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Effect of Different Levels and Sources of Nitrogen on Nutrient Uptake and Yield of Spinach in Sodic Soil

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Abstract

The research aimed to study effect of different levels and sources of nitrogen on nutrient uptake, and yield of spinach grown on sodic soil. The field experiment was carried out at research farm of Department of Soil Science, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra state, India, during summer season, 2024-25. The experiment was laid out in randomized block design with eleven treatments and three replications. The treatments were consisting of varying levels and doses of nitrogen *viz*; 40 kg N ha^{-1}, 80 kg N ha^{-1} and 100 kg N ha^{-1} through urea and ammonium sulphate, 40 kg N ha^{-1} and 80 kg N ha^{-1} through urea along with 0.2% two foliar spray of nano urea and 40 kg N ha^{-1} and 80 kg N ha^{-1} through ammonium sulphate along with 0.2% two foliar spray of nano urea. The results revealed that the application of 80 kg N ha^{-1} through Ammonium sulphate along with 0.2% foliar spray of nano urea recorded highest yield and N, P, K uptake of spinach. However, the application of 80 kg N ha^{-1} through Ammonium sulphate along with 0.2% foliar spray recorded higher net monetary returns (Rs. 1,08,676 ha^{-1}) and B:C ratio (2.13). Hence application of 80 kg N ha^{-1} through ammonium sulphate along with 0.2% two foliar sprays of nano urea at 35 and 50 days after sowing is recommended in spinach for achieving higher net monetary returns in sodic soils.

Key words : Nutrient availability, nitrogen levels and sources, urea, ammonium sulphate, nano urea, sodic soil, uptake, spinach, yield.

Spinach (*Spinacia oleracea*) is an annual leafy green vegetable plant native to central and western Asia. It is of the order *caryophyllales*, family amaranthaceae (Swarup, 2014). Spinach leaves are valued for their medicinal properties and it is used in inflammation, paralysis, headache and remedy for disease of spleen and liver, it also acts as mild lacerative besides other medicinal values, it supplies most of the nutrients in which other foods are deficient. It is used as a fresh vegetable for cooking and also as a salad form. It contains 86.49% of moisture, 0.7 g of fibre, 3.4 g of protein, 2.2 g of minerals, 6.5 g of carbohydrates, 0.5 g of riboflavin, 380 mg of calcium, 16.2 mg of iron, 0.26 g of thiamine, 9770 IU of vitamin A, 70 mg of vitamin C and 100 mg of edible portion (Swarup, 2014). Salinity represents one of the most pressing threats to agricultural productivity on a global scale. Approximately 10% of the Earth's terrestrial area and nearly half of all irrigated agricultural land are facing negative impacts by saline soils (Ruan *et al*., 2010). When the nitrogenous fertilizers are added to soil, they are undergoing ammonical fixation in soil and rendered unavailable to the plant. In addition to these the nitrogen from fertilizers is also lost from soil-water system through denitrification, volatilization and leaching. It is observed that utilization of urea applied to soil is not as effective as when the urea is supplied to plants through foliage by soil application. When nano-urea is applied on surface of leaves there will not be any fixation losses thus, increases NUE. The application of nano-urea during key developmental stages of crops significantly enhances nitrogen utilization, resulting in improved yield and produce quality compared to traditional urea fertilizers. Nano urea (in liquid form) comprises nanoscale nitrogen particles, which offer a surface area almost 10,000 times greater than that of conventional granular urea. Upon foliar application, the nano-formulation is readily absorbed through the leaf surface due to its ultrafine particle size and favourable surface characteristics, ensuring more efficient nitrogen delivery to plant tissues (Kulal, 2023). In view to above, present study is undertaken to study effect of different levels and sources of nitrogen on soil properties, nutrient uptake, and yield of spinach grown in sodic soil.

Materials and Methods

Experimental site : The experiment was conducted at Post Graduate Institute Farm, MPKV, Rahuri. Geographically, the experimental fixed site lies at 19°34' North latitude and 74°64' East longitude and at an altitude of 511 m above mean sea level. The tract is lying on eastern site of Western ghat and falls under rain shadow area.

