

SEAWEED EXTRACT- BASED INTEGRATED NUTRIENT MANAGEMENT IMPROVES GROWTH, YIELD, NUTRIENT UPTAKE, AND NITROGEN USE EFFICIENCY IN KHARIF MAIZE (ZEA MAYS L.)

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ABSTRACT

Maize plays a critical role in global agriculture, supporting farmer livelihoods and serving as a key staple for food, livestock feed, and industry. Optimizing its nutrient management by blending lower fertilizer inputs with supplementary nutrients presents a sustainable path toward higher productivity and superior nitrogen efficiency in semi-arid climates. A field experiment was conducted during *kharif* season 2025 at the Research Farm of GD Goenka University, Gurugram, Haryana, India. The experiment was carried out in Randomized Block Design with eleven treatments and three replications with maize hybrid “LAXMI 3960”. The results revealed that application of 75 % RDF + seaweed extract as foliar spray at 30 and 60 DAS (T₇) recorded the maximum plant height (300.00 cm), grain yield (4.38 t ha⁻¹), stover yield (5.79 t ha⁻¹) and biological yield (10.00 t ha⁻¹). It also recorded maximum nutrient uptake by grain and stover (70.08 and 45.16 kg N ha⁻¹, 33.73 and 26.06 kg P ha⁻¹ and 45.99 and 111.17 kg ha⁻¹, respectively). Agronomic efficiency (13.42 kg grain kg⁻¹ N) and recovery efficiency (56.00%) were observed to be maximum under T₇. Physiological efficiency and partial factor productivity were not significant. The study found that integration of 75% RDF with seaweed extract is an effective nutrient management strategy to improve crop growth, productivity, nutrient uptake and nitrogen use efficiency, while reducing dependence on conventional fertilizers. This approach offers a promising nutrient management strategy for enhancing resource-use efficiency and promoting sustainable maize production under semi-arid conditions.

KEYWORDS: Maize, INM, Nitrogen Use Efficiency, Seaweed Extract and Productivity

INTRODUCTION

Maize (*Zea mays* L.) is the most significant cereal crop of the world and ranks third after wheat and rice in area and production. Maize is generally recognized as the “Queen of cereals” due to its enormous potential output, great adaptability and multiple uses as food, fodder, feed and industrial raw material. Maize is the most produced cereal crop in the world with a global production of about 1.2 billion tones (FAO, 2024). Maize has emerged as a major commercial cereal crop in India with production of roughly 43.41 million tones in 2024-25 (APEDA, 2025). The growing demand for maize grain from the poultry, livestock, starch, and biofuel industries needs the implementation of sustainable agricultural technology that can boost productivity while preserving soil health (Davies and Colter, 2021).

Nutrient management is one of the most important elements determining maize productivity. Maize is a nutrient-dense crop that requires proper nutrition for optimal development and yield. Although chemical fertilizers have significantly enhanced agricultural productivity, the continued and uneven use of inorganic fertilizers has led in nutrient depletion, deterioration of soil health, and decreased nutrient use efficiency (Gezahegn, 2021). Under semi-arid environments, nitrogen losses due to volatilization, leaching, and fixation impair fertilizer effectiveness and crop yield (Davies and Colter, 2021). As a result, implementing sustainable nutrient management strategies has become critical for sustaining soil fertility and increasing crop output. Integrated nutrient management has evolved as a viable method for ensuring sustainable agricultural production by combining inorganic fertilizers, organic manures, and bio fertilizers (Gezahegn, 2021). Organic nutrient sources including farmyard manure and vermicomposting improve soil physical, chemical, and biological characteristics, increase nutrient availability, and stimulate microbial activity (Chen *et al.*, 2024). Azospirillum and phosphate-solubilizing bacteria are bio fertilizers that promote crop nutrient absorption via biological nitrogen fixation and phosphorous solubilisation (Sairam *et al.*, 2023). Data-driven approaches support efficient crop management and resource utilization (Taqvi, 2025). Integrating recommended fertilizers with seaweed extracts may improve maize growth, nutrient uptake, and nitrogen-use efficiency under semi-arid conditions.

