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NITROGEN SUBSTITUTION THROUGH SEWAGE SLUDGE: IMPACT ON PRODUCTIVITY, QUALITY, AGRO-PHYSIOLOGICAL AND AGRO-METEOROLOGICAL PARAMETERS OF FODDER SORGHUM UNDER CANAL AND TUBE WELL IRRIGATION

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ABSTRACT

A field experiment was conducted at Research Farm, Department of Agronomy, CCS Haryana Agricultural University, Hisar, Haryana, India during *kharif* 2024 to study effect of nitrogen substitution through sewage sludge on productivity, quality, agro-physiological and agro-meteorological parameters of fodder sorghum under canal and tube well irrigation. The experiment was laid out in split plot design with varieties (HJ 541 and HJ 1514) and irrigation (canal and tube well irrigation) assisted as main plot treatments and four nitrogen management levels viz. 100% RDN through urea, 75% RDN through urea + 25% through sewage sludge, 50% RDN through urea + 50% through sewage sludge, 25% RDN through urea + 75% through sewage sludge in sub plots with three replications. Significantly higher productivity, quality, agro-physiological and agro-meteorological parameters were recorded with variety HJ1514 over HJ541. Similarly, significantly higher value of productivity, quality, agro-physiological and agro-meteorological parameters were observed under canal water irrigation over tubewell water irrigation. Among nitrogen management, significantly higher productivity, quality, agro-physiological and agro-meteorological parameters were recorded under the treatment where 100% RDN was applied through urea as compared to integrated application. Application of 25% RDN through urea + 75% through sewage sludge was resulted in comparatively higher accumulation of heavy metals (Pb, Cd, Ni, and Cu) in soil though the values remained in permissible limits.

Key words : Fodder sorghum, Growth, Heavy metals, Irrigation, Sewage sludge.

Introduction

Sorghum (*Sorghum bicolor*) referred as camel crop, jowar, Chari and durra is a key forage crop widely cultivated in tropical and subtropical regions, valued for its adaptability to adverse climatic conditions, rapid growth and high biomass yield (Kumar *et al.*, 2025). Productivity levels of sorghum differ considerably across different states and seasons. This disparity highlights the influence of various factors, including soil health, irrigation and farming techniques on crop yields. Application of fertilizer

is crucial for increasing agricultural productivity, boosting yield by increasing nutrient availability and raising soil resilience to climate change. The continued use of imbalanced fertilizers results in soil acidification and nutrient depletion, which is a severe danger to environmental quality. The sorghum crop exhausts more nutrients than other forage crops and being cereal crop, requires higher amount of nutrients for higher productivity. The adverse effect of chemical fertilizers on soil health and prohibitive cost of chemical fertilizers and poor

purchasing power of small and marginal farmers restrict the use of this vital input. Therefore, it is time to develop a strategy for integrated use of organic manures particularly use of sewage sludge in conjunction with chemical fertilizer to boost crop production (Patel *et al.*, 2024). Effective nitrogen management not only impacts crop yield but also augments its overall quality. In this context, considering the increasing need for sustainable nutrient management and efficient utilization of organic wastes such as sewage sludge, the present investigation was undertaken to evaluate the effect of substitution of nitrogen through sewage sludge under canal and tube well irrigation on productivity, quality, agro-physiological and meteorological parameters of fodder sorghum varieties.

