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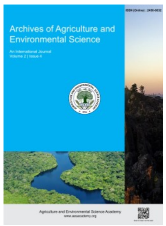

ORIGINAL RESEARCH ARTICLE

Evaluation of growth and yield performance of broccoli (*Brassica oleracea var. italica* L.) under conventional urea, nano urea and azotobacter biofertilizer

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ABSTRACT

Conventional urea, while being the predominant nitrogen source in Nepalese agriculture, presents significant challenges including import dependency, low nitrogen use efficiency, and environmental pollution. A field experiment was conducted in Tulsipur, Dang, during 2024-25 season to evaluate Nano urea and *Azotobacter* biofertilizer as potential partial or complete substitutes for conventional urea in broccoli cultivation. The study employed a randomized complete block design with three replications and nine treatments, including reduced (75%, 50%) doses of recommended conventional urea supplemented with Nano urea and *Azotobacter*, using full conventional urea (N 100% PK full) as control. The treatment with 75% conventional urea and both supplements produced a significantly ($p<0.05/0.01$) superior plant height (56.31 cm) and the largest canopy diameter (57.97 cm) at harvest, while 50% conventional urea with Nano urea resulted in longest leaves (38.30 cm) and broadest leaves (19.82 cm) of broccoli at harvest. The combination of 50% conventional urea with *Azotobacter* achieved the highest economic yield (26.96 t/ha), while 75% conventional urea with both supplements yielded maximum biological production (67.2 t/ha) of broccoli. Correlation analysis revealed a strong positive correlation ($r = 0.947$) between head diameter and economic yield which was further quantified by a linear regression model ($y = -18.44 + 2.87x$, $R^2 = 0.896$), confirming head diameter as a key predictor for yield of broccoli. Hence, the study concludes that integrating Nano urea or *Azotobacter* can reduce conventional urea use by 25-50% without compromising yield, offering a sustainable strategy that addresses both import dependency and environmental concerns.

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INTRODUCTION

Broccoli (*Brassica oleracea var. italica*) stands as a highly valued vegetable crop worldwide, esteemed for its nutritional richness and potential health benefits (Salim *et al*., 2018). In Nepal, broccoli cultivation has shown a notable increase in both area and production over recent years, reflecting its growing acceptance as a profitable crop among farmers. According to Ministry of Agriculture and Livestock Development, MoALD (2017), the total area under broccoli cultivation was 1,986 hectares, yielding 20,048 metric tons with a productivity of 10 metric tons per hectare however by 2022/23, this area had expanded to 3164 hectares, with total production reaching 38,821 metric tons and productivity rising to 12.27 metric tons per hectare (MoALD, 2024). Nitrogen, a critical macronutrient, plays a crucial role in broccoli growth and development as it is essential for chlorophyll synthesis, protein formation, and overall plant vigour (Bika *et al*., 2018). Traditional nitrogen fertilization in Nepal relies predominantly on conventional urea application. While conventional urea has its contribution on increased vegetable production, it is associated with several environmental, warehousing, and economic challenges. Nitrogen use efficiency (NUE) of conventional urea is relatively low, leading to reduced crop productivity. Studies show that up to 30-35% of applied urea can be lost to the environment due to its limited effectiveness (Swify *et al.*, 2024). Ammonia volatilization is a major concern and nitrogen losses through leaching and runoff contaminate ground and surface water resources, leading to water pollution (Guo *et al.*, 2020). From warehousing aspect, conventional urea's bulky and hygroscopic nature complicates the storage and handling, particularly for small-scale farmers. Economically, Nepal relies heavily on import of conventional urea, which is most consumed chemical fertilizer in the country. Government imports cover only one-fourth of the total national requirement, with the remaining met through informal channels, including illegal purchase from India (Prasad Vista *et al.*, 2022). This deficit leads to inconsistent and untimely availability of urea for crop production. Considering the several challenges associated with conventional urea, innovative and sustainable alternatives are imperative to enhance nitrogen use efficiency and minimize environmental harm. Nano-urea and biofertilizers offer promising alternatives to conventional nitrogen fertilizers, addressing environmental concerns and improving nutrient use efficiency. Liquid nano urea is a foliar spray alternative to conventional urea, providing nitrogen efficiently during critical growth stages and minimizing environmental losses through controlled release (Behera *et al.*, 2023). Biofertilizers, particularly those containing nitrogen-fixing microorganisms such as *Azotobacter*, provide sustainable solutions for improving soil fertility and plant growth (Abd-Alla *et al.*, 2023). These microbial inoculants can increase nitrogen availability in the root zone, stimulate root growth, and enhance overall soil health (Thomas & Singh, 2019). However, despite the existence of these alternatives, effectiveness of nano-urea and *Azotobacter* biofertilizer remain inadequately researched in Nepal. Furthermore, Sikka *et al.* (2025) found that the application of two foliar sprays of nano urea combined with 50% recommended dose of nitrogen (RDN) significantly reduced the grain yield of rice and wheat by 13% and 17.2%, respectively, compared to 100% RDN applied to soil. Such trials have raised skepticism about nano-urea's performance, creating uncertainty about whether its benefits are genuine or overstated (Kapil, 2024). Since, nano urea is a relatively new technology and most existing studies have been conducted under controlled laboratory conditions, there is need for research assessing its effectiveness under real-world farming conditions (Ramalingappa *et al.*, 2023). This research will help to confirm whether the claimed advantages of nano urea and *Azotobacter* biofertilizer are valid in practical conditions and whether it can enhance performance of a crop. This research also explores these alternatives as important sources of nitrogen during periods of conventional urea shortage, which is a recurring problem in Nepal and also explores the feasibility of integrated approach of these alternatives to determine whether they can fully or partially replace conventional urea.

