrient imbalances, declining soil quality, and reduced sustainability of production systems (Mahajan *et al.*, 2021). Therefore, there is a growing need to develop integrated nutrient management strategies that improve nutrient availability while maintaining soil health and productivity.

Organic amendments have been widely recognized for their beneficial effects on soil fertility and crop production. Among them, compost serves as an important source of organic matter and plant nutrients and contributes to improved soil structure, microbial activity, nutrient cycling, and moisture retention (Agegnehu *et al.*, 2017). The gradual decomposition and mineralization of compost provide a sustained supply of nutrients, thereby improving nutrient synchronization with crop demand. Several studies have reported that compost application enhances nutrient uptake, nutrient use efficiency, and productivity of vegetable crops under different agro-climatic conditions (Lazcano *et al.*, 2013; Adekiya *et al.*, 2020). Canal silt, a fine-textured material excavated periodically from irrigation canals, represents a valuable but underutilized resource for improving sandy soils. Due to its relatively higher clay and silt fractions, canal silt can improve soil physical properties, increase water-holding capacity, enhance cation exchange capacity, and reduce nutrient losses through leaching (Kumar *et al.*, 2018). Incorporation of canal silt into coarse-textured soils has been shown to improve soil moisture availability and nutrient retention, leading to better crop growth and productivity. However, scientific information regarding its integration with organic amendments and fertilizer management practices remains limited. Nutrient uptake and nutrient use efficiency are important indicators of crop response to nutrient management practices and are critical for sustainable agricultural production. Improving nutrient use efficiency not only increases

crop productivity but also minimizes nutrient losses and environmental degradation (Cassman *et al.*, 2002). Integrated use of organic amendments and mineral fertilizers has been reported to enhance nutrient recovery by improving soil biological activity, nutrient retention, and root growth, thereby creating a favorable rhizosphere environment for efficient nutrient utilization (Ladha *et al.*, 2022). Such integrated approaches are particularly important in arid sandy soils where nutrient losses and poor nutrient retention frequently limit crop performance.

Despite the recognized benefits of organic amendments and mineral fertilizers, information on the combined use of compost and canal silt for improving nutrient concentration, nutrient uptake, and nutrient use efficiency of onion seed crop under hyper-arid sandy soils is limited. Most previous studies have focused on the individual effects of organic manures, inorganic fertilizers, or soil conditioners, whereas their integrated influence on nutrient dynamics and utilization efficiency in onion seed production systems has received little attention. Furthermore, limited information is available regarding the response of macro- and micronutrient uptake to combined application of compost and canal silt under the coarse-textured soils of western Rajasthan. It was hypothesized that the integrated application of compost and canal silt would improve nutrient availability, moisture retention, and nutrient-holding capacity of sandy soils, thereby enhancing nutrient concentration, nutrient uptake, and nutrient use efficiency of onion seed crop compared with sole application of either amendment or inorganic fertilizers alone. Therefore, the objectives of the present study were to: (i) evaluate the effects of compost, canal silt, and fertilizer levels on macro- and micronutrient concentration in onion seed and dry matter; (ii) quantify their influence on nutrient uptake by onion seed crop; and (iii) assess nutrient use efficiency under different integrated nutrient management practices in a hyper-arid sandy soil of western Rajasthan. The novelty of this study lies in the evaluation of canal silt, a locally available and underutilized resource, in combination with compost and graded fertilizer levels for improving nutrient uptake and nutrient use efficiency of onion seed crop in hyper-arid sandy soils, thereby providing a sustainable nutrient management strategy for seed production systems in arid regions.

MATERIALS AND METHODS

Experimental Site and Soil Characteristics

A field experiment was conducted during the *Rabi* season of 2021–22 at the Agricultural Research Station, Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan, India. The experimental site is located at 28°10' N latitude and 73°18' E longitude with an altitude of 223.88 m above mean sea level. The region falls under Agro-climatic Zone Ic (hyper-arid partially irrigated western plain) and is characterized by hot summers, cold winters, low and erratic rainfall, and high evaporative demand. Prior to the initiation of the experiment, composite surface soil samples (0–15 cm) were collected from the experimental field and analyzed for their physico-chemical properties using standard procedures. The initial soil properties are presented in Table 1.

