Plant Archives Vol. 26, No. 1, 2026 pp. 29-36 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.no.1.004

EFFECT OF DOSE AND TIME OF NITROGEN APPLICATION ON DRY MATTER PARTITIONING, PRODUCTION EFFICIENCY AND MONETARY EFFICIENCY OF SPRING MAIZE (*ZEA MAYS* L.) IN WESTERN INDO-GANGETIC PLAINS OF INDIA

Kailash Chand Verma[1]*, Ashok Kumar[2], Sanjay Kumar Thakral[2] and Manoj Kumar[3]

[1]Department of Agronomy, SKN Agriculture University, Jobner- Jaipur, Rajasthan, India
[2]Department of Agronomy, CCS Haryana Agricultural University, Hisar, Haryana, India
[3]Department of Agronomy, Agriculture University, Jodhpur, Rajasthan, India
*Corresponding author E-mail: mahawatkai@gmail.com
(Date of Receiving-29-11-2025; Date of Revision-05-01-2026; Date of Acceptance-02-02-2026)

ABSTRACT

Maize is a major and economically important crop of the Western Indo-Gangetic Plains of India. However, its productivity remains low due to improper nitrogen fertilizer rates and inappropriate timing of nitrogen application. Hence, evaluate the effect of nitrogen dose and time of nitrogen application on dry matter partitioning, production efficiency and monetary efficiency of spring maize, a field experiment was conducted during two consecutive spring seasons at the Regional Research Station, Uchani, Karnal, C.C.S. Haryana Agricultural University, Hisar. The experiment was conducted using a strip plot design with three replications. Four nitrogen doses (N_1 -150 kg ha^{-1}, N_2 – 165 kg ha^{-1}, N_3 -180 kg ha^{-1}and N_4 - 195 kg ha^{-1}) were assigned to the main plots, while four time of nitrogen application were allotted to sub-plots, S_1 - 50% + 25% + 25 % (sowing+ 8 leaf + tassel initiation), S_2 - 25% + 25% + 25% + 25% (sowing+ 4 leaf + 8 leaf + silking), S_3 - 20% + 30% + 40% + 10% (sowing+ 6 leaf + flowering + grain formation) and S_4 - 20% + 30% + 40% + 10% (2 leaf+ 6 leaf +tassel initiation + grain formation). The results showed that dry weight of individual plant parts (leaf, stem, tassel and cob dry weight) except tassel dry weight plant^{-1} were significantly influenced due to dose and time of nitrogen application except at 25 days during both the years. Maximum leaf, stem and cob dry weight were achieved by application of 195 kg N ha^{-1} (N_4) which was statistically similar with 180 kg N ha^{-1}(N_3) but higher than 165 and 150 kg N ha^{-1}. The split application of nitrogen under S_2 (25% at sowing, 25% at the 4-leaf stage, 25% at the 8-leaf stage, and 25% at silking) resulted in significantly higher leaf, stem and cob dry weight and remained statistically comparable with S_1 (50% at sowing, 25% at the 8-leaf stage, and 25% at tassel initiation), while both treatments outperformed than other nitrogen application. The highest production efficiency and monetary efficiency were achieved with the application of 195 kg N ha^{-1} (N_4) followed by 180 kg N ha^{-1} (N_3). Among the nitrogen applications, S_2 (25% at sowing, 25% at the 4-leaf stage, 25% at the 8-leaf stage, and 25% at silking) resulted in greater production and monetary efficiency than S_1 (50% at sowing, 25% at the 8-leaf stage, and 25% at tassel initiation) as well as the remaining treatments during both years of experimentation.

***Key words*: Dry matter, production, monetary efficiency, dose and time of nitrogen**

Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops worldwide due to its wide adaptability, high yield potential and diverse uses, about 28% of maize production is utilized for human consumption, about 11% for livestock feed, about 48% for poultry feed, 12% in the wet milling industry and about 1% as seed (Layek *et al.,* 2016). In India, maize follows rice and wheat as a major cereal, covering 9.89 million hectares and yielding 31.65 million tonnes, contributing about 9% to the national food supply (ICAR-IIMR 2021). Globally, maize ranks third among cereal crops after rice and wheat. In India, maize is emerging as a strategic crop due to its expanding demand and adaptability across agro-ecological regions. In particular, the Western Indo-Gangetic Plains (WIGP) has witnessed increasing cultivation of spring maize under irrigated conditions because of its higher productivity and economic returns compared to rainy-season maize (Kumar *et al.*, 2025). Despite its high yield potential, the productivity of maize in the WIGP remains constrained due to sub-optimal crop and nutrient management practices. Among essential plant nutrients, nitrogen is the most limiting macronutrient for maize growth and yield production. Nitrogen is a key constituent of chlorophyll, amino acids, proteins, and enzymes and it plays a pivotal role in photosynthesis, leaf area development, biomass accumulation and grain formation. Adequate nitrogen availability is therefore crucial for enhancing dry matter production and its effective partitioning between vegetative & reproductive organs and grain yield (Ciampitti and Vyn, 2011).