MATERIALS AND METHODS

Research site and experimental design

The research was carried out in Tulsipur-12 of Dang district of Nepal. Geographically, this site is positioned at latitude of 28.1545° N and a longitude of 82.3235° E, with an elevation of 725masl. It exhibits tropical climatic condition with average rainfall around 1500-2000 mm. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications, comprising a total of nine treatments. Altogether, 27 plots were established, each plot consisting 25 plants, resulting in a total plant population of 675. From each plot, five plants were randomly sampled excluding the border plants for data collection. The spacing of 45cm × 30 cm was maintained. Data were collected at three intervals: 35 days after transplanting (DAT), 50 DAT, and at harvest.

Treatment details

Nine treatments were used for this study (Table 1). Centauro Hybrid variety of broccoli was used for the experimentation. The recommended dose of fertilizers for broccoli includes 10 t/ha farm yard manure (FYM) and 380:180:80 kg/ha of Urea, DAP, and MOP respectively (*Agriculture and Livestock Diary*, 2081). For all treatments, full dose of DAP and MOP was applied as basal dose. For control/T_1 and treatments involving reduced conventional urea levels (T_2-T_7), half dose of conventional urea was applied as basal dose and the remaining half was applied in two equal split doses at 30 and 50 DAT. Nano urea was applied as foliar spray at the rate of 4 ml/litre of water at 25 DAT and 50 DAT. For treatments involving *Azotobacter*, 22-days old broccoli seedlings were treated with liquid *Azotobacter* at the rate of 10ml/litre of water before transplanting. To reduce margin of error FYM was also treated with liquid *Azotobacter* at the rate of 25ml/litre of water. Treated and untreated FYM was incorporated into respective plots seven days prior to transplanting. Other intercultural operations (weeding, irrigation, pesticide application) were carried out in all experimental plots.

Statistical analysis

Statistical software such as MS EXCEL, GENSTAT 18th edition and IBM SPSS statistics v.25 were used for the data entry, analysis of variance and correlation & regression analysis respectively. 5% and 1% level of significance were considered for ANOVA, and correlation & regression analysis.

Table 1. Detail of treatments used in the study.