Experimental Design and Treatments

The experiment was laid out in a split-plot design with three replications. Four soil amendment treatments were assigned to the main plots: control (A_0), canal silt @ 2% (A_1), compost @ 30 t ha⁻¹ (A_2), and canal silt @ 2% + compost @ 30 t ha⁻¹ (A_3). The sub-plots consisted of four fertilizer levels: control

(F_0), 75% recommended dose of fertilizers (RDF) (F_1), 100% RDF (F_2), and 125% RDF (F_3). The recommended fertilizer dose comprised 100 kg N, 50 kg P₂O₅, and 100 kg K₂O ha⁻¹. The experiment consisted of 48 plots, each measuring 3 m × 3 m. Onion bulbs of cultivar 'Sikar Local' were planted at a spacing of 45 cm × 30 cm.

Crop Management

Compost and canal silt were uniformly applied and incorporated into the soil 12 days before planting according to the treatment specifications. Nitrogen, phosphorus, and potassium fertilizers were supplied through urea, single superphosphate (SSP), and muriate of potash (MOP), respectively. The full dose of phosphorus and potassium was applied as basal, whereas nitrogen was applied in three equal splits during the crop growth period. All other agronomic and plant protection practices were followed as per regional recommendations for onion seed production.

Nutrient Analysis and Nutrient Uptake

Representative samples of seed and dry matter were collected from each plot at harvest, oven-dried, ground, and analyzed for nutrient concentration. Nitrogen content was determined by the colorimetric

Table 1. Initial soil properties of soil

Soil properties	Value	Methods of analysis with reference
A. Mechanical Composition		
Sand (%)	86.5	Hydrometer method (Bouyoucos, 1962)
Silt (%)	4.8	
Clay (%)	8.7	
Texture	Loamy Sand	Texture triangle (Weil & Brady (2016)
B. Physical properties		
Bulk density (Mg m ⁻³)	1.58	Core sampler method (Bodman, 1942)
Particle density (Mg m ⁻³)	2.66	Pycnometer method (Black, 1963)
Total porosity (%)	40.7	Calculated (Richards, 1954)
Hydraulic conductivity	12.7	Constant head method (Klute, 1965).
C. Chemical properties		
Soil pH (1:2 soil: water)	8.58	(Jackson, 1973)
EC (dSm ⁻¹) (1:2 soil: water)	0.198	(Chopra and Kanwar,1991)
Organic carbon (%)	0.168	Walkley and Black method, (1934)
Available N (kg ha ⁻¹)	98.1	Alkaline KMnO ₄ method (Subbiah and Asija, 1956)
Available P ₂ O ₅ (kg ha ⁻¹)	21.4	Olsen's method (Olsen <i>et al.</i> , 1954)
Available K ₂ O (kg ha ⁻¹)	190.1	Flame photometer (Jackson, 1973)
Available Fe (mg kg ⁻¹)	3.38	DTPA extractable method (Lindsay and Norwell,1978)
Available Cu (mg kg ⁻¹)	0.268	
Available Zn (mg kg ⁻¹)	0.358	
Available Mn (mg kg ⁻¹)	3.60	
D. Biological properties		
Dehydrogenase activity (µg TPF g ⁻¹ soil 24 h ⁻¹)	52.36	(Tabatabai, 1982)

method following digestion with sulphuric acid and hydrogen peroxide (Snell and Snell, 1939). Phosphorus concentration was determined using the vanadomolybdate yellow color method (Jackson, 1973), while potassium concentration was measured using a flame photometer (Richards, 1954). Micronutrients (Fe, Zn, Mn, and Cu) were determined after di-acid digestion using an atomic absorption spectrophotometer (Elwell and Gridley, 1967).

Nutrient uptake by seed and dry matter was calculated using nutrient concentration and corresponding yield data according to the following equations:

Macronutrient uptake (kg ha^{-1}) = (Nutrient concentration (%) $\times$ Yield (kg ha^{-1})) / 100

Micronutrient uptake (g ha^{-1}) = (Nutrient concentration (ppm) $\times$ Yield (kg ha^{-1})) / 1000

Nutrient Use Efficiency

Nutrient use efficiency (NUE, PUE, and KUE) was calculated based on nutrient uptake according to the following expression:

Nutrient use efficiency (%) = (Nutrient uptake in treated plot – Nutrient uptake in control plot) / Amount of nutrient applied.