The dose of nitrogen application significantly influences nitrogen dry matter production and grain yield in maize. Increasing nitrogen levels improved plant height, leaf area index, dry matter accumulation and grain yield up to an optimum level beyond which yield gains diminish and environmental risks increase. The improved nitrogen supply prolongs the duration of dry matter accumulation and increases the rate of biomass production contributing more than 70% to final grain yield (Zhai *et al.,* 2022). Nitrogen also enhances leaf area index, chlorophyll content and root growth which increase biomass and grain yield up to optimal rates of nitrogen in maize (Meena *et al.,* 2016 and Jyothsna *et al.,* 2024). Dry matter accumulation produced through photosynthesis, is a key factor determining maize yield. The partitioning of dry matter between vegetative organs (leaves and stems) and reproductive organs (grains) determines the efficiency of grain formation and harvestable yield (Zhai *et al.,* 2022 and Ming *et al.*, 2022). Increasing nitrogen rates enhanced leaf area development, photosynthetic capacity and duration of active growth leading to greater dry matter accumulation (Zhang *et al.,* 2020). Therefore, Adequate nitrogen supply ensures that more assimilates are directed toward reproductive organs, improving grain filling and final grain yield. Conversely, nitrogen deficiency limits vegetative growth reduces photosynthetic efficiency and alters the pattern of dry matter partitioning resulting in lower grain yield (Yang *et al.*, 2023). The maize responds positively to increasing nitrogen doses up to an optimum level after which additional nitrogen may not significantly increase biomass or yield (Parmar and Sharma, 2001). Moreover, the nitrogen doses between 120–180 kg N ha^{-1} have been reported to maximize dry matter accumulation and grain yield in spring maize under rainfed and irrigated conditions (Singh *et al.,* 2025). However, excessive or imbalanced nitrogen application leads to poor NUE, nitrate leaching, gaseous nitrogen losses, reducing production efficiency and sustainability (Bhatt *et al.,* 2025).

The timing of nitrogen application is equally critical for synchronizing nutrient availability with crop demand. Split application of nitrogen at critical growth stages such as basal, knee-height and tasseling stages have been found superior to single basal application in improving nitrogen uptake, post-anthesis dry matter accumulation, grain filling and yield (Singh *et al.,* 2025 and Gamit *et al.,* 2023). Optimized nitrogen scheduling enhances nitrogen remobilization from vegetative tissues to grains resulting in higher harvest index and improved NUE (Padhan *et al.,* 2020 and Kumar *et al.,* 2023). Nitrogen application at a time when it is needed most and taken up at high rates by maize plants could enhance nitrogen use efficiency by reducing the immobilization, denitrification and leaching losses (Rizwan *et al.,* 2003) Nitrogen deficiency from seedling to V8 stage cause 30% reduction in yield, withhold nitrogen supply from V8 to maturity reduce yield by 22%, however, there is no yield reduction when nitrogen is deficient from silking or 3 week after silking to physiological maturity (Subedi and Ma, 2005). Hassan *et al.,* (2010) reported that application of nitrogen in three splits at planting, V4 and V6 stages significantly increased number of leaves $plant^{-1}$, plant height, leaf area index, leaf area duration, crop growth rate and total dry matter. Mariga *et al.,* (2000) reported that biomass yield in maize considerably increased when nitrogen was applied up to tassel initiation stage. Nemati *et al.,* (2012) reported that highest protein content (12.9%) was recorded with nitrogen application timing T_1 (1/3 in planting + 1/3 in 8-10 leaf stages + 1/3 in tassel initiation) followed by T_3 (½ in planting + ¼ in 8-10 leaf stages + ¼ in tassel initiation) and T_2(½ planting + ½ in tassel initiation). Production efficiency and monetary efficiency are important indicators for evaluating the agronomic and economic performance of nitrogen management practices. Optimized nitrogen dose improved agronomic efficiency, partial factor productivity and net returns by reducing input costs and enhancing yield (Hussain *et al.,* 2023). Despite extensive research on nitrogen management in maize, comprehensive studies integrating dry matter partitioning, production efficiency, and monetary efficiency under varying nitrogen doses and application timings are limited for spring maize in the Western Indo-Gangetic Plains. Therefore, the present investigation was undertaken to evaluate the effect of dose and time of nitrogen application on dry matter partitioning, production efficiency and monetary efficiency of spring maize (*Zea mays* L.) in the Western Indo-Gangetic Plains of India.