Symbol	Treatments
T_1	N 100% PK full (RDF)/Control
T_2	N 75% PK full (RDF) + Nano urea
T_3	N 75% PK full (RDF) + *Azotobacter*
T_4	N 75% PK full (RDF) + *Azotobacter* + Nano urea
T_5	N 50% PK full (RDF) + Nano urea
T_6	N 50% PK full (RDF) + *Azotobacter*
T_7	N 50% PK full (RDF) + *Azotobacter* + Nano urea
T_8	Nano urea + PK full (RDF)
T_9	*Azotobacter* + PK full (RDF)

RESULTS AND DISCUSSION

Plant height and canopy diameter

Plant height and canopy diameter (Table 2) showed significant treatment effects at all growth stages ($p<0.05$ at 35 DAT; $p<0.01$ at 50 DAT and harvest). At 35 DAT, T_2 produced the tallest plants (42.34 cm) and largest canopy (40.28cm), statistically comparable to T_1 (control). The initial superiority of T_2, producing tallest plants and largest canopy can be due to the rapid absorption and efficient mobilization of nitrogen from Nano urea (Behera & Duhan, 2024). On the other hand, T_9 showed the minimum plant height and canopy diameter statistically at par with T_8. By 50 DAT, all treatments including conventional urea (T_1-T_7) formed a statistically homogeneous group, significantly outperforming the treatments excluded of conventional urea. This trend continued through harvest, where T_4 achieved the maximum height (56.31 cm) and canopy diameter (57.97cm), statistically comparable to all treatments, except T_8 and T_9, suggesting that reducing conventional urea by 25-50%, supplemented with Nano urea or *Azotobacter* does not significantly limit the canopy expansion of broccoli. Similar results were obtained from the study done by (Nethra *et al.*, 2024) in watermelon emphasizing the role of integration for influencing growth attributes.

Leaf parameters

In case of leaf parameters, at 35 DAT, T_2 produced the longest leaves (31.34 cm), whereas for leaf breadth (Table 3) T_5 produced the broadest leaves (17.23 cm) significantly outperforming the control. Both of these treatments have foliar application of Nano urea in common so that may be the reason for increase in leaf length and breadth. By 50 DAT, all treatments receiving conventional urea (T_1-T_7) were statistically identical, forming a single high-performing group that was significantly superior to the conventional urea-deficient T_8 and T_9. This trend held firm until harvest, with T_5 recording the highest leaf length (38.30 cm) and leaf breadth (17.23 cm) that were statistically at par with all treatments except the zero-conventional urea treatments (T_8 and T_9) consistently showing the lowest measurements of leaf parameters across all stages. The consistent and significantly poorer performance in both leaf length and breadth in the T_8 and T_9 provides enough evidence of the indispensable role of conventional urea and the need of integrated nitrogen management as well. These results are supported in the review paper by (Bastakoti *et al.*, 2024).

Yield parameters

Highly significant treatment effects occurred for all yield parameters ($p<0.01$) (Table 4). For head diameter all treatments with reduced conventional urea (T_2-T_7) along with control T_1 formed a statistically identical group with diameters ranging from 14.13 cm of T7 to 15.90 cm of T_2. Minimum head diameter of 10.37 cm was found in T_9 which as statistically at par with T_8. For head height, T_3 produced the tallest curd (13.00 cm), though it was part of a large statistical group that included the control and most other treatments. T_4 achieved the maximum biological yield (67.2 t/ha) which was statistically similar to control T_1 and other treatments with reduced conventional urea. The treatments without conventional urea; T_8 and T_9 had the lowest biological yield and were statistically equivalent, confirming the essential role of conventional urea in biomass accumulation. T_6 achieved the highest economic yield (26.96 t/ha), followed by T_3 with economic yield of (26.12 t/ha). Treatments involving reduced conventional urea (T_2-T_7) along with control (T_1) were statistically identical and lowest economic yield were observed in treatments excluded of conventional urea (T_8 and T_9).

These findings are not isolated but are instead part of a compelling and consistent scientific consensus that validates this integrated approach to nitrogen management. The viability of a 50% reduction in conventional urea, as demonstrated in this research, is directly corroborated by the work of (Subedi *et al.*, 2019), who achieved equivalent yields in cauliflower using *Azotobacter* as a substitute for half the conventional urea requirement. Furthermore, the success of a 25% reduction strategy is strongly affirmed by (Behera & Duhan, 2024) who recorded an 18.29% increase in yield and profitability using nano urea with 75% of the recommended nitrogen in sponge gourd.