Statistical Analysis

The experimental data were subjected to analysis of variance (ANOVA) appropriate for a split-plot design following the procedure described by Fisher

(1950). Treatment means were compared using the critical difference (CD) test at the 5% level of significance (Gomez and Gomez, (1984).

RESULTS AND DISCUSSION

Nutrient Content

The data presented in Table 2 and Table 3 revealed that soil amendments and fertilizer levels influenced nutrient concentration in seed and dry matter of onion seed crop. In general, combined application of 2% canal silt + compost @ 30 t ha^{-1} (A_3) recorded the highest nutrient accumulation, whereas control treatment (A_0) produced the lowest values.

Effect of Soil Amendments

Among soil amendments, treatment A_3 significantly enhanced macronutrient content in both seed and dry matter. Nitrogen content increased from 1.54 and 0.52% under control to 2.06 and 0.72%, registering an increase of 33.77 and 38.46%, respectively. Similarly, phosphorus content increased from 0.178 and 0.152% to 0.282 and 0.236%, showing improvement of 58.43 and 55.26% over control. Potassium content also increased significantly and reached 1.98 and 2.84% in seed and dry matter, representing 19.28 and 44.16% higher values than control. Application of compost alone (A_2) also substantially improved nutrient concentration and remained superior over canal silt alone (A_1). The improvement in nutrient

Table 2. Effect of soil amendments and fertilizer levels on nitrogen, phosphorus and potassium in Seed and dry matter of onion seed crop

Treatments	Nitrogen (%)		Phosphorus (%)		Potassium (%)	
	Seed	Dry matter	Seed	Dry matter	Seed	Dry matter
Soil amendments						
A_0 - Control	1.54	0.52	0.178	0.152	1.66	1.97
A_1 - 2 % Canal silt	1.87	0.59	0.239	0.189	1.90	2.27
A_2 - Compost @ 30 t ha^{-1}	1.95	0.64	0.254	0.206	1.92	2.50
A_3 - 2 % Canal silt + compost @ 30 t ha^{-1}	2.06	0.72	0.282	0.236	1.98	2.84
S.Em $\pm$	0.03	0.02	0.005	0.008	0.01	0.09
CD (0.05)	0.10	0.07	0.017	0.028	0.03	0.30
Fertilizer levels						
F_0 - 0 % RDF	1.80	0.54	0.228	0.150	1.51	1.95
F_1 - 75 % RDF	1.84	0.60	0.236	0.181	1.96	2.23
F_2 - 100 % RDF	1.86	0.66	0.239	0.223	1.99	2.66
F_3 - 125 % RDF	1.93	0.68	0.250	0.230	2.01	2.73
S.Em $\pm$	0.03	0.01	0.004	0.006	0.01	0.06
CD (0.05)	0.07	0.04	0.012	0.017	0.01	0.18

Table 3. Effect of soil amendments and fertilizer levels on micronutrients content (ppm) in seed and dry matter of onion seed crop

Treatments	Iron		Manganese		Copper		Zinc	
	Seed	Dry matter	Seed	Dry matter	Seed	Dry matter	Seed	Dry matter
Soil amendments								
A ₀ - Control	18.15	10.36	18.64	9.13	4.00	2.43	19.90	13.01
A ₁ - 2 % Canal silt	19.32	11.53	19.75	10.43	4.36	3.08	21.88	14.97
A ₂ - Compost @ 30 t ha ⁻¹	20.28	11.89	20.72	11.06	4.59	3.44	22.44	15.11
A ₃ - 2 % Canal silt + compost @ 30 t ha ⁻¹	21.47	13.05	21.91	12.70	4.99	4.06	24.12	16.83
S.Em±	0.60	0.33	0.30	0.36	0.08	0.16	0.49	0.48
CD (0.05)	2.07	1.14	1.04	1.24	0.27	0.55	1.679	1.67
Fertilizer levels								
F ₀ - 0 % RDF	19.04	11.66	19.37	10.23	4.19	2.96	21.46	14.36
F ₁ - 75 % RDF	19.87	11.66	20.50	10.88	4.61	3.38	21.82	14.73
F ₂ - 100 % RDF	20.11	11.73	20.55	11.07	4.55	3.33	22.43	15.37
F ₃ - 125 % RDF	20.21	11.77	20.61	11.14	4.58	3.36	22.63	15.45
S.Em±	0.37	0.19	0.48	0.35	0.18	0.18	0.40	0.47
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