Materials and Methods

Experimental site and weather conditions

The experiment was carried out at Regional Research Station, Uchani, Karnal of Chaudhary Charan Singh Haryana Agricultural University, Hisar during *spring* seasons of 2013 and 2014. The experimental site is situated in semi-arid, sub-tropics at 29° 43´N latitude and 76° 58´E longitude at an altitude of 245 meters above the mean sea level. The soil of experimental field was sandy loam in texture, slightly alkaline in reaction (8.10), low in organic carbon (0.36%) and available nitrogen (149.0 kg ha^{-1}), medium in available phosphorus (11.0 kg ha^{-1}) and potassium (175.0 kg ha^{-1}). The mean maximum temperature is as high as 45 ^{0}C during summer and minimum temperature near 0 ^{0}C accompanied by frost in peak winter months of December and January is common feature of the climate of this region. Mean weekly meteorological data were recorded during crop season from March to July during both the year. The mean of two year weekly maximum and minimum temperature fluctuated between 25.75 and 44.55^{0}C and between 11.3 and 27.75^{0}C respectively. The total rainfall was recorded to be 169.6 mm and 178.8 mm during the crop seasons of 2013 and 2014, respectively.

Experimental design and field implementation

This experiment was laid out in a strip plot design with four nitrogen doses in main plots (N_1 -150 kg ha^{-1}, N_2 – 165 kg ha^{-1}, N_3 -180 kg $ha^{-1}$and N_4 - 195 kg ha^{-1}) and four time of nitrogen applications (S_1 - 50% + 25% + 25 % (sowing+ 8 leaf + tassel initiation), S_2 - 25% + 25% + 25% + 25% (sowing+ 4 leaf + 8 leaf + silking), S_3 - 20% + 30% + 40% + 10% (sowing+ 6 leaf + flowering + grain formation) and S_4 - 20% + 30% + 40% + 10% (2 leaf+ 6 leaf +tassel initiation + grain formation) in sub plots. The sixteen treatments were comprised with a gross plot size of 4 m × 3.75 m and three replications for each treatment, the total gross plot area was 15 m^2. The net plot size was decreased to 11.52 m^2 (3.20 m × 3.60 m) for observational purposes. Nitrogen nutrient in the form of urea (46% N) was used for the study. Nitrogen was applied at different dose and time based on treatments. Pre-sowing irrigation was applied to the field to facilitate preparatory tillage and seed germination. The seed bed was prepared by two harrowing followed by cultivator twice followed by planking and then opening of furrows in dry condition for dibbling of maize manually. The maize variety HQPM-1 was sown on 5 March and 10 March 2013 and 2014, respectively. Crop was sown using 20 kg ha^{-1} seed by dibbling method on dry ridges apart 60 cm with plant to plant spacing of 20 cm followed by irrigation up to half of the ridge to ensure proper soil moisture for better germination of seed. Seeds were treated with 2 g carbendazim kg^{-1} seed to control fungal diseases. The recommended rate of phosphorus and potassium nutrients (60 kg ha^{-1}) was applied uniformly to all plots at the time of sowing. SSP and MOP were used as a source of phosphorous and potassium in the form of P_2O_5 and K_2O.

Sampling and measurement

The five randomly selected plants for growth observations were used to record the dry matter production at various stages of growth. The sampled plants were separated into leaves, stem, tassel and cobs with husk. These samples were dried at 70 °C to constant dry weight. Dry weight was recorded separately at each stage to assess dry matter accumulation in different parts and total dry matter production was expressed in gram $plant^{-1}$. The daily production capacity of a specific treatment referred to as production efficiency (PE) was measured in kilograms per hectare per day ($kgha^{-1}$ day^{-1}) and was calculated using the following formula:

$$\text{PE (kgha}^{-1}\text{ day}^{-1}) = \frac{\text{Total grain yield (kg ha}^{-1})}{\text{Cropping period (Days)}}$$

Monetary efficiency (ME) is a measure of the daily economic return capacity for each treatment and is expressed in units of Rs. ha^{-1} day^{-1}. This value was calculated using the following equation:

$$\text{ME (Rs. ha}^{-1}\text{ day}^{-1}) = \frac{\text{Total net returns (Rs. ha}^{-1})}{\text{Cropping period (Days)}}$$

Data recorded for the various parameters were analysed using analysis of variance (ANOVA) following the strip-plot design as described by Gomez and Gomez (1983). The analysis was performed using SAS software (version 9.1; SAS Institute, Cary, NC). When the ANOVA indicated significant effects, treatment means were compared using Tukey's test at the 5% level of significance (P = 0.05).