Table 2. Mean plant height and canopy diameter of broccoli at periodic growth stages.

Treatment details	Plant height (cm)			Canopy diameter (cm)		
	35DAT	50DAT	Harvest	35DAT	50DAT	Harvest
(T_1) N 100% PK full (RDF)	40.23^{c}	47.15^{b}	53.10^{b}	37.93^{bc}	46.48^{cd}	56.33^{b}
(T_2) N 75% PK full (RDF) + NU	42.34^{c}	47.66^{b}	52.97^{b}	40.28^{c}	47.26^{d}	57.55^{b}
(T_3) N 75% PK full (RDF) + AZ	38.35^{abc}	46.83^{b}	52.79^{b}	37.60^{bc}	44.48^{cd}	55.92^{b}
(T_4) N 75% PK full (RDF) + AZ + NU	38.92^{bc}	48.17^{b}	56.31^{b}	37.38^{bc}	44.68^{cd}	57.97^{b}
(T_5) N 50% PK full (RDF) + NU	41.29^{c}	48.23^{b}	54.44^{b}	38.03^{bc}	44.36^{cd}	55.50^{b}
(T_6) N 50% PK full (RDF) + AZ	40.55^{c}	47.45^{b}	54.09^{b}	38.82^{bc}	47.16^{d}	57.28^{b}
(T_7) N 50% PK full (RDF) + AZ + NU	40.09^{c}	48.51^{b}	51.37^{b}	36.44^{abc}	42.55^{bc}	56.07^{b}
(T_8) PK full (RDF) + NU	35.81^{ab}	39.38^{a}	42.77^{a}	34.23^{ab}	37.32^{a}	46.12^{a}
(T_9) PK full (RDF) + AZ	34.60^{a}	39.91^{a}	41.24^{a}	32.37^{a}	38.71^{ab}	48.60^{a}
Grand mean	39.13	45.92	51.01	37.01	43.67	54.59
SEM (+−)	1.307	1.565	1.965	1.459	1.331	1.694
F-test	*	**	**	*	**	**
$LSD_{0.05}$	3.918	4.693	5.891	4.373	3.992	5.080
CV %	5.8	5.9	6.7	6.8	5.3	5.4

Means with same letter in column are not significantly different at p = 0.05 by DMRT. *significant at 5% (p < 0.05), **significant at 1% (p < 0.01) and ns: not significantly different at 5% (p > 0.05). SEM = Standard error of mean, LSD = Least significant difference, CV = Coefficient of variance, N = Nitrogen through conventional urea, NU = Nano urea, AZ = *Azotobacter*.

Table 3. Mean leaf length and breadth of broccoli at periodic growth stages.

Treatment details	Leaf length (cm)			Leaf breadth (cm)		
	35DAT	50DAT	Harvest	35DAT	50DAT	Harvest
(T_1) N 100% PK full (RDF)	28.86^{abc}	33.18^{b}	37.09^{b}	15.09^{bc}	17.37^{b}	18.11^{b}
(T_2) N 75% PK full (RDF) + NU	31.34^{c}	34.57^{b}	35.69^{b}	15.62^{cd}	17.78^{b}	18.99^{b}
(T_3) N 75% PK full (RDF) + AZ	28.44^{abc}	33.67^{b}	37.02^{b}	14.89^{abc}	16.86^{b}	17.99^{b}
(T_4) N 75% PK full (RDF) + AZ + NU	28.70^{abc}	35.04^{b}	37.84^{b}	16.14^{cd}	16.91^{b}	18.53^{b}
(T_5) N 50% PK full (RDF) + NU	30.44^{c}	34.03^{b}	38.30^{b}	17.23^{d}	18.10^{b}	19.82^{b}
(T_6) N 50% PK full (RDF) + AZ	30.27^{c}	34.97^{b}	36.76^{b}	16.42^{cd}	17.87^{b}	18.40^{b}
(T_7) N 50% PK full (RDF) + AZ + NU	29.23^{bc}	34.61^{b}	36.77^{b}	14.84^{abc}	16.66^{b}	17.76^{b}
(T_8) PK full (RDF) + NU	25.43^{ab}	27.95^{a}	28.90^{a}	13.36^{ab}	14.66^{a}	15.06^{a}
(T_9) PK full (RDF) + AZ	24.90^{a}	27.34^{a}	28.80^{a}	13.16^{a}	14.08^{a}	14.87^{a}
Grand mean	28.62	32.82	35.24	15.19	16.70	17.73
SEM (+−)	1.215	1.097	1.316	0.585	0.592	0.615
F-test	*	**	**	**	**	**
$LSD_{0.05}$	3.644	3.287	3.946	1.754	1.775	1.844
CV %	7.4	5.8	6.5	6.7	6.1	6.0