concentration under combined amendment application may be attributed to enhanced nutrient availability, improved soil physical conditions and greater nutrient uptake efficiency. A similar trend was observed for micronutrient concentration. The highest iron content under A₃ was 21.47 ppm in seed and 13.05 ppm in dry matter, which was 18.29 and 25.97% higher than control. Manganese concentration increased from 18.64 and 9.13 ppm to 21.91 and 12.70 ppm, registering 17.54 and 39.10% improvement in seed and dry matter, respectively. Copper content showed a marked increase under A₃ and reached 4.99 and 4.06 ppm, corresponding to 24.75 and 67.08% enhancement over control. Likewise, zinc concentration increased from 19.90 and 13.01 ppm to 24.12 and 16.83 ppm, indicating 21.21 and 29.36% higher values than A₀. Overall, combined application of canal silt and compost proved most effective in improving both macro and micronutrient concentration. The present study demonstrated that the combined application of compost and canal silt significantly enhanced the concentration of macro- and micronutrients in onion seed and dry matter. The increase in nitrogen, phosphorus, and potassium concentrations may be attributed to the direct nutrient contribution from compost and its gradual mineralization, which ensured a continuous supply of nutrients throughout the crop growth period. Compost addition improves soil organic matter content, microbial activity, and nutrient cycling, thereby increasing nutrient availability in the rhizosphere (Agegnehu *et al.*, 2017). Furthermore, organic matter released during

compost decomposition can reduce nutrient fixation and improve nutrient mobility, resulting in greater nutrient absorption by plants (Adekiya *et al.*, 2020). The beneficial effect of canal silt on nutrient concentration could be associated with improvements in soil physical properties. The incorporation of fine-textured canal silt into sandy soils enhances moisture retention, cation exchange capacity, and nutrient-holding capacity, thereby reducing nutrient losses through leaching and improving nutrient availability to plants (Kumar *et al.*, 2018). Improved moisture availability under canal silt application may also have facilitated greater root proliferation and nutrient transport within the plant. The increased concentrations of Fe, Zn, Mn, and Cu observed under integrated application of compost and canal silt could be attributed to enhanced micronutrient solubility and availability resulting from the release of organic acids during compost decomposition. These organic compounds can chelate micronutrient cations and maintain them in plant-available forms (Lindsay, 1979). Similar improvements in micronutrient concentration following the application of organic amendments have been reported by Adekiya *et al.*, (2020) and Agegnehu *et al.*, (2017).

Effect of Fertilizer Levels

Regarding fertilizer levels, increasing RDF levels resulted in progressive improvement in macronutrient concentration. Application of 125% RDF (F₃) recorded maximum nitrogen content (1.93

and 0.68%) and increased it by 7.22 and 25.93% over 0% RDF (F_0) in seed and dry matter, respectively. Phosphorus concentration under F_3 increased by 9.65% in seed and 53.33% in dry matter, whereas potassium content increased by 33.11 and 40.00%, respectively, over F_0 . Thus, higher fertilizer dose enhanced nutrient uptake and accumulation in plant tissues. For micronutrients, numerical increases were observed with increasing fertilizer levels; however, differences among fertilizer treatments remained non-significant for iron, manganese, copper and zinc content in both seed and dry matter. Nevertheless, maximum values were recorded under 125% RDF, where iron, manganese, copper and zinc increased by 6.14, 6.40, 9.31 and 5.45% in seed and 0.94, 8.89, 13.51 and 7.59% in dry matter, respectively, over F_0 . Therefore, soil amendments exerted a stronger influence on micronutrient enrichment than fertilizer levels. The significant increase in nutrient concentration with increasing fertilizer levels may be attributed to greater nutrient availability in the soil solution and enhanced nutrient absorption by plants. Adequate nutrient supply through balanced fertilization promotes root development and metabolic activity, thereby increasing nutrient accumulation in plant tissues (Ladha *et al.*, 2022).