Recent improvements in nutrient management have also emphasized the potential of nano-fertilizers and seaweed-based bio stimulants to improve crop growth, nutrient utilization, and production (Beesigamukama *et al.*, 2022). Nutrient absorption and utilization efficiency are critical indices of crop response to nutrient management

strategies (Nagendrachi *et al.*, 2024). Improving nitrogen efficiency minimizes fertilizer losses, lowers production costs, and increases crop productivity (Govindasamy *et al.*, 2023). Recent developments in precision and smart farming emphasize the importance of improved monitoring and data-driven crop management for efficient resource utilization and sustainable agricultural productivity (Geetanjali and Singh, 2025). These approaches complement integrated nutrient management by highlighting the need to optimize agricultural inputs while maintaining crop productivity. Kumari *et al.* (2017) showed significant gains in maize productivity, nutrient uptake, and nutrient usage efficiency when integrated nutrient management strategies were implemented. Although various studies have shown that integrated nutrition management improves maize production, there is minimal information on the combined use of organic, inorganic, and biological fertilizer sources, as well as foliar nutrient supplementation, under semi-arid settings. As a result, the current study was conducted to assess the impact of integrated nutrient management strategies on nutrient uptake, nitrogen usage efficiency, and yield of *Kharif* maize grown in semi-arid environments.

MATERIALS AND METHOD

The present study was carried out at Agriculture Research Farm, GD Goenka University Gurugram in 2025. The experimental site is situated at 28°16"N latitude and 77°04"E longitude with 215.2 m above mean sea level in north-west part of India. The soil was sandy loam in texture, slightly alkaline in reactivity (pH 7.8), had an electrical conductivity of 0.37 dS m⁻¹, and contained 0.33% organic carbon. The soil had a poor availability of phosphorus (12 kg ha⁻¹), but a medium availability of nitrogen (180 kg ha⁻¹) and potassium (130 kg ha⁻¹).

The experiment was laid out in Randomized block design (RBD) with three replications, viz T₁: Control; T₂: 100% RDF (150:60:60 kg N: P₂O₅:K₂O ha⁻¹); T₃: 100% RDF + Azospirillum @ 2 kg ha⁻¹ + PSB @ 2 kg ha⁻¹ through soil application; T₄: 75% RDF + FYM @ 5 t ha⁻¹; T₅: 75% RDF + vermicompost @ 2.5 t ha⁻¹; T₆: 75% RDF + nano urea as 2% foliar spray at 30 and 60 DAS; T₇: 75% RDF + seaweed extract as foliar spray at 30 and 60 DAS; T₈: 50% RDF + FYM @ 10 t ha⁻¹ + Azospirillum + PSB through soil application; T₉: 50% RDF + vermicompost @ 5 t ha⁻¹ + Azospirillum + PSB through soil application; T₁₀: 50% RDF + nano urea as 2% foliar spray + Azospirillum + PSB through soil application; and T₁₁: 50% RDF + seaweed extract as foliar spray at 30 and 60 DAS + Azospirillum + PSB through soil application. The treatments included various combinations of the necessary doses of fertilizers, farmyard manure, vermicompost, Azospirillum, phosphate-solubilizing bacteria, nano-urea, and seaweed extract.

The plot size was 5.0 m × 4.0 m & 60 × 20 cm maize hybrid (Laxmi 3960) spacing. In the first year trial sowing of the crop was done on 24th June 2025. Representative soil samples were collected from different plots at a depth of 0–15 cm and analyzed to determine nutrient availability. Organic manures and bio fertilizers were sprayed according to the treatment schedule prior to sowing, with foliar treatments of nano urea and seaweed extract administered 30 and 60 days after sowing (DAS). All required agronomic techniques were followed consistently during the crop growing period. Growth parameters were measured at the appropriate growth phases. Yield parameters such as cob length, cob girth, number of grains per cob, and test weight, as well as grain yield, stover yield, and harvest index, were recorded during harvest using standard protocols. Grain and stover samples were tested for nitrogen, phosphorus, and potassium levels, and nutrient uptake was calculated by combining nutrient concentration and dry matter yield. Nitrogen usage efficiency indices, such as agronomic efficiency (AE) using Eqs (i), recovery efficiency (RE) using Eqs (ii), physiological efficiency (PE) using Eqs (iii), and partial factor productivity (PFP) using Eqs (iv), were calculated using established methods. The data recorded during study for various parameters was statistically analyzed with the help of OPSTAT available at CCS HAU, Hisar.