Collection and analysis of plant samples : The leaf samples were collected separately from each plot during spinach harvest. The samples were oven dried at 60°C and were analyzed for total N by micro kjeldahl method in H_2SO_4:H_2O_2 (1:1) digestion (Parkinson and Allen 1975), total P by vanadomolybdate yellow colour method in nitric acid H_2SO_4:$HClO_4$: HNO_3 (1:4:10) digestion (Jackson, 1973), total K on flame photometer in H_2SO_4:$HClO_4$: HNO_3 (1:4:10) digestion (Chapman and Pratt, 1961).

Experimental Details : The field experiment was laid out in RBD with eleven treatments and three replications. The treatments were absolute control (T_1), 40 kg N ha^{-1} through urea (T_2), 80 kg N ha^{-1} through urea (T_3), 100 kg N ha^{-1} through urea (T_4), 40 kg N ha^{-1} through

Uptake of nutrient (kg ha^{-1}) = Total dry matter (kg ha^{-1}) x Concentration of nutrient (%) / 100

Uptake of micronutrient (g ha^{-1}) = Total dry matter (kg ha^{-1}) x Concentration of nutrient (mg kg^{-1}) / 1000

Nitrogen use efficiency (%) = (N accumulation by leaves in the fertilized plot (Nf) - N accumulation by the leaves in the unfertilized plot (Nu) x 100) / Quantity of N applied (Nq)

Result and discussion

The research was conducted at Post Graduate Institute Research Farm (Inceptisol), MPKV, Rahuri during summer, 2024-25.

Effect of different levels and sources of nitrogen on nutrient uptake of spinach

Uptake of nitrogen : The results pertaining to the effect of different levels and sources of nitrogen on of nitrogen on the total nitrogen uptake ammonium sulphate (T_5), 80 kg N ha^{-1} through ammonium through urea sulphate (T_6), 100 kg N ha^{-1} through ammonium sulphate (T_7), 40 kg N ha^{-1} through urea + 0.2% foliar spray of nano urea (T_8), 80 kg N ha^{-1} through urea + 0.2% foliar spray of nano urea (T_9), 40 kg N ha^{-1} through ammonium sulphate + 0.2% foliar spray of nano urea (T_{10}), 80 kg N ha^{-1} through ammonium sulphate + 0.2% foliar spray of nano urea (T_{11}). The statistical analysis was done by procedure suggested by Panse and Sukhatme (1989) was found to be significant. Among total depicted in Table 1. The effect of different levels and sources different treatments, the maximum total nitrogen uptake (69.80 kg ha^{-1}) was recorded in treatment T_{11} - 80 kg N ha^{-1} as ammonium sulphate + foliar spray of 0.2% nano urea and it was at par with the treatments T_9 - 80 kg N ha^{-1} as urea + foliar spray of 0.2% nano urea (54.60 kg ha^{-1} and T_6 - 80 kg N ha^{-1} as ammonium sulphate (42.88 kg ha^{-1}). The minimum total nitrogen uptake (49.55 kg ha^{-1}) was recorded in treatment absolute control - T_1. Increasing nitrogen levels significantly improved uptake, indicating an enhanced nitrogen demand and capacity for utilization during active vegetative and reproductive phases. The treatments receiving ammonium sulphate consistently showed higher nitrogen uptake compared to those receiving urea alone. This is because ammonium sulphate not only supplies nitrogen in the ammonium (NH_4^+) form, which is more stable and less prone to leaching but also provided sulphur, an essential secondary nutrient that played a constituent role in protein synthesis, nitrogen assimilation, and enzyme activation. Furthermore, the foliar spray of 0.2% nano urea as a foliar spray significantly boosted nitrogen uptake across treatments. Nano urea, due to its ultrafine particle size and high surface area-to-volume ratio, easily absorbed by the plant leaves and translocated efficiently within the plant system. It led to a more targeted and sustained supply of nitrogen during critical stages of crop growth, thereby reducing nitrogen losses through leaching, volatilization, and denitrification. Moreover, the foliar application ensured that nitrogen directly available for immediate use, especially when root uptake is limited due to environmental or soil constraints. The results are in accordance with Khalaj *et al.*, (2012); Kafle and Sharma (2015) and Kamble and Todmal (2020).