Nutrient Uptake

The results presented in Table 4 and Table 5 clearly demonstrated that uptake of macro and micronutrients by onion seed crop was markedly

influenced by soil amendments and fertilizer levels. The magnitude of nutrient uptake increased with improvement in nutrient availability and crop biomass production.

Effect of Soil Amendments

Under soil amendment treatments, A_3 significantly improved uptake of nitrogen, phosphorus and potassium in both seed and dry matter over control. Nitrogen uptake increased from 5.52 to 12.59 kg ha⁻¹ in seed and from 5.31 to 12.33 kg ha⁻¹ in dry matter, accounting for an increase of 128.08 and 132.20 per cent, respectively, over A_0 . Likewise, phosphorus uptake under A_3 reached 1.73 kg ha⁻¹ in seed and 4.08 kg ha⁻¹ in dry matter, which represented 174.60 and 158.23 per cent higher uptake than control. Potassium uptake also exhibited a similar response and attained 12.15 and 48.81 kg ha⁻¹ in seed and dry matter, respectively, reflecting an increase of 100.83 and 140.21 per cent over A_0 . Treatment A_2 (compost @ 30 t ha⁻¹) remained statistically at par with or next superior to A_3 for several parameters and recorded appreciably higher uptake than A_1 and control. The uptake of micronutrients followed a comparable trend under soil amendments. Treatment A_3 recorded the highest uptake of iron, zinc, manganese and copper in seed as well as dry matter. Iron uptake increased by 103.41 per cent in seed and 114.99 per cent in dry matter, while zinc uptake increased by 107.20 and 119.42 per cent, respectively, over control. Similarly, manganese uptake showed an increase of 102.26 per

Table 4. Effect of soil amendments and fertilizer levels on uptake of nitrogen, phosphorus and potassium in seed and dry matter of onion seed crop

Treatments	Uptake of nitrogen (kg ha ⁻¹)		Uptake of phosphorus (kg ha ⁻¹)		Uptake of potassium (kg ha ⁻¹)	
	Seed	Dry matter	Seed	Dry matter	Seed	Dry matter
Soil amendments						
A_0 - Control	5.52	5.31	0.63	1.58	6.05	20.32
A_1 - 2 % Canal silt	9.35	7.58	1.19	2.45	9.54	29.32
A_2 - Compost @ 30 t ha ⁻¹	10.49	8.71	1.37	2.82	10.44	34.00
A_3 - 2 % Canal silt + compost @ 30 t ha ⁻¹	12.59	12.33	1.73	4.08	12.15	48.81
S.Em $\pm$	0.25	0.77	0.04	0.28	0.27	3.19
CD (0.05)	0.88	2.68	0.12	0.97	0.94	11.05
Fertilizer levels						
F_0 - 0 % RDF	7.59	5.77	0.98	1.62	6.31	20.98
F_1 - 75 % RDF	9.06	7.98	1.16	2.44	9.56	30.00
F_2 - 100 % RDF	10.13	9.56	1.31	3.26	10.71	38.90
F_3 - 125 % RDF	11.17	10.62	1.48	3.60	11.59	42.57
S.Em $\pm$	0.36	0.40	0.05	0.16	0.34	1.74
CD (0.05)	1.05	1.18	0.15	0.45	0.98	5.09

Table 5. Effect of soil amendments and fertilizer levels on micronutrient (iron, zinc, manganese and copper) in seed and dry matter onion seed crop