Means with same letter in column are not significantly different at p = 0.05 by DMRT. *significant at 5% ($p < 0.05$), **significant at 1% ($p < 0.01$) and ns: not significantly different at 5% ($p > 0.05$). SEM = Standard error of mean, LSD = Least significant difference, CV = Coefficient of variance, N = Nitrogen through conventional urea, NU = Nano urea, AZ = *Azotobacter*.

Table 4. Mean leaf length and breadth of broccoli at periodic growth stages.

Treatment details	Yield parameters			
	Head height (cm)	Head diameter (cm)	Biological yield (t/ha)	Economic yield (t/ha)
(T_1) N 100% PK full (RDF)	15.40^{b}	11.80^{bcd}	64.4^{b}	25.63^{b}
(T_2) N 75% PK full (RDF) + NU	15.90^{b}	12.87^{cd}	63.0^{b}	25.48^{b}
(T_3) N 75% PK full (RDF) + AZ	15.77^{b}	13.00^{d}	61.6^{b}	26.12^{b}
(T_4) N 75% PK full (RDF) + AZ + NU	14.90^{b}	11.10^{bc}	67.2^{b}	25.53^{b}
(T_5) N 50% PK full (RDF) + NU	14.85^{b}	11.63^{bcd}	63.4^{b}	24.99^{b}
(T_6) N 50% PK full (RDF) + AZ	14.87^{b}	12.07^{cd}	63.9^{b}	26.96^{b}
(T_7) N 50% PK full (RDF) + AZ + NU	14.13^{b}	11.63^{bcd}	63.8^{b}	23.41^{b}
(T_8) PK full (RDF) + NU	10.80^{a}	10.20^{ab}	39.6^{a}	10.57^{a}
(T_9) PK full (RDF) + AZ	10.37^{a}	9.30^{a}	35.0^{a}	10.07^{a}
Grand mean	14.11	11.51	58.0	22.09
SEM (+−)	0.863	0.545	4.18	1.978
F-test	**	**	**	**
$LSD_{0.05}$	2.588	1.632	12.53	5.930
CV %	10.6	8.2	12.5	15.5

Means with same letter in column are not significantly different at p = 0.05 by DMRT. *significant at 5% ($p < 0.05$), **significant at 1% ($p < 0.01$) and ns: not significantly different at 5% ($p > 0.05$). SEM = Standard error of mean, LSD = Least significant difference, CV = Coefficient of variance, N = Nitrogen through conventional urea, NU = Nano urea, AZ = *Azotobacter*.

Table 5. Correlation among various parameters of broccoli.

	SDH	PHH	LNH	LLH	LBH	CDH	HHH	HDH
SDH	-	-	-	-	-	-	-	-
PHH	0.444*	-	-	-	-	-	-	-
LNH	0.217	0.786**	-	-	-	-	-	-
LLH	0.452*	0.932**	0.687**	-	-	-	-	-
LBH	0.383*	0.740**	0.657**	0.726**	-	-	-	-
CDH	0.513**	0.902**	0.799**	0.821**	0.714**	-	-	-
HHH	0.283	0.602**	0.764**	0.611**	0.636**	0.665**	-	-
HDH	0.391*	0.731**	0.830**	0.698**	0.756**	0.770**	0.878**	-
EY	0.490**	0.849**	0.844**	0.822**	0.853**	0.853**	0.837**	0.947**

* and ** indicates the probability levels 5 and 1%, respectively of significant for Pearson correlation (2-tailed). Where, SDH = stem diameter at harvest, PHH = plant height at harvest, LNH = leaf number at harvest, LBH = leaf breadth at harvest, CDH = canopy diameter at harvest, HHH = head height at harvest, HDH = head diameter at harvest and EY = economic yield.