Uptake of phosphorous : The results obtained from the effect of different levels and sources of nitrogen on total phosphorus uptake depicted in Table 1. The effect of different levels and sources of nitrogen on the total phosphorus uptake was found significant. Among different treatments, the maximum total phosphorus uptake (15.41 kg ha^{-1}) was recorded in treatment T_{11} - 80 kg N ha^{-1} as ammonium sulphate + foliar spray of 0.2% nano urea and it was statistically at par with the treatments T_9 - 80 kg N ha^{-1} as urea + 0.2% nano urea (13.88 kg ha^{-1} and T_{10} - 40 kg N ha^{-1} as ammonium sulphate + foliar spray of 0.2% nano urea (12 kg ha^{-1}). The minimum total phosphorus uptake (3 kg ha^{-1}) was recorded in absolute control - T_1. The rise in phosphorus uptake across the treatments might be due to synergistic effect of nitrogen fertilization, sulphur supplementation and nano urea application, all of which enhanced phosphorus availability and plant uptake. Nitrogen stimulates root growth and enzyme activity, improved the plant's ability to explore soil phosphorus, while ammonium

Table 1. Effect of different levels and sources of nitrogen on nutrient uptake and NUE of spinach

Treatment	**Nutrient uptake (kg ha^{-1})**			**NUE**
	N	**P**	**K**	
T_1 - Absolute control	10.21^{f}	3.00^{g}	14.89^{f}	-
T_2 - 40 kg N ha^{-1} urea	17.29^{ef}	5.30^{f}	22.87^{ef}	17.70
T_3 - 80 kg N ha^{-1} urea	31.16^{cde}	6.49^{def}	32.38^{de}	26.19
T_4 - 100 kg N ha^{-1} urea	37.52^{bcde}	7.21^{cde}	35.97^{cde}	27.31
T_5 - 40 kg N ha^{-1} ammonium sulphate	25.51^{de}	5.72^{ef}	24.09^{ef}	38.25
T_6 - 80 kg N ha^{-1} ammonium sulphate	42.88^{abcd}	7.61^{cde}	38.40^{cde}	40.84
T_7 - 100 kg N ha^{-1} ammonium sulphate	45.89^{abc}	8.16^{bcd}	40.55^{bcde}	35.68
T_8 - 40 kg N ha-1 urea + foliar spray 0.2% nano urea	37.30^{bcde}	11.17^{abc}	47.72^{abcd}	20.52
T_9 - 80 kg N ha^{-1} urea + + foliar spray 0.2% nano urea	54.60^{ab}	13.88^{ab}	58.41^{ab}	25.81
T_{10} - 40 kg N ha^{-1} ammonium sulphate + + foliar spray 0.2% nano urea	44.81^{abc}	12.00^{abc}	52.05^{abc}	26.21
T_{11} - 80 kg N ha^{-1} ammonium sulphate + + foliar spray 0.2% nano urea	69.80^{a}	15.41^{a}	63.77^{a}	34.65
S. Em (±)	1.83	0.53	2.37	
C.D (5%)	5.40	1.57	6.99	

sulphate contributed to localized acidification of the rhizosphere, which increased phosphorus solubility, particularly in alkaline soils. The foliar application of nano urea, with its high efficiency and rapid absorption, further enhanced metabolic processes and nutrient demand, leading to greater phosphorus uptake. The similar findings were reported by Rathore and Manohar (1989); Polara *et al*., (2014) and Kamble and Todmal (2020).