Results and Discussion

Effect of dose and time of nitrogen application on leaf dry weight (g)

Leaf dry weight of maize was markedly affected by different nitrogen does at all growth stages except at 25 DAS during both years of experimentation. The increasing in nitrogen dose resulted in higher leaf dry weight (Table

Table 1: Effect of dose and time of nitrogen application on leaf dry weight plant^{-1} (g) of spring maize.

Treatments	25 DAS		50 DAS		75 DAS		100 DAS		At harvest	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Nitrogen dose (kg ha^{-1})										
N_1-150	4.20	4.12	14.50	12.98	20.20	17.87	21.78	19.32	19.72	16.78
N_2-165	4.32	4.22	16.07	14.69	22.51	20.06	24.44	21.35	22.30	18.84
N_3-180	4.47	4.30	17.59	16.09	25.76	21.94	27.67	24.25	25.56	21.74
N_4-195	4.58	4.40	18.65	17.17	27.26	23.74	29.08	25.67	27.07	23.15
SEm±	0.11	0.11	0.45	0.56	0.77	0.71	0.87	0.75	0.89	0.63
C.D.(0.05)	NS	NS	1.54	1.93	2.67	2.47	3.01	2.59	3.07	2.17
Time of nitrogen application										
S_1	4.47	4.29	17.41	15.97	25.03	22.33	27.30	24.56	25.29	22.04
S_2	4.68	4.41	18.85	17.37	27.31	24.96	30.43	26.93	28.32	24.42
S_3	4.19	4.13	14.86	13.38	20.50	17.65	21.64	18.41	19.53	15.88
S_4	4.24	4.21	15.69	14.21	21.90	18.67	23.59	20.59	21.51	18.18
SEm±	0.12	0.13	0.48	0.61	1.04	0.88	0.94	0.90	1.13	0.97
C.D.(0.05)	NS	NS	1.65	2.10	3.61	3.05	3.26	3.12	3.90	3.34

1). The highest leaf dry weight plant^{-1} was observed under the application of 195 kg N ha^{-1}(N_4) which remained statistically comparable with 180 kg N ha^{-1} (N_3) at 50, 75, and 100 DAS as well as at harvest in both years. This might be due to the fact that greater nitrogen supply resulted into more cell division and expansion and consequently more leaf areas and therefore, more leaf dry weight. Among the recorded stages, leaf dry weight peaked at 100 DAS, registering values of 29.08 and 25.67 g plant^{-1} during 2013 and 2014, respectively, followed by a slight decline at harvest stage (27.07 and 23.15 g plant^{-1}). Nitrogen-limiting conditions can hinder plant development by delaying silking, decreasing pre-anthesis crop growth rate, reducing leaf area index during flowering, and accelerating leaf senescence rates throughout the plant's life cycle. The different time of nitrogen application significantly influenced leaf dry weight plant^{-1} at all the growth stages except at 25 DAS during both the years. The maximum leaf dry weight plant^{-1} was obtained under S_2 - 25% + 25% + 25% + 25% (sowing+ 4 leaf + 8 leaf + silking) at 50, 75, 100 DAS and at harvest which was at par with S_1 - 50% + 25% + 25 % (sowing+ 8 leaf + tassel initiation) during both years of investigation. Whereas, minimum leaf dry weight plant^{-1} was obtained with S_3 - 20% + 30% + 40% + 10% (sowing+ 6 leaf + flowering + grain formation) which was statistically similar with S_4 - 20% + 30% + 40% + 10% (2 leaf+ 6 leaf +tassel initiation + grain formation) at 50, 75, 100 DAS and at harvest. Similar results were reported by Greef *et al.*, (1999) who reported that increase in nitrogen rates and split application for nitrogen at critical stage delayed silking and promoting longer vegetative growth period of maize resulting into higher leaves dry weight plant^{-1}. Pandy *et al.*, (2000) and Turgut (2000) also reported that maize differed in dry matter production at different levels of nitrogen.

Effect of dose and time of nitrogen application on stem dry weight (g)