AGRONOMIC EFFICIENCIES:

- (i) Agronomic efficiency = $AE = \frac{Y_t - Y_c}{U_t - U_c} \times 100$
- (ii) Recovery efficiency = $RE(\%) = \frac{Y_t - Y_c}{U_t - U_c} \times 100$
- (iii) Physiological efficiency = $PE = \frac{Y_t - Y_c}{U_t - U_c}$
- (iv) Partial factor productivity = $PFP = \frac{Y_t}{N}$

RESULTS AND DISCUSSION

Growth parameters and Yield attributes

Integrated nutrient management (INM) had a significant positive influence on the growth and development of maize, as reflected in plant height, leaf area index (LAI), and dry matter accumulation. Among the treatments, T₇ recorded the greatest plant height at harvest (300.0 cm), the highest LAI at 60 days after sowing (5.20), and the maximum dry matter accumulation at harvest (330.0 g plant⁻¹). These values were statistically on par with T₃ and T₄, while the control (T₁) recorded the lowest values for all growth parameters. The superior growth under T₇ may be attributed to the balanced and sustained availability of nutrients, along with the biostimulant action of seaweed extract, which enhanced photosynthetic activity, nutrient uptake and utilization efficiency, and overall biomass production. The combined application of inorganic fertilizers, biofertilisers, and seaweed extract therefore promoted vigorous crop growth throughout the growing season. Similar findings were reported by Singh *et al.* (2017) and Ponmozhi *et al.* (2019).

Table 1: Effect of integrated nutrient management (INM) on growth parameters and yield attributes of *Kharif* maize

Treatments	Plant height (cm)	Leaf area index	Dry matter accumulation (g plant ⁻¹)	Cob Length (cm)	Cob Girth (cm)	No. of Grains/cob	Test weight (g)
T ₁	240.0	3.80	255.0	15.30	12.80	395.0	20.50
T ₂	250.0	3.90	265.0	15.40	12.90	396.0	20.60
T ₃	292.0	5.00	320.0	17.90	14.80	455.0	25.50
T ₄	290.0	4.90	318.0	17.80	14.70	450.0	25.00
T ₅	255.0	4.05	268.0	15.60	13.10	400.0	20.80
T ₆	252.0	4.00	268.0	15.50	13.00	397.0	20.70
T ₇	300.0	5.20	330.0	18.00	15.00	460.0	26.00
T ₈	262.0	4.20	276.0	15.90	13.40	404.0	21.10
T ₉	265.0	4.25	278.0	16.00	13.50	405.0	21.50
T ₁₀	258.0	4.10	272.0	15.70	13.20	401.0	20.90
T ₁₁	260.0	4.15	275.0	15.80	13.30	403.0	21.00
SEm ±	11.50	0.29	15.26	0.65	0.49	15.8	1.34
CD (P=0.05)	34.16	0.87	45.34	1.95	1.48	47.0	4.00

The improvement in vegetative growth under INM was carried through to the reproductive phase and was clearly reflected in the yield attributes of maize. T₇ produced the longest cobs (18.0 cm), the greatest cob girth (15.0 cm), the highest number of grains per cob (460), and the maximum test weight (26.0 g), all of which were statistically comparable to T₃ and T₄. In contrast, the control treatment (T₁) recorded the lowest values for every yield attribute. The enhancement in yield-contributing characters under integrated nutrient management can be ascribed to the continuous and balanced nutrient supply during the reproductive stage, which favoured better cob development, efficient assimilate partitioning, and improved grain filling. Moreover, the greater photosynthetic capacity and dry matter production observed under T₇ provided a stronger source for translocation of photosynthates to the developing grains, thereby resulting in larger cobs, more grains per cob, and heavier grains. The integrated use of inorganic fertilizers, biofertilisers, and seaweed extract thus improved the physiological efficiency of the crop, linking vigorous vegetative growth with superior yield formation. These results are in agreement with Jeevabharathi *et al.* (2020) and Mahato *et al.* (2020), who observed similar improvements in maize yield attributes under integrated nutrient management practices.