Uptake of potassium : The results pertaining to the effect of different levels and sources of nitrogen on total potassium uptake depicted in Table 4.18. The effect of different levels and sources of nitrogen on the total potassium uptake was found to be significant. The significantly highest total potassium uptake (63.77 kg ha^{-1}) was recorded in treatment T_{11} - 80 kg N ha^{-1} as ammonium sulphate + foliar spray of 0.2% nano urea. It was at par with the treatments T_9 - 80 kg N ha^{-1} as urea + foliar spray of 0.2% nano urea (58.41 kg ha^{-1}), T_{10} - 40 kg N ha^{-1} as ammonium sulphate + 0.2% nano urea (52.05 kg ha^{-1}) and T_8 - 40 kg N ha^{-1} urea + foliar spray of 0.2% nano urea (47.72 kg ha^{-1}). The minimum total potassium uptake (14.89 kg ha^{-1}) was recorded in treatment absolute control - T_1. The increase in potassium uptake is closely linked to the enhanced nitrogen supply, source of nitrogen and use of nano urea which collectively improved overall plant growth and nutrient absorption efficiency. Higher nitrogen levels stimulate vigorous vegetative growth and root development, increased the plant's demand for and ability to absorb potassium. The treatments with ammonium sulphate showed greater potassium uptake than those with urea, likely due to ammonium sulphate improved root system activity and nutrient transport through better nitrogen-sulphur synergy. The inclusion of 0.2% nano urea significantly enhanced uptake by promoting photosynthetic efficiency, enzyme activation, and nutrient mobility, thereby improving potassium utilization. The improved metabolic activity and leaf area under nano urea application further increased potassium translocation to developing tissue. The results were corroborated with Malligwada (1994); Khalil (2014) and Kamble and Todmal (2020).

Table 2. Effect of different levels and sources of nitrogen on green matter and dry matter yield of spinach

Treatment	**Green matter yield (q ha^{-1})**				
	1^{st} cutting	**2^{nd} cutting**	**3^{rd} cutting**	**Total yield**	**Total dry matter yield**
T_1 - Absolute control	33.42^{e}	26.69^{f}	13.64^{e}	73.76^{f}	7.27^{f}
T_2 - 40 kg N ha^{-1} urea	42.17^{de}	36.99^{ef}	17.22^{de}	96.38^{ef}	9.21^{de}
T_3 - 80 kg N ha^{-1} urea	56.14^{abc}	49.66^{bc}	22.09^{bc}	127.90^{bc}	10.27^{bcd}
T_4 - 100 kg N ha^{-1} urea	57.50^{ab}c	54.55^{abc}	23.36^{abc}	135.41^{abc}	11.37^{abc}
T_5 - 40 kg N ha^{-1} ammonium sulphate	48.19^{cd}	42.42^{de}	18.94^{cd}	109.55^{de}	9.98^{cd}
T_6 - 80 kg N ha^{-1} ammonium sulphate	62.59^{ab}	59.97^{ab}	25.42^{ab}	147.98^{ab}	12.19^{ab}
T_7 - 100 kg N ha^{-1} ammonium sulphate	67.38^{a}	61.70^{a}	27.69^{a}	156.78^{a}	12.60^{a}
T_8 - 40 kg N ha^{-1} urea + foliar spray 0.2% nano urea	46.39^{cd}	40.69^{de}	18.08^{cd}	105.16^{de}	8.32^{ef}
T_9 - 80 kg N ha^{-1} urea + + foliar spray 0.2% nano urea	61.76^{ab}	54.63^{abc}	23.20^{abc}	139.58^{abc}	11.32^{bcd}
T_{10} - 40 kg N ha^{-1} ammonium sulphate ++ foliar spray 0.2% nano urea	53.01^{bc}	46.67^{cd}	19.89^{cd}	119.58^{cd}	8.97^{de}
T_{11} - 80 kg N ha^{-1} ammonium sulphate ++ foliar spray 0.2% nano urea	68.85^{a}	64.08^{a}	26.70^{a}	159.63^{a}	12.81^{a}
S. Em (±)	3.13	3.67	0.89	6.45	0.55
C.D (5%)	9.23	10.82	2.61	19.04	1.62