The nitrogen dose significantly affected stem dry weight plant^{-1}. Maize grown in 2013 had higher stem dry weight than maize grown in 2014. Increase in nitrogen dose from 150 to 195 kg ha^{-1} increased stem dry weight at all the growth stages except 25 DAS during both the years. (Table 2). The maximum stem dry weight was recorded in plots to which nitrogen was applied at N_4-195 kg N ha^{-1}, it was statistically similar with N_3-180 kg N ha^{-1} at 50, 75, 100 DAS and at harvest during both the year of study, whereas minimum stem dry weight was obtained in plots to which nitrogen was applied at N_1-150 kg N ha^{-1}. Similar results reported by Anas *et al.*, (2020) who observed that optimum nitrogen levels can enhance the growth rate, extend the duration of vegetative activity, promote greater leaf expansion and ultimately lead to increased dry matter accumulation in maize. The time of nitrogen application also significantly influenced stem dry weight at different growth stages except at 25 DAS during both the years. In general, four equal split of nitrogen produced more stem dry weight than four unequal split and three split of nitrogen. Application of S_2 - 25% + 25% + 25% + 25% (sowing+ 4 leaf + 8 leaf + silking) produced higher stem dry weight which was statistically similar with S_1 - 50% + 25% + 25 % (sowing+ 8 leaf + tassel initiation) at 50, 75, 100 DAS and at harvest than other timing of nitrogen application during both the years. Lowest stem dry weight was recorded with S_3 - 20% + 30% + 40% + 10% (sowing+ 6 leaf + flowering + grain formation) at 25 DAS during both the years. Similar result was reported by Hammad *et al.*, (2011).

Table 2: Effect of dose and time of nitrogen application on stem dry weight plant^{-1} (g) of spring maize

Treatments	25 DAS		50 DAS		75 DAS		100 DAS		At harvest	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Nitrogen dose (kg ha^{-1})										
N_1-150	3.41	3.30	18.34	17.30	34.61	30.18	46.91	38.31	51.53	43.43
N_2-165	3.52	3.41	20.12	19.20	39.57	35.03	52.35	43.23	57.05	48.86
N_3-180	3.61	3.49	21.64	20.60	45.17	40.49	58.54	48.35	63.49	54.06
N_4-195	3.72	3.60	22.79	21.78	47.43	43.77	62.74	54.60	68.37	60.21
SEm±	0.11	0.12	0.55	0.56	1.30	1.00	1.29	1.85	1.48	1.83
C.D.(0.05)	NS	NS	1.93	1.94	4.49	3.46	4.45	6.39	5.13	6.34
Time of nitrogen application										
S_1	3.64	3.53	21.43	20.46	43.57	38.99	57.58	49.35	62.46	54.81
S_2	3.85	3.73	22.87	21.86	47.40	42.95	60.41	53.23	65.82	57.89
S_3	3.36	3.25	18.88	17.87	36.53	32.54	49.65	38.92	54.38	44.54
S_4	3.42	3.30	19.71	18.70	39.29	35.01	52.90	42.99	57.77	49.31
SEm±	0.12	0.14	0.46	0.49	1.24	1.72	1.54	1.53	1.52	0.97
C.D.(0.05)	NS	NS	1.58	1.70	4.28	5.94	5.34	5.30	5.26	3.35

Effect of dose and time of nitrogen application on tassel dry weight (g)

Statistically analysis of two year data indicated that nitrogen dose and time of nitrogen application had no significant influence on tassel dry weight (Table 3). It might be due to the fact that the size of tassel is controlled more by genetic factors rather than environmental factors. Similar observations have been reported in earlier studies by Dar *et al.,* (2014).

Effect of dose and time of nitrogen application on dry weight of cob (g)

Two-year statistical analysis of data revealed that cob dry weight was significantly affected by dose and time of nitrogen application at all growth stages, except at 75 DAS during the 2013 season. An increase in nitrogen dose from 150 to 195 kg N ha^{-1} resulted in a progressive improvement in cob dry weight (Table 4). The highest cob dry weight was recorded at harvest under the application of 195 kg N ha^{-1} (N_4) with values of 95.06 g in 2013 and 84.07 g in 2014. This treatment was statistically at par with 180 kg N ha^{-1} (N_3), which recorded cob dry weights of 87.75 and 76.74 g during 2013 and 2014, respectively, but significantly superior to the lower nitrogen levels of 165 and 150 kg N ha^{-1}. These findings are consistent with those of Biswas *et al.,* (2021) who reported greater cob weight with nitrogen application up to 200 kg ha^{-1}. The time of nitrogen application significantly influenced cob dry weight at different growth stages during both the years. The equal four split of nitrogen produced more cob dry weight than unequal four split of nitrogen and three split. Application of S_2 - 25% + 25% + 25% + 25% (sowing+ 4 leaf + 8 leaf + silking) produced higher cob dry weight which was at par with S_1 - 50% + 25% + 25 % (sowing+ 8 leaf + tassel initiation) than the rest of the application times. However, lowest cob dry weight was observed with S_3 - 20% + 30% + 40% + 10% (sowing+ 6 leaf + flowering + grain formation) at 75 DAS (9.89 and 8.50 g) during both the year of investigation, respectively. The application of more nitrogen during the reproductive period improved cob dry weight. Greater availability of mineral nutrients especially nitrogen may lead to higher leaf area and rates of photosynthesis and their partitioning to reproductive structures including cob formation. Similar differences in partition of dry matter in maize were reported by Pandy *et al.,* (2000) and Turgut (2000).