Treatments	Uptake of iron (g ha ⁻¹)		Uptake of zinc (g ha ⁻¹)		Uptake of manganese (g ha ⁻¹)		Uptake of copper (g ha ⁻¹)	
	Seed	Dry matter	Seed	Dry matter	Seed	Dry matter	Seed	Dry matter
Soil amendments								
A ₀ - Control	6.46	10.34	7.08	13.13	6.64	9.20	1.43	2.46
A ₁ - 2 % Canal silt	9.67	14.56	10.95	18.99	9.89	13.23	2.18	3.93
A ₂ - Compost @ 30 t ha ⁻¹	10.93	15.93	12.11	20.22	11.18	14.88	2.48	4.64
A ₃ - 2 % Canal silt + compost @ 30 t ha ⁻¹	13.14	22.23	14.67	28.81	13.43	21.62	3.09	6.96
S.Em±	0.31	1.31	0.40	1.70	0.32	1.19	0.07	0.47
CD (0.05)	1.09	4.52	1.38	5.87	1.12	4.12	0.25	1.64
Fertilizer levels								
F ₀ - 0 % RDF	7.91	12.27	8.94	15.39	8.05	10.90	1.75	3.24
F ₁ - 75 % RDF	9.70	15.56	10.67	19.55	10.01	14.69	2.26	4.56
F ₂ - 100 % RDF	10.84	17.08	12.06	22.29	11.18	16.10	2.50	4.90
F ₃ - 125 % RDF	11.76	18.16	13.13	23.92	11.90	17.23	2.67	5.27
S.Em±	0.51	0.60	0.41	1.03	0.56	0.70	0.18	0.38
CD (0.05)	1.48	1.76	1.20	3.01	1.63	2.05	0.54	1.11

cent in seed and 135.00 per cent in dry matter under A₃. Copper uptake exhibited the greatest response and increased by 116.08 and 182.93 per cent, respectively, over control. The enhanced uptake under integrated soil amendments may be associated with improved nutrient solubility, better root proliferation and increased translocation of nutrients within the crop. The combined application of compost and canal silt markedly increased the uptake of both macro- and micronutrients by onion seed crop. Nutrient uptake is a function of nutrient concentration and biomass production; therefore, the higher uptake observed under integrated amendment treatments was associated with increased nutrient availability as well as greater seed and dry matter yield. The enhanced uptake of nitrogen, phosphorus, and potassium under compost-amended treatments may be attributed to improved nutrient mineralization, increased microbial activity, and sustained nutrient release from organic matter (Agegnehu *et al.*, 2017). Compost has been reported to improve root growth and nutrient acquisition by enhancing soil aggregation, porosity, and water-holding capacity (Lazcano *et al.*, 2013). Improved root growth increases the volume of soil explored by roots, thereby facilitating greater nutrient absorption. In addition, decomposition of organic residues releases humic substances and low-molecular-weight organic acids that can increase nutrient availability and nutrient uptake efficiency (Adekiya *et al.*, 2020). The increase in nutrient uptake due to canal silt

application may be related to its role in improving soil moisture storage and nutrient retention in coarse-textured soils. Enhanced moisture availability promotes nutrient diffusion and mass flow processes, resulting in improved nutrient transport to plant roots (Kumar *et al.*, 2018). Moreover, the clay fraction present in canal silt increases the adsorption of nutrient ions, thereby reducing nutrient losses and ensuring a more continuous nutrient supply during crop growth. Micronutrient uptake also increased significantly under integrated application of compost and canal silt. This may be attributed to improved micronutrient availability and enhanced biomass production. Organic ligands released during compost decomposition increase the mobility of micronutrients and facilitate their uptake by plants (Lindsay, 1979). Similar positive effects of organic amendments on micronutrient uptake have been reported in several vegetable crops (Adekiya *et al.*, 2020).

Effect of Fertilizer Levels

Among fertilizer levels, progressive increase in RDF significantly improved uptake of all macronutrients. Application of 125% RDF (F₃) recorded maximum uptake of nitrogen (11.17 and 10.62 kg ha⁻¹ in seed and dry matter, respectively), which was 47.17 and 84.06 per cent higher than F₃. Phosphorus uptake under F₃ increased by 51.02 per cent in seed and 122.22 per cent in dry matter, whereas potassium uptake increased by 83.68 and