Nitrogen use efficiency : The results pertaining to the effect of different levels and sources of nitrogen on nitrogen use efficiency depicted in Table 1. The maximum nitrogen use efficiency (40.84%) was recorded in 80 kg N ha^{-1} ammonium sulphate and the minimum nitrogen use efficiency (17.70%) was recorded in T_2 - 40 kg N ha^{-1} urea. The observed trend might be due to moderate nitrogen levels especially when applied through ammonium-based sources or in combination with nano urea, often led to higher nitrogen use efficiency. The balanced nitrogen application that matches the plant's demand, minimized losses due to leaching, volatilization, or denitrification. The treatments with 100 kg ha^{-1} nitrogen tend to show reduced nitrogen use efficiency because of luxury consumption or loss of unutilized nitrogen, while very low nitrogen levels could not meet the plant's growth needs, resulting in inefficient uptake and utilization. The use of nano urea improves nitrogen use efficiency by supplying nitrogen directly to leaves, increased metabolic efficiency. The results were in accordance with the findings of Huang *et al*., (2015); Kamble and Todmal (2020) and Xiao-hong *et al*., (2021).

Effect of different levels and sources of nitrogen on yield of spinach

Green matter yield at each cutting : The results showed that as the levels of nitrogen increased from 40 kg N ha^{-1} to 100 kg N ha^{-1}. The green matter yield was also significantly increased for both urea and ammonium sulphate sources during all three cuttings showed that ammonium sulphate performed better than urea in enhancing yield. The results depicted in Table 2. The maximum green matter yield (68.85 and 64.08 q ha^{-1}) was recorded in treatment 80 kg N ha^{-1} ammonium sulphate + foliar spray of 0.2% nano urea - T_{11} during first and second cutting, respectively. It was statistically at par with treatment 100 kg N ha^{-1} ammonium sulphate - T_7 (67.38 and 61.70 q ha^{-1}), 80 kg N ha^{-1} ammonium sulphate - T_6 (62.59 and 59.97 q ha^{-1}) and 80 kg N ha^{-1} urea + foliar spray of 0.2% nano urea - T_9 (61.76 and 54.63 q ha^{-1}) during first and second cutting respectively. The lowest green matter yield (33.42 and 26.69 q ha^{-1}) was recorded in absolute control (T_1) at first and second cutting, respectively. In the third cutting, the maximum green matter yield (26.70 q ha^{-1}) was recorded

Table 3. Effect of different levels and sources of nitrogen on economics of spinach cultivation

Treatment	Economics (Rs. ha^{-1})			B:C ratio
	Cost of cultivation	Gross returns	Net returns	
T_1 - Absolute control	20832	73760^{e}	52928^{f}	2.54
T_2 - 40 kg N ha^{-1} urea	41410.22	96380^{de}	54969^{ef}	1.33
T_3 - 80 kg N ha^{-1} urea	41876.27	127900^{bc}	86023^{bc}	2.05
T_4 - 100 kg N ha^{-1} urea	42109.32	135410^{abc}	93300^{abc}	2.21
T_5 - 40 kg N ha^{-1} ammonium sulphate	44753.71	109550^{cd}	64796^{de}	1.45
T_6 - 80 kg N ha^{-1} ammonium sulphate	48563.31	147980^{ab}	99416^{ab}	2.05
T_7 - 100 kg N ha^{-1} ammonium sulphate	50467.91	156780^{a}	1063129^{a}	2.11
T_8 - 40 kg N ha^{-1} urea + foliar spray 0.2% nano urea	43800.22	105160^{cd}	61359^{de}	1.40
T_9 - 80 kg N ha^{-1} urea + + foliar spray 0.2% nano urea	44266.27	139580^{abc}	95313^{abc}	2.15
T_{10} - 40 kg N ha^{-1} ammonium sulphate + + foliar spray 0.2% nano urea	47143.71	119580^{cd}	72436^{cd}	1.54
T_{11} - 80 kg N ha^{-1} ammonium sulphate + + foliar spray 0.2% nano urea	50953.31	159630^{a}	108676^{a}	2.13
S. Em (±)			6453.93	
C.D (5%)			19039.07	