Table 3: Effect of dose and time of nitrogen application on tassel dry weight plant^{-1} (g) of spring maize.

Treatments	75 DAS		100 DAS		At harvest	
	2013	2014	2013	2014	2013	2014
Nitrogen dose (kg ha^{-1})						
N_1-150	5.30	4.43	5.61	5.04	4.59	3.79
N_2-165	5.77	4.97	6.01	5.27	4.88	4.06
N_3-180	5.93	4.90	6.12	5.44	4.92	4.23
N_4-195	6.29	5.42	6.74	5.83	5.52	4.36
SEm±	0.21	0.21	0.26	0.15	0.31	0.21
C.D.(0.05)	NS	NS	NS	NS	NS	NS
Time of nitrogen application						
S_1	5.91	4.86	6.27	5.43	5.12	4.21
S_2	6.20	5.67	6.36	6.02	5.20	4.54
S_3	5.44	4.40	5.81	4.86	4.67	3.65
S_4	5.74	4.79	6.05	5.28	4.93	4.05
SEm±	0.15	0.26	0.12	0.27	0.18	0.28
C.D.(0.05)	NS	NS	NS	NS	NS	NS

Effect of dose and time of nitrogen application on production efficiency (kg ha^{-1} day^{-1})

Data pertaining to the production efficiency of maize

Table 4: Effect of dose and time of nitrogen application on dry weight cob^{-1} (g) of spring maize.

Treatments	75 DAS		100 DAS		At harvest	
	2013	2014	2013	2014	2013	2014
Nitrogen dose (kg ha^{-1})						
N_1-150	10.07	8.28	49.04	40.78	58.60	48.64
N_2-165	11.36	10.48	59.89	51.28	73.58	61.36
N_3-180	11.88	10.51	71.18	61.67	87.75	76.74
N_4-195	12.80	11.40	80.44	69.61	95.06	84.07
SEm±	0.57	0.36	2.49	2.87	2.79	3.51
C.D.(0.05)	NS	1.24	8.63	9.95	9.64	12.14
Time of nitrogen application						
S_1	12.31	10.88	70.46	59.63	84.11	71.48
S_2	13.07	11.79	79.86	70.31	93.06	83.26
S_3	9.89	8.50	50.76	43.01	64.68	54.68
S_4	10.83	9.50	59.48	50.39	73.14	61.39
SEm±	0.43	0.28	3.17	4.37	2.83	3.43
C.D.(0.05)	1.49	0.97	10.98	15.11	9.81	11.86

as influenced by nitrogen dose and time of application are presented in Table 5. The results indicated that production efficiency increased progressively with increasing nitrogen levels from 150 to 195 kg N ha^{-1}. Among the nitrogen doses, application of 195 kg N ha^{-1} (N_4) recorded the highest production efficiency (48.09 and 45.73 kg ha^{-1} day^{-1}) which was closely followed by 180 kg N ha^{-1} (N_3) with values of 46.56 and 43.87 kg ha^{-1} day^{-1} during 2013 and 2014, respectively. It indicates that maize responded positively to higher nitrogen availability under the experimental conditions. Similar responses have been reported by Zhao *et al.*, (2019) who observed that increased nitrogen rates significantly enhanced maize productivity and growth efficiency by prolonging leaf greenness and improving radiation use efficiency. The relatively lower production efficiency at reduced nitrogen levels may be attributed to nitrogen deficiency during critical growth stages which restricts crop growth rate, accelerates leaf senescence and reduces assimilate production (Ciampitti and Vyn, 2018). The variations in maize production efficiency were also observed due to the time of nitrogen application. The results revealed that nitrogen applied in four equal splits S_2 - 25% + 25% + 25% + 25% (sowing+ 4 leaf + 8 leaf + silking) resulted in the highest production efficiency (46.69 and 43.95 kg ha^{-1} day^{-1}) which was superior to S_4 recording lower values of 43.00 and 40.70 kg ha^{-1} day^{-1} during 2013 and 2014, respectively. This was followed by S_3 which recorded the lowest production efficiency (40.42 and 37.70 kg ha^{-1} day^{-1}). Application of nitrogen under S_1 resulted in production efficiency values of 45.97 and 43.83 kg ha^{-1} day^{-1} which were comparable with S_2, but higher than S_2 and S_4 during both years. This practice

Table 5: Effect of dose and time of nitrogen application on production efficiency and monetary efficiency of spring maize.