102.91 per cent, respectively, compared to 0% RDF. A similar increasing trend was observed for micronutrient uptake with increasing fertilizer dose. Application of 125% RDF resulted in highest uptake of iron (11.76 and 18.16 g ha⁻¹), zinc (13.13 and 23.92 g ha⁻¹), manganese (11.90 and 17.23 g ha⁻¹) and copper (2.67 and 5.27 g ha⁻¹) in seed and dry matter, respectively. Relative to F₀, iron uptake increased by 48.67 and 48.00 per cent, zinc by 46.87 and 55.43 per cent, manganese by 47.83 and 58.07 per cent, and copper by 52.57 and 62.65 per cent, respectively. Higher fertilizer levels further enhanced nutrient uptake owing to increased nutrient availability and greater crop growth. Balanced fertilization improves photosynthetic activity, root development, and biomass accumulation, leading to increased nutrient demand and uptake (Cassman *et al.*, 2002). The significant increase in nutrient uptake under integrated nutrient management highlights the synergistic interaction between organic amendments and mineral fertilizers in improving nutrient acquisition by crops.

Nutrient Use Efficiency

The data presented in Table 6 revealed that nutrient use efficiency of onion seed crop was markedly influenced by different soil amendments and fertilizer levels. Nitrogen use efficiency (NUE), phosphorus use efficiency (PUE) and potassium use efficiency (KUE) increased progressively with application of soil amendments and fertilizer levels over control.

Effect of Soil Amendments

Among soil amendments, the highest nutrient use efficiency was recorded under combined

application of 2% canal silt + compost @ 30 t ha⁻¹ (A₃). This treatment registered 14.09% NUE, 7.20% PUE and 34.59% KUE, which represented an increase of 131.36, 82.28 and 177.02 per cent, respectively, over A₁ (2% canal silt) and 68.34, 81.82 and 91.42 per cent, respectively, over A₂ (compost @ 30 t ha⁻¹). Treatment A₂ recorded the second highest nutrient use efficiency with values of 8.37% NUE, 3.96% PUE and 18.07% KUE, followed by A₁, which recorded 6.09% NUE, 2.85% PUE and 12.49% KUE. Control treatment (A₀) did not record nutrient use efficiency values. The results of the present investigation revealed that nutrient use efficiency of onion seed crop was significantly influenced by soil amendments and fertilizer levels. Higher values of nitrogen use efficiency (NUE), phosphorus use efficiency (PUE) and potassium use efficiency (KUE) under integrated nutrient management treatments indicated more efficient utilization and recovery of applied nutrients by the crop. Nutrient use efficiency is an important indicator of crop response because it reflects the capacity of plants to absorb available nutrients and convert them into economic yield and biomass production. Among soil amendments, combined application of 2% canal silt + compost @ 30 t ha⁻¹ (A₃) recorded maximum NUE, PUE and KUE compared to other treatments. The improvement in nutrient use efficiency under integrated amendment application may be attributed to better synchronization between nutrient release and crop demand. Compost acts as a reservoir of nutrients thereby reducing nutrient losses through leaching and volatilization (Agegnehu *et al.*, 2017). Compost acts as a slow-release nutrient source and improves soil organic matter content, while canal silt enhances soil physical condition and enhanced moisture retention and nutrient storage in the root zone improve nutrient recovery by plants and reduce fertilizer losses (Kumar *et al.*, 2018). These changes improve nutrient availability throughout crop growth period and reduce nutrient losses through leaching, runoff and fixation. Similar findings were reported by Paramesh *et al.* (2023) who observed that integrated nutrient management enhanced nutrient recovery and improved nutrient use efficiency through improvement in soil biological activity and nutrient cycling. The higher nitrogen use efficiency observed under combined amendment treatment may be due to improved nitrogen retention and gradual mineralization of organic nitrogen sources which maintained continuous nitrogen supply during

Table 6. Effect of soil amendments and fertilizer levels on nutrient use efficiency (per cent) of onion seed crop

Treatments	NUE	PUE	KUE
Soil amendments			
A ₀ - Control	-	-	-
A ₁ - 2 % Canal silt	6.09	2.85	12.49
A ₂ - Compost @ 30 t ha ⁻¹	8.37	3.96	18.07
A ₃ - 2 % Canal silt + compost @ 30 t ha ⁻¹	14.09	7.20	34.59
Fertilizer levels			
F ₀ - 0 % RDF	-	-	-
F ₁ - 75 % RDF	4.89	2.70	16.35
F ₂ - 100 % RDF	6.33	3.95	21.50
F ₃ - 125 % RDF	6.74	3.97	22.33