Yield Parameters

Integrated nutrient management (INM) significantly improved the grain, stover, and biological yields of maize (Table 2). T₇ recorded the highest grain yield (4.38 t ha⁻¹), stover yield (5.79 t ha⁻¹), and biological yield (10.00 t ha⁻¹). These values were statistically on par with those of T₃ and T₄ but significantly higher than those of the control (T₁). In contrast, T₁ recorded the lowest grain, stover, and biological yields (2.87, 4.37, and 7.25 t ha⁻¹, respectively), indicating the limitations of crop production in the absence of balanced nutrient supply. The harvest index ranged from 39.5 to 43.9% and did not differ significantly among the treatments, suggesting that the treatments increased total biomass production and economic yield in a similar proportion rather than altering the partitioning of assimilates to the grain.

Table 2: Effect of integrated nutrient management (INM) on yield of *Kharif* maize

Treatments	Grain yield (t ha ⁻¹)	Stover yield (t ha ⁻¹)	Biological yield (t ha ⁻¹)	Harvest Index (%)
T ₁	2.87	4.37	7.25	39.5
T ₂	3.31	4.64	7.95	41.4
T ₃	3.96	5.31	9.30	43.9
T ₄	3.87	5.23	9.15	42.7
T ₅	3.43	4.72	8.15	42.1
T ₆	3.35	4.68	8.05	41.7
T ₇	4.38	5.79	10.0	43.9
T ₈	3.54	4.98	8.35	42.6
T ₉	3.57	5.04	8.40	42.7
T ₁₀	3.46	4.76	8.25	42.3
T ₁₁	3.49	4.80	8.30	42.5
SEm ±	0.24	0.24	0.46	4.19
CD (P=0.05)	0.73	0.71	1.36	NS

The higher yields under T₇ may be attributed to the combined application of inorganic fertilisers and seaweed extract, which improved nutrient availability, uptake, and utilisation efficiency throughout the crop growth period. The biostimulant properties of seaweed extract, which are associated with growth-promoting compounds such as

natural plant hormones, most likely enhanced root development, photosynthetic activity, and metabolic efficiency. This in turn is likely to have accelerated plant growth, improved the translocation of assimilates from source to sink, and promoted grain filling, thereby resulting in greater biomass accumulation and higher grain and stover yields. The balanced supply of nutrients under integrated nutrient management also ensured that the crop's requirements were met during critical growth stages, which contributed to the superior performance of T₇. Comparable results have been reported by Fatima and Al-Yasari (2024) and Trivedi *et al.* (2018).

Nutrient uptake

Table 3 reveals that integrated nutrient management (INM) had a significant influence on the uptake of nitrogen (N), phosphorus (P), and potassium (K) by both maize grain and stover. Among the treatments, T₇ recorded the highest nutrient uptake in grain (70.08 kg N ha⁻¹, 33.73 kg P ha⁻¹, and 45.99 kg K ha⁻¹) as well as in stover (45.16 kg N ha⁻¹, 26.06 kg P ha⁻¹, and 111.17 kg K ha⁻¹). These values were statistically on par with T₃ and T₄ for most of the parameters studied. In contrast, the control treatment (T₁) recorded the lowest N, P, and K uptake in both grain and stover, indicating the limited nutrient supply and poor nutrient-use efficiency in the absence of external nutrient inputs.

Table 3: Effect of integrated nutrient management (INM) on nutrient uptake (grain and stover) of *Kharif* maize

Treatments	Grain (kg ha ⁻¹)			Stover (kg ha ⁻¹)		
	N	P	K	N	P	K
T ₁	32.14	10.33	13.78	20.10	10.05	66.42
T ₂	40.71	12.25	16.22	21.81	11.14	71.46
T ₃	62.57	30.10	41.18	39.29	23.36	101.42
T ₄	59.99	29.03	39.86	37.65	22.50	98.85
T ₅	43.56	13.38	17.49	23.13	12.27	74.58
T ₆	41.88	12.73	16.75	22.46	11.70	73.48
T ₇	70.08	33.73	45.99	45.16	26.06	111.17
T ₈	46.02	14.87	19.12	25.90	14.44	80.18
T ₉	46.77	15.35	19.64	26.70	15.12	82.66
T ₁₀	44.29	13.83	17.99	23.80	12.85	75.68
T ₁₁	45.02	14.31	18.50	24.48	13.44	76.80
SEm ±	6.80	5.15	7.25	5.15	3.40	8.76
CD (P=0.05)	20.22	15.31	21.55	15.30	10.10	26.04