Treatments	Production efficiency (kg ha^{-1} day^{-1})		Monetary efficiency (Rs. ha^{-1} day^{-1})	
	2013	2014	2013	2014
Nitrogen dose (kg ha^{-1})				
N_1-150	39.47	37.22	314.94	291.15
N_2-165	41.97	39.37	351.26	322.72
N_3-180	46.56	43.87	412.72	383.41
N_4-195	48.09	45.73	433.24	408.01
SEm±	-	-	-	-
C.D.(0.05)	-	-	-	-
Time of nitrogen application				
S_1	45.97	43.83	406.12	385.23
S_2	46.69	43.95	416.40	387.51
S_3	40.42	37.70	325.24	293.98
S_4	43.00	40.70	364.42	338.56
SEm±	-	-	-	-
C.D.(0.05)	-	-	-	-

ensures a continuous and balanced nitrogen supply throughout the crop growth period, particularly during rapid vegetative growth like tasseling and grain filling stages. Improved synchronization reduces nitrogen losses and enhances nitrogen uptake and utilization efficiency, thereby increasing daily productivity (Li *et al.*, 2021 and Xu *et al.*, 2022).

Effect of dose and time of nitrogen application on monetary efficiency (Rs. ha^{-1} day^{-1})

The monetary efficiency of maize was influenced by nitrogen dose during both years of experimentation (Table 5). The crop grown in 2013 recorded comparatively higher monetary efficiency than that grown in 2014. Among the nitrogen doses, application of N_4-195 kg N ha^{-1} resulted in the maximum monetary efficiency of Rs. 433.24 and Rs. 408.01 ha^{-1} day^{-1} during 2013 and 2014, respectively. This treatment was superior to N_3-180 kg N ha^{-1} which recorded monetary efficiency values of Rs. 412.72 and Rs. 383.41 ha^{-1} day^{-1} in the respective years. The lowest monetary efficiency was recorded under N_1-150 kg N ha^{-1}). These results support earlier findings by Ciampitti and Vyn (2018) and Li *et al.*, (2021), who emphasized that optimized nitrogen management enhances economic returns in maize production. Among the nitrogen application, treatment of S_2 - 25% + 25% + 25% + 25% (sowing+ 4 leaf + 8 leaf + silking) recorded the highest monetary efficiency (Rs 416.40 and Rs 387.51 ha^{-1} day^{-1} followed closely by S_1 (Rs 406.12 and Rs 385.23 ha^{-1} day^{-1}. The lowest monetary efficiency was observed under S_3 (Rs 325.24 and Rs 293.98 ha^{-1} day^{-1} during both years. These observations are consistent with the findings of Xu *et al.*, (2022) and Zhang *et al.*, (2018), who reported improved economic performance of maize under appropriately timed split nitrogen applications.

Acknowledgment

This work forms part of my Ph.D. research. I gratefully acknowledge all the authors whose work has contributed to this study. I am sincerely thankful to CCS Haryana Agricultural University for providing the necessary infrastructural facilities and support during the course of my research.

Conflict of interest: The authors do not have any conflicts of interest.

References

Anas, M., Liao F., Verma K.K., Sarwar M. A., Aamir M., Chen Z-L., Li Q., Zeng X-P., Liu Y. and Li Y-R. (2020). Fate of nitrogen in agriculture and environment: agronomic, eco-physiological and molecular approaches to improve nitrogen use efficiency. *Biological Research*. **53(47)**. https://doi.org/10.1186/s40659-020-00312-4

Bhatt, R., Kunal Moulick D., Barek V., Brestic M., Gaber A. and Skalicky M. (2025). Sustainable strategies to limit nitrogen loss in agriculture through improving its use efficiency-aiming to reduce environmental pollution. *Journal of Agriculture and Food Research*. **101957 (22)**, 1-12. https://doi.org/10.1016/j.jafr.2025.101957

Biswas, P.K., Sarna N.J. and Shome S. (2021). Influence of nitrogen dose and application method on growth and yield of baby corn. *Bangladesh Agronomy Journal*. **24(2)**, 83-90.

Ciampitti, I.A. and Vyn T.J. (2011). A comprehensive study of plant density consequences on nitrogen uptake dynamics of maize plants from vegetative to reproductive stages. *Field Crops Research*, **121(1)**, 2–18.

Ciampitti, I.A. and Vyn T.J. (2018). Physiological perspectives of nitrogen use efficiency in maize. *Field Crops Research*. **225**, 10–18.

Dar, E.A., Harika A.S., Datta A. and Jat H.S. (2014). Growth, yield and economic returns from the dual-purpose baby corn (*Zea mays* L.) under different planting geometry and nitrogen levels. *Indian Journal of Agronomy*. **59(3)**, 468–470.