Materials and Methods

Field experiment was conducted at Agronomy Research Farm of the CCS Haryana Agricultural University, Hisar, Haryana, India (29° 10' North latitude and 75° 46' East longitude at an elevation of 215.2 m above mean sea level). The soil of the experimental site was sandy loam in texture, having pH (8.0), organic carbon (0.40%), available nitrogen (139.8 kg ha⁻¹), available phosphorus (27 kg ha⁻¹), and available potassium (257.6 kg ha⁻¹), Pb (0.56 mg/kg), Cd (0.029 mg/kg), Ni (0.011 mg/kg) Cu (0.51 mg/kg) and Cr (ND). The climate is semiarid and subtropical, hot and dry summer. Rainfall being monsoonal in nature; 70-80% is received during the months of July, August and September, which coincides with the active growing season of sorghum. The mean weekly maximum and minimum temperature ranged from 32.7 to 42.5°C and 23.8 to 29.0°C, respectively during the crop growing period. The weekly mean relative humidity ranged from 43 to 94% in morning hours and 17 to 83% in evening hours. The experiment was laid out in split plot design consisting of varieties (HJ 541 and HJ 1514) and irrigation (canal and tube well irrigation) as main plot treatments and four nitrogen management levels *viz.* 100% RDN through urea, 75% RDN through urea + 25% through sewage sludge, 50% RDN through urea + 50% through sewage sludge, 25% RDN through urea + 75% through sewage sludge in sub plots with three replications. The pre-sowing irrigation was applied through canal water, and the seed bed was prepared at field capacity. Sorghum variety HJ1541 and HJ 541 were sown by drilling in rows using 40 kg seed ha⁻¹ during *Kharif* season of 2024. The sewage sludge was applied 15 days before sowing as per treatment. The composition of sewage sludge was N (1.37%), P (0.61%), K (0.80%), Cd (ND), Cr (ND), Pb (1.82 mg/kg), Cu (0.25 mg/kg) and Ni (1.24 mg/kg). The electrical

conductivity of canal and tubewell water was 0.35 and 2.95 ds/m, respectively. Nutrients were applied as per treatment using urea (46% N) and single super phosphate (16% P₂O₅) as the sources of nitrogen and phosphorus, respectively as per recommendation of CCSHAU, Hisar. During the growing season, two irrigations at 15 and 35 days after sowing (DAS) were applied through border strip flood irrigation method as per treatment. Growth parameters, crude protein, nutrient uptake (N, P and K), agro-physiological and meteorological parameters in plants were calculated as per standard described procedure. For assessment of heavy metals, DTPA-extractable lead (Pb), cadmium (Cd), nickel (Ni), copper (Cu) and chromium (Cr) contents in plants were analyzed by standard DTPA extraction procedure and expressed in mg kg⁻¹. The recorded data were analyzed using the online statistical analysis package of OPSTAT for split-plot design (Sheoran *et al.*, 1998).

Results and Discussion

Growth and growth indices

Different treatments have significant effect on growth and growth indices. Between varieties significantly taller plants, higher dry matter accumulation and growth indices *viz.* CGR (Crop growth rate) were recorded with variety HJ1514 over HJ541. It is new improved variety developed through selective breeding for higher biomass and adaptability and recorded higher green fodder yield over national check and variety HJ 541. This varietal superiority can be attributed by their genetic traits, efficient nutrient absorption, plant height, growth rate and dry matter production. These interconnected factors contribute to increased growth-related traits (Kumari *et al.*, 2023). Similarly, significantly taller plants, higher dry matter accumulation and crop growth rate were observed under canal water irrigation over tubewell water irrigation. This improvement may be attributed to better water quality and soil moisture availability under canal irrigation, which enhanced nutrient uptake, photosynthetic activity and biomass production. Similar findings have been reported by Thakur and Patel (2025). Among nitrogen management, significantly taller plants, higher dry matter accumulation and growth indices *viz.*; CGR (Crop growth rate) were recorded with the application of 100% RDN through urea, owing to the immediate availability of nitrogen, which promoted chlorophyll synthesis, leaf development and dry matter production. Progressive substitution of urea nitrogen with sewage sludge resulted in reduced growth, probably due to the slower mineralization and delayed release of nitrogen from sewage sludge, which could not fully meet

Table 1 : Growth, growth indices, fodder yield, crude protein and nutrient uptake of sorghum as influenced by nutrient and irrigation sources

Treatments	Plant height (cm)	Dry matter accumulation (g/m ²)	Crop growth rate (g m ⁻² day ⁻¹)				Fodder yield (q/ha)	Crude protein (%)	Nutrient uptake (kg ha ⁻¹)		
	90 DAS	90 DAS	0-20 DAS	20-40 DAS	40-60 DAS	60-90 DAS			N	P	K
Varieties											
HJ 541	376.1	139.7	6.22	96.7	38.1	278.5	465.4	7.36	127.5	17.5	95.2
HJ 1514	386.1	170.0	6.66	66.3	47.5	373.0	479.7	7.47	135.5	21.8	126.2
CD at 5%	4.8	3.4	0.21	1.8	2.4	9.8	4.2	0.08	2.4	0.3	2.50
Irrigation Source											
Tube well	367.1	133.3	6.32	75.6	30.7	256.1	447.6	7.31	121.4	17.5	104.7
Canal	395.1	176.5	6.56	87.0	54.9	395.4	497.5	7.52	141.5	21.8	116.7
CD at 5%	4.8	3.47	0.21	1.8	2.4	9.8	4.2	0.08	2.4	0.3	2.5
Nitrogen management											
100% RDN through urea	391.0	166.3	7.94	86.48	50.2	363.2	511.1	8.70	145.6	24.5	169.0
75% RDN through urea + 25% through Sewage sludge	384.6	164.1	6.78	81.30	46.2	353.7	485.2	7.68	136.5	22.1	158.6
50% RDN through urea + 50% through Sewage sludge	378.5	145.6	5.98	80.00	37.9	296.5	420.2	6.95	124.2	17.2	134.1
25% RDN through urea +75 % through Sewage sludge	370.2	143.5	5.06	78.38	37.0	289.6	356.7	6.31	119.5	16.0	131.2
CD at 5%	6.9	4.0	0.22	1.88	2.7	10.2	8.2	0.16	3.7	0.9	4.0

the crop's nitrogen demand during rapid vegetative growth. Similar results were reported by Patel *et al.* (2024). Treatment where 50% RDN through urea and 50% RDN through sewage sludge was applied did not differ significantly from the treatment 25% RDN through urea + 75% through sewage sludge in respect of growth indices and dry matter accumulation except in respect of CGR at 0-20 DAS. However, these treatments differ significantly in respect of plant height (Table 1). Prajapati *et al.* (2025) also reported significantly greater plant height and dry matter accumulation under higher nitrogen availability in sorghum.

Fodder yield, crude protein, nutrient and heavy metal uptake

Between varieties, significantly higher fodder yield, nutrient uptake (N, P and K) and Crude protein value were recorded with the variety HJ1514 as compared to HJ54 which may be attributed to its superior genetic potential for biomass production, efficient nutrient utilization and greater dry matter accumulation. Similar findings were reported by Kumari *et al.* (2023), who

observed higher forage productivity and quality in HJ 1514 over HJ 541. Higher value of heavy metal content was found in variety HJ1514 over HJ 541; however, it was within the permissible limit. Similarly, significantly higher fodder yield, nutrient uptake (N, P and K) and crude protein value were found under canal irrigation as compared to tubewell irrigation. This improvement may be attributed to better water quality and favourable soil moisture conditions, which enhanced nutrient availability, photosynthetic activity and biomass production. Similar results were reported by Vennila and Ananthi (2024) in fodder sorghum. Higher value of heavy metal content was found under tubewell irrigation as compared to canal irrigation. Among nitrogen management, significantly higher fodder yield, nutrient uptake (N, P and K) and crude protein value were recorded under the treatment where 100 per cent RDN was applied through urea as compared to integration of lower levels of nitrogen with sewage sludge. The readily available nitrogen from urea synchronized with crop demand, thereby promoting protein synthesis, dry matter production and nutrient

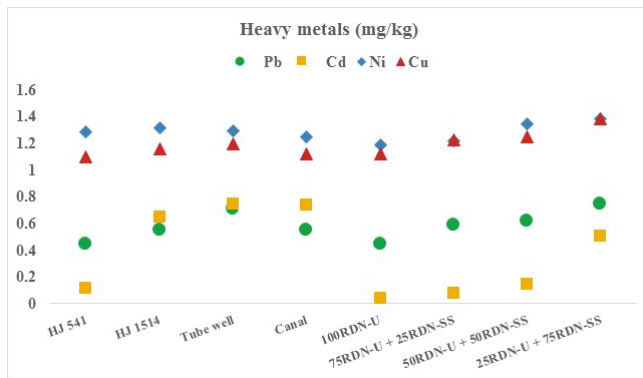


Fig. 1 : Effect of varieties, irrigation source and nitrogen management on plant heavy metal content (mgkg^{-1}).
 *100RDN-U:-100% RDN through urea; 75RDN-U + 50RDN-SS:- 75% RDN through urea + 25% through sewage sludge; 50RDN-U + 50RDN-SS:- 50% RDN through urea + 50% through sewage sludge, 25RDN-U + 75RDN-SS:- 25% RDN through urea + 75% through sewage sludge

metal content was found under with the treatment where 25% RDN was applied through urea + 75% RDN was applied through sewage sludge as compared to other treatments. Lowest value of heavy metal content was recorded with 100% RDN treatment (Table 2 and Fig. 1). Similar, observations were reported by Arlo *et al.* (2022), who observed that sewage sludge application increased nutrient uptake and biomass production in sorghum, while heavy metal concentrations in plant tissues remained within the permissible limits for agricultural use.

Physiological and agrometeorological parameters

Different varieties did not differ in respect of chlorophyll content except at 40 DAS. At 40 DAS significantly higher value of chlorophyll content was recorded with HJ 1514 over HJ541. Similarly, significantly higher relative water content was maintained by variety HJ1514 as compared to HJ541 at different days after sowing. Significantly higher agrometeorological indices

Table 2 : Physiological and agrometeorological parameters of fodder sorghum as influenced by nutrient and irrigation sources.

Treatments	Chlorophyll content				Relative water content (%)				Agro-metrological indices		
	20 DAS	40 DAS	60 DAS	90 DAS	20 Days	40 days	60 days	90 DAS	TUE ($\text{kg ha}^{-1} \text{ } ^\circ\text{C day}^{-1}$)	PTUE ($\text{kg ha}^{-1} \text{ } ^\circ\text{C day hr}^{-1}$)	HTUE ($\text{kg ha}^{-1} \text{ } ^\circ\text{C day hr}^{-1}$)
Varieties											
HJ 541	41.8	35.7	36.1	38.1	72.2	73.6	78.9	77.5	22.9	1.76	4.03
HJ 1514	37.9	38.6	37.4	41.6	73.7	77.5	81.4	80.9	23.6	1.81	4.15
CD at 5%	NS	0.7	NS	NS	0.6	1.1	0.9	1.1	0.2	0.01	0.03
Irrigation source											
Tube well	41.3	36.3	34.2	38.3	71.2	75.8	78.9	77.8	22.0	1.69	3.87
Canal	38.4	38.0	39.3	41.4	72.5	77.9	81.4	80.5	24.5	1.88	4.30
CD at 5%	NS	0.7	1.5	NS	0.92	1.45	1.1	1.2	0.2	0.01	0.03
Nitrogen management											
100% RDN through urea	41.0	41.8	39.4	42.1	72.1	75.6	80.2	80.1	29.7	2.27	5.21
75% RDN through urea + 25% through Sewage sludge	40.4	36.4	36.2	40.4	72.2	76.4	82.6	80.9	25.2	1.93	4.42
50% RDN through urea + 50% through Sewage sludge	39.8	35.5	36.0	38.6	75.5	78.5	85.0	84.1	20.7	1.58	3.63
25% RDN through urea + 75% through Sewage sludge	38.4	34.9	35.4	38.2	69.3	71.2	79.4	78.5	17.5	1.34	3.08
CD at 5%	NS	0.7	2.4	NS	0.7	1.19	1.28	1.26	0.4	0.03	0.07

absorption. Similar findings were reported by Ismaeil *et al.* (2024), Patel *et al.* (2024) and Kumar *et al.* (2026), who observed significant improvements in forage yield, crude protein content and nutrient uptake under adequate nitrogen fertilization. However, the higher value of heavy

viz. thermal use efficiency, photothermal use efficiency and helio-thermal use efficiency were observed with variety HJ1514 over HJ541. The superior physiological performance of HJ 1514 may be attributed to its better genetic potential for maintaining plant water status, higher

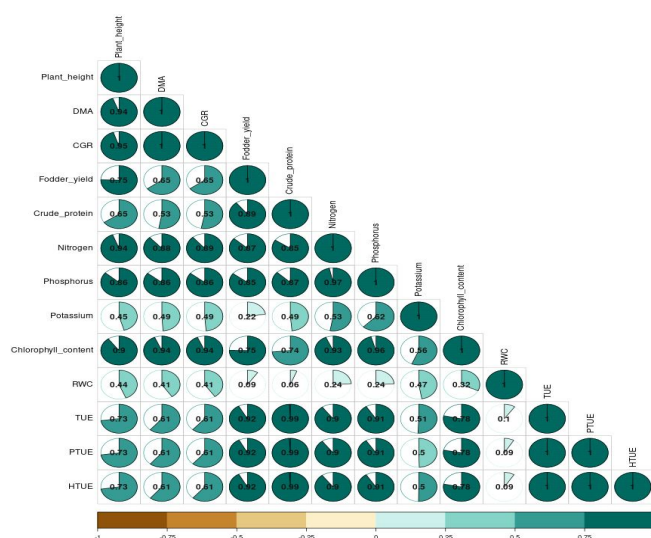


Fig. 2 : Pearson's correlation matrix depicting relationships among plant growth, fodder yield, quality, agro-physiological and agro-meteorological parameters.

photosynthetic efficiency and more efficient utilization of thermal resources, resulting in greater biomass production. Similar findings were reported by Kumari *et al.* (2023). Between irrigation sources, significantly higher value of chlorophyll content, relative water content and agrometeorological indices were recorded under canal water application over tube well irrigation except chlorophyll content at 20 and 90 DAS. The higher values under canal irrigation may be attributed to better quality irrigation water, which maintained favorable soil moisture conditions and enhanced nutrient uptake, thereby improving chlorophyll synthesis, leaf water status and utilization of accumulated heat units for biomass

production. Similar findings were reported by Danquah *et al.* (2025). Among nitrogen management, significantly higher value of chlorophyll content and agrometeorological indices were observed under the treatment where 100 per cent RDN was applied through urea as compared to integration of lower levels of nitrogen with sewage sludge except at 40 and 90 DAS in respect of chlorophyll content, owing to the readily available nitrogen, which promoted chlorophyll synthesis, photosynthetic activity and efficient conversion of thermal energy into biomass. However, significantly higher value of relative water content was found with the treatment where 50% RDN was applied through urea + 50% RDN was applied through sewage sludge as compared to other treatments. Lowest value of physiological and agrometeorological parameters were observed where 25% RDN was applied through urea + 75% RDN was applied through sewage sludge (Table 2). These results indicate the beneficial role of sewage sludge in improving soil organic matter, water-holding capacity and moisture availability to plants. Increasing substitution of mineral nitrogen with sewage sludge beyond 50 percent level reduced chlorophyll content and agrometeorological indices, possibly because of slower nitrogen mineralization and reduced nitrogen availability during active crop growth. Kumar *et al.* (2026) also reported similar findings.

Correlation analysis

Correlation analysis ($p=0.05$) showed strong positive associations among growth, agro-physiological, nutrient, and productivity traits (Fig. 2). Plant height was highly correlated with CGR ($r = 0.95$), nitrogen ($r = 0.94$),

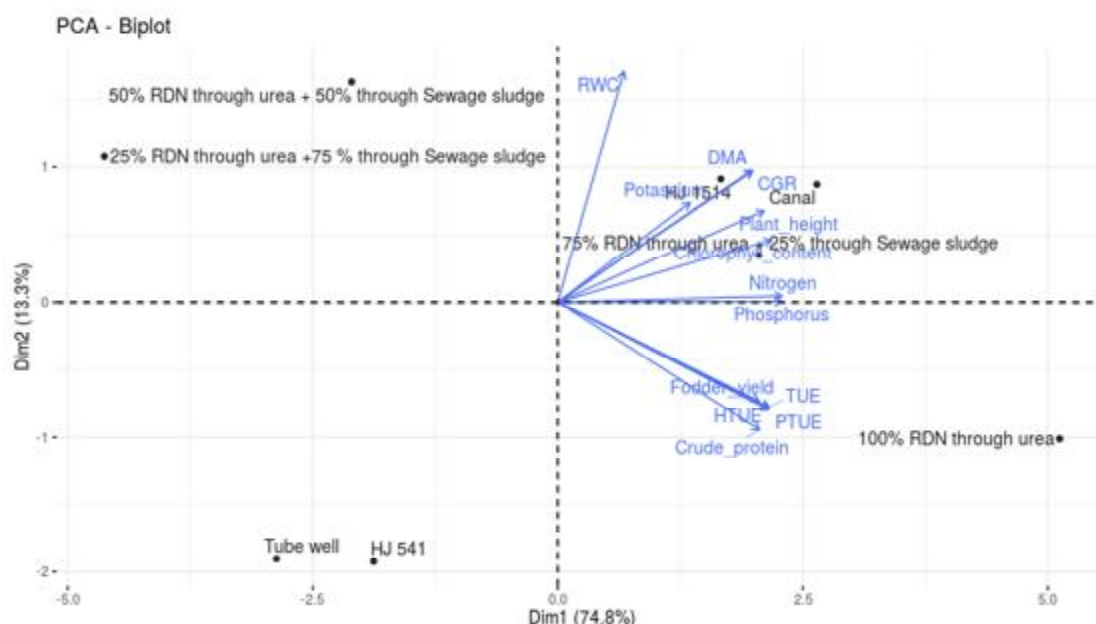


Fig. 3 : Principal component analysis (PCA) biplot showing the relationships among plant growth, fodder yield, quality, agro-physiological and agro-meteorological parameters.

chlorophyll content ($r = 0.90$), and fodder yield ($r = 0.75$). Fodder yield revealed strong positive relationships with crude protein ($r = 0.89$) and agro-meteorological indices (TUE, PTUE and HTUE; $r = 0.92$, respectively). Nitrogen and phosphorus were strongly associated and positively correlated with chlorophyll content ($r = 0.93$ - 0.96) and agro-meteorological indices ($r = 0.90$ - 0.91). In contrast, RWC exhibited relatively weak correlations with most traits ($r = 0.06$ - 0.47), indicating a limited contribution to yield variation.

Principal component analysis (PCA)

The PCA biplot distinguished nutrient management treatments based on growth, physiological and productivity responses (Fig. 3). Most agronomic traits, including plant height, dry matter accumulation, CGR, chlorophyll content, nitrogen, phosphorus, crude protein, fodder yield, and agro-meteorological indices, clustered together with positive PC1 loadings, indicating strong interrelationships. The 100% RDN through urea treatment aligned closely with these trait vectors, reflecting superior crop performance, whereas tube well irrigation and HJ-541 were positioned opposite, indicating comparatively lower performance. Sewage sludge-based treatments occupied intermediate positions, demonstrating moderate improvements in crop growth and productivity.

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