The enhanced nutrient uptake under integrated nutrient management may be attributed to the improved nutrient availability in the soil and the synchronized release of nutrients from inorganic fertilizers, organic manures, and biofertilisers. This balanced and continuous supply throughout the crop growth period promoted greater nutrient absorption by the roots, better root proliferation, and higher dry matter production, which in turn increased the nutrient content and uptake in the economic as well as the vegetative parts of the plant. In addition, the superior performance of T₇ suggests that seaweed extract, owing to its biostimulant properties and the presence of growth-promoting substances, may have improved nutrient mobilization, absorption, and accumulation within the maize plant. The combined use of inorganic fertilizer, biofertilisers, and seaweed extract therefore enhanced the overall physiological efficiency of the crop and its capacity to utilize the available nutrients effectively. Comparable results were reported by Kumari *et al.* (2017), Eazhilkrishna *et al.* (2017), and Sairam *et al.* (2023).

Nutrient use efficiency

Integrated nutrient management (INM) significantly improved the agronomic efficiency (AE) and recovery efficiency (RE) of maize, whereas physiological efficiency (PE) and partial factor productivity (PFP) were not significantly affected by the treatments (Table 4). Among the treatments, T₇ recorded the highest AE (13.42 kg grain kg⁻¹ N) and RE (56.00%), indicating that a larger proportion of the applied nitrogen was taken up by the crop and converted into economic yield. In contrast, T₂ recorded the lowest values among the fertilized treatments (2.93 kg grain kg⁻¹ N for AE and 6.85% for RE), suggesting poor nitrogen use when the nutrient supply was not supported by biological or organic sources. Physiological efficiency ranged from 21.97 to 42.80 kg grain kg⁻¹ N absorbed, while PFP ranged from 22.07 to 47.60 kg grain kg⁻¹ N applied, and neither parameter differed significantly across treatments.

Table 4: Effect of integrated nutrient management (INM) on efficiencies of *Kharif* maize

Treatments	Agronomic Efficiency	Recovery Efficiency	Physiological Efficiency	Partial Factor Productivity
T ₁	-	-	-	-
T ₂	2.93	6.85	42.80	22.07
T ₃	7.27	33.07	21.97	26.40
T ₄	8.89	40.36	22.03	34.40
T ₅	4.97	12.84	38.75	30.49
T ₆	4.27	10.76	39.67	29.78
T ₇	13.42	56.00	23.97	38.93

T₈	8.92	26.24	34.04	47.20
T₉	9.33	28.30	32.97	47.60
T₁₀	7.87	21.13	37.22	46.13
T₁₁	8.27	23.01	35.91	46.53
SEm ±	1.79	8.61	5.77	7.26
CD (P=0.05)	5.36	25.80	NS	NS

The higher AE and RE under INM reflect more efficient nitrogen utilization and recovery, which can be attributed to better synchronization between fertilizer supply and crop demand throughout the growing season. The combined use of inorganic fertilizer's, biofertilisers, and seaweed extract probably reduced nitrogen losses through leaching, volatilization, and immobilization, while improving root growth and nutrient uptake. The superior performance of T₇ further suggests that seaweed extract, through its biostimulant action, enhanced nitrogen uptake and assimilation, leading to greater grain production per unit of nitrogen applied and a higher proportion of applied nitrogen recovered by the crop. The absence of significant differences in PE and PFP indicates that the improvement in nitrogen use efficiency was driven mainly by greater nitrogen uptake and recovery rather than by changes in the internal conversion of absorbed nitrogen into grain. Similar improvements in nitrogen use efficiency under integrated nutrient management have been reported by Davies and Colter (2021), Beesigamukama *et al.* (2022), and Nagendra Chari *et al.* (2024).

CONCLUSION

The present study demonstrated that integrated nutrient management (INM) significantly enhanced the growth, yield, nutrient uptake, and nitrogen use efficiency of maize under semi-arid conditions. Among all treatments, T₇ (75% RDF + foliar spray of seaweed extract) recorded superior growth at 30 and 60 DAS, along with higher grain yield, NPK uptake, agronomic efficiency, and recovery efficiency compared to the other treatments. Combining a reduced dose of inorganic fertilizer with seaweed extract improved nutrient utilization and crop productivity without any yield penalty. Therefore, the application of 75% RDF along with seaweed extract can be recommended as a sustainable nutrient management strategy for improving maize productivity and nitrogen use efficiency in semi-arid regions.

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