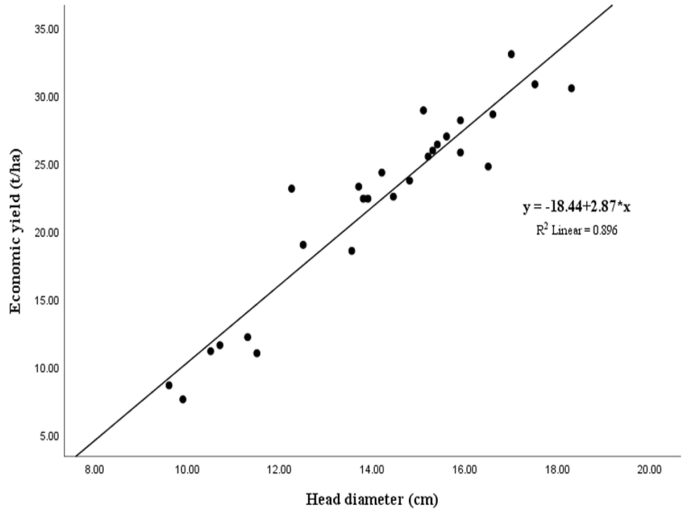

Figure 1. *Regression analysis of head diameter and economic yield of broccoli.*

Pearson correlation and Regression analysis

The Pearson correlation analysis (Table 5) revealed a highly significant and positive correlation between economic yield and head diameter at harvest (r=0.947, p<0.01). This profound correlation underscores that head diameter is the most influential factor in determining economic yield. Similar findings were observed in the work of (Bagale *et al.*, 2024), who found a strong positive correlation (r = 0.95) between head diameter and yield in broccoli.

The linear regression analysis between head diameter (independent variable) and economic yield (dependent variable) (Figure 1) provided a quantitative model to predict yield. The regression equation, y = −18.44 + 2.87x, with a high coefficient of determination (r^2 = 0.896), suggested that 89.6% of the variation in economic yield can be explained by the variation in head diameter alone. This provides a powerful predictive tool for farmers and confirms that optimizing for head diameter is the most effective strategy to maximize final yield.

Conclusion

This study provides clear evidence that integrated nutrient management strategies can effectively reduce dependence on conventional urea in broccoli cultivation while maintaining yield potential. The research demonstrates that nano urea and *Azotobacter* biofertilizer can successfully replace 25-50% of conventional urea without compromising broccoli growth or yield parameters, thereby addressing the core research question of whether these alternatives can serve as viable substitutes. The findings of this research indicate that treatments combining reduced conventional urea (50-75% of recommended dose) with either nano urea or *Azotobacter* performed comparably to the full recommended dose across most growth and yield parameters. This effectively challenges the prevailing reliance of Nepalese agriculture on conventional urea as the sole nitrogen source. The research confirms the indispensable role of a basal application of conventional urea, as treatments devoid of it performed significantly poorer. Furthermore, correlation and regression analysis established head diameter as the principal determinant of economic yield, providing a robust predictive model for yield prediction. In summation, this research concludes that integrating these alternative nitrogen sources can significantly mitigate the economic and environmental drawbacks associated with conventional urea dependence, without compromising productivity of broccoli cultivation.

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DECLARATIONS

Author contribution statement: Conceptualization: K.K.; Methodology: K.K., A.C., A.A.; Software and validation: K.K., A.C, R.A., D.L.; Formal analysis and investigation: K.K.; Data curation: K.K., A.C., R.A, D.L., A.A, S.K.; Writing—original draft preparation: K.K.; Writing—review and editing: A.C., R.A, D.L., A.A, S.K.; Visualization: K.K.; Supervision: M.B.; Project administration: K.K.; Funding acquisition: K.K., A.C., R.A. All authors have read and agreed to the published version of the manuscript.

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