Gamit, M.K., Bavalgave V.G., Patel K.K. and Ganvit J.M. (2023). *Effect of different levels and times of nitrogen application on grain and forage quality of sweet corn (Zea mays* L. saccharata*). International Journal of Environment and Climate Change*. **13(12)**, 457–464.

Gomez, K.A. and Gomez A.A. (1983). Statistical procedures for agricultural research. Second Adi. *An International Rice Research Institute book*.

Greef, J.M., Ott H., Wulfes R. and Taube F. (1999). Growth analysis of dry matter accumulation and nitrogen uptake of forage cultivars affected by nitrogen supply. *Journal of Agricultural Science*. **132(1)**, 31-43.

Hammad, H.M., Ahmad A., Wajid A. and Akhter J. (2011). Maize response to time and rate of nitrogen application. *Pakistan Journal of Botany*. **43(4)**, 1935-1942.

Hassan, S.W., Oad F.C., Tunio S., Candahi A.W., Siddiqui M.H., Oad S.M. and Jagirani A.W. (2010). Effect of N application and N splitting strategy on maize N uptake, biomass production and physio-agronomic characteristics. *Sarhad Journal of Agriculture*. **26(4)**, 551-558.

Hussain, T., Mulla D.J., Hussain N., Qin R., Tahir M., Liu K., Harrison M.T., Sinutok S. and Duangpan S. (2023). Optimizing nitrogen fertilization to enhance productivity and profitability of upland rice using CSM–CERES–Rice. *Plants*. **12(21)**, 3685. https://doi.org/10.3390/plants12213685.

ICAR-IIMR (2021). Annual Report 2020–2021. ICAR-Indian Institute of Maize Research, Pusa, New Delhi.

Jyothsna, K., Padmaja J., Sreelatha D., Mahender Kumar R. and Madhavi A. (2024). Different management of nitrogen application affected growth characteristic of maize (*Zea mays* L.). *International Journal of Environment and Climate Change*. **14(4)**, 487–493. https://doi.org/10.9734/ijecc/2024/v14i44134.

Kumar, K., Parihar C.M., Nayak H.S., Godara S., Avinash G. and Patra K. (2023). Enhancing maize yield in a conservation agriculture-based maize (*Zea mays*)–wheat (*Triticum aestivum*) system through efficient nitrogen management. *The Indian Journal of Agricultural Sciences*. **93(4)**, 420–424.

Kumar, M., Pannu R.S. and Malik D.P. (2025). An economic appraisal and resource use efficiency of spring maize cultivation in Haryana . *Indian Journal of Agricultural Research*, **59(5)**, 833-838. doi: 10.18805/IJARe.A-6116.

Layek, J., Ramkrushna G.I., Suting D., Ngangom B., Krishnappa R., Utpal De and Das A. (2016). Evaluation of maize cultivars for their suitability under organic production system in North eastern hill region of India. *Indian Journal of Hill Farming*. **29(2)**, 19–24.

Li, S., Zhang Y., Liu Y., Gao Y. and Shen Q. (2021). Split nitrogen application improves nitrogen use efficiency and maize yield. *Agronomy Journal*. **113**, 1–12.

Mariga, I.K., Jonga M. and Chivinge O.A. (2000). The effect of timing of application of basal and top dressing fertilizers on maize yield at two rates of basal fertilizer. *Crop Research*. **20**, 372-380.

Meena, S.K., Mundra, S.L. and Mali H. (2016). Effect of nitrogen and zinc fertilization on quality and productivity of maize (*Zea mays* L.). *Agricultural Research Journal*. **53(2)**, 196–199. https://doi.org/10.5958/2395-146X.2016.00037.5

Ming, H., Cai F., Mi N., Zhang Y., Zhang H., Zhang S., Zhao X. and Feng Y. (2022). Allometric relationships between dry matter weights of maize organs and their responses to drought. *Water*. **15(1)**, 99. https://doi.org/10.3390/w15010099.

Nemati, A.R. and Sharifi R.S. (2012). Effects of rates and nitrogen application timing on yield, agronomic characterstics and nitrogen use efficiency in corn. *International Journal of Agriculture and Crop Sciences.* **4(9)**, 534-539.

Padhan, B.K., Sathee L. and Jain V. (2020). *Nitrogen remobilization and its importance in nitrogen use efficiency (NUE) of crops*. The *Indian Journal of Agricultural Sciences.* **90(12)**, 2251–2261.

Pandey, R.K., Maranville J.W. and Chetima M.M. (2000). Deficit irrigation and nitrogen effects on maize in a Sahelian environment. II. Shoot growth, nitrogen uptake and water extraction. *Agriculture and Water Management*. **46**, 15-27.

Parmar, D.K. and Sharma V. (2001). Nitrogen