crop growth. Enhanced microbial activity and increased root proliferation under organic amendments further improve nutrient absorption efficiency and nutrient translocation within the plant system. Similar results were reported by Zhang *et al.*, (2022) who documented increased nitrogen recovery efficiency and better nutrient utilization under integrated use of organic and inorganic nutrient sources. Improvement in phosphorus use efficiency under Af may be explained by increased phosphorus solubilization and reduced phosphorus fixation under organic matter enriched conditions. Organic compounds released during decomposition lower phosphorus immobilization and increase nutrient mobility in the rhizosphere, resulting in greater phosphorus acquisition by plant roots. Similar observations were reported by Bindraban *et al.*, (2023) who concluded that integrated nutrient management improved phosphorus availability and enhanced phosphorus utilization efficiency in crop production systems.

Potassium use efficiency was comparatively higher than NUE and PUE under all amendment treatments. The increase in KUE may be associated with improved cation exchange capacity and greater availability of exchangeable potassium under compost and canal silt application. Improved soil moisture conditions and better root development may also have contributed to efficient potassium uptake and utilization. Similar findings were reported by Selvaprabu and Sundaram (2024) who observed significant improvement in potassium use efficiency under integrated nutrient management practices.

Effect of Fertilizer Levels

With respect to fertilizer levels, nutrient use efficiency increased with increasing fertilizer dose and maximum values were observed under 125% RDF (Ff). This treatment recorded 6.74% NUE, 3.97% PUE and 22.33% KUE, which showed an increase of 37.83, 47.04 and 36.57 per cent, respectively, over 75% RDF (F•). However, improvement between 100% RDF (F,) and 125% RDF (Ff) was comparatively lower, indicating stabilization of nutrient use efficiency at higher fertilizer levels. Treatment 100% RDF (F,) recorded 6.33% NUE, 3.95% PUE and 21.50% KUE, followed by 75% RDF (F•) with values of 4.89, 2.70 and 16.35 per cent, respectively. With respect to fertilizer levels, nutrient use efficiency increased

progressively with increasing fertilizer dose and reached maximum under 125% RDF (Ff). The improvement in nutrient use efficiency at higher fertilizer levels may be due to adequate nutrient availability that supported better crop establishment, enhanced root growth and increased physiological efficiency of nutrient absorption. Higher fertilizer availability improves photosynthetic activity and promotes efficient movement of nutrients towards developing reproductive organs. Similar findings were reported by Rathore *et al.*, (2022) and Vairavan *et al.*, (2023) who reported improved nutrient recovery and nutrient use efficiency in onion under balanced fertilizer application. However, the relatively smaller increase in nutrient use efficiency from 100% RDF to 125% RDF compared with lower fertilizer levels suggests that nutrient utilization efficiency tends to stabilize beyond optimum nutrient supply. This may occur because nutrient uptake does not always increase proportionally with nutrient application and a part of applied nutrients may remain unavailable to plants. Comparable observations were reported by Kumar *et al.*, (2024) in integrated nutrient management studies where nutrient efficiency showed diminishing response at higher fertilizer doses.

CONCLUSION

The present study demonstrated that integrated application of compost and canal silt significantly improved nutrient concentration, nutrient uptake, and nutrient use efficiency of onion seed crop grown under hyper-arid sandy soil conditions. Among the soil amendment treatments, the combined application of compost @ 30 t ha⁻¹ and canal silt @ 2% consistently recorded the highest concentrations and uptake of macro- (N, P, and K) and micronutrients (Fe, Zn, Mn, and Cu) in both seed and dry matter. The improvement was attributed to enhanced nutrient availability, improved soil moisture retention, increased nutrient-holding capacity, and greater biological activity in the rhizosphere. Nutrient use efficiencies (NUE, PUE, and KUE) were also markedly enhanced under integrated amendment treatments, indicating more efficient utilization of applied nutrients. The findings suggest that combining compost with canal silt and balanced fertilization represents an effective and sustainable nutrient management strategy for improving nutrient acquisition and fertilizer use efficiency in onion seed production under arid sandy

soil environments. Further studies may be undertaken to evaluate the long-term effects of these amendments on soil fertility and crop productivity under different agro-climatic conditions.

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