in treatment 100 kg N ha^{-1} ammonium sulphate - T_7 and it was statistically at par with the treatment 80 kg N ha^{-1} ammonium sulphate + foliar spray of 0.2% nano urea - T_{11} (27.69 q ha^{-1}) and 80 kg N ha^{-1} ammonium sulphate - T_6 (25.42 q ha^{-1}) which were at par. The lowest green matter yield (13.64 q ha^{-1}) was recorded in absolute control (T_1). The treatments combining higher doses of ammonium sulphate with nano urea i.e. 80 kg N ha^{-1} ammonium sulphate + foliar spray of 0.2% - T_{11} nano urea resulted in highest yield might be attributed to improved photosynthesis and early vegetative growth. Ammonium sulphate consistently outperformed urea at the same nitrogen levels, due to slow release and longer availability of nitrogen. The urea-based treatments showed limited effectiveness due to ammonia volatilization and leaching in sodic soil. Additional sulphur nutrition supported protein synthesis and enzyme activation. Nano urea increased nitrogen use efficiency and allowed quick vegetative response during key growth stages. The physiological vigour and resource availability in the first cutting contribute to a higher yield than in the second and third cuttings. The results are in agreement with Goh and Kesker *et al*., (1983); Raikova (2000); Tehlan (2008) and Ahmadu *et al*., (2025).

Total green matter yield : The results pertaining to the effect of different levels and sources of nitrogen in combination with nano urea on total green matter yield depicted in Table 2. Among different treatments 80 kg N ha^{-1} through ammonium sulphate + foliar spray of 0.2% nano urea - T_{11} recorded the significantly highest total green matter yield (159.63 q ha^{-1}). It was followed by treatment 100 kg N ha^{-1} ammonium sulphate - T_7 (156.78 q ha^{-1}) and 80 kg N ha^{-1} ammonium sulphate - T_6 (147.98 q ha^{-1}). The lowest green matter yield (73.76 q ha^{-1}) was observed in absolute control (T_1). The findings are in accordance with Bhore *et al*., (2000); Suchorska (2004) and Zayed *et al*., (2014).

Total dry matter yield : The data related to total dry matter yield of spinach plant as influenced by different levels and sources of nitrogen is reported in Table 2. The results showed that nitrogen application at the rates (40, 80 and 100 kg N ha^{-1}) significantly influenced the total dry matter yield. However, ammonium sulphate as N source was more effective in enhancing total dry matter yield. The significantly highest dry matter yield (12.81 q ha^{-1}) was observed in treatment 80 kg N ha^{-1} ammonium sulphate + foliar spray of 0.2% nano urea - T_{11}. However, it was at par with the treatment 100 kg N ha^{-1} through urea - T_4 (11.37 81 q ha^{-1}), 80 kg N ha^{-1} urea + foliar spray of 0.2% nano urea - T_9 (11.32 81 q ha^{-1}), 80 kg N ha^{-1} ammonium sulphate - T_6 (12.19 81 q ha^{-1}) and 100 kg N ha^{-1} through ammonium sulphate - T_7 (12.60 81 q ha^{-1}) and were at par. The lowest dry matter yield (7.27 81 q ha^{-1}) was obtained in absolute control(T1). The similar results were reported by Mohammed (2012); Elsayed and Abdelarouf (2011); Bassyouni (2016) and Nisar *et al*., (2024).

Effect of different levels and sources of nitrogen on economics of spinach : The pooled mean gross returns, net returns and B:C ratio were computed and depicted in Table 3. It was observed that the highest gross return (Rs. 159630 ha^{-1}), cost of cultivation (Rs. 50953.31 ha^{-1}) and net return (Rs. 108676 ha^{-1}) was recorded in the treatment T_{11} with 80 kg N ha^{-1} ammonium sulphate + foliar spray of 0.2% nano urea. However, the application of 100 kg N ha^{-1} urea recorded the higher B: C ratio (2.21) over the rest of other treatments. The results are corroborated with Kamble and Todmal (2020).

Conclusions

The maximum nutrient uptake, yield and net returns (1,08,676 Rs. ha^{-1}) and B:C ratio (2.13) was recorded by the application of 80 kg N ha^{-1} through ammonium sulphate along with two sprays of 0.2% nano urea to spinach. Hence application of 80 kg N ha^{-1} through ammonium sulphate along with two sprays of 0.2% nano urea along with phosphorus (40 kg ha^{-1}) and potassium (40 kg ha^{-1}) + 10 t FYM ha^{-1} to spinach for achieving higher net monetary returns is recommended in sodic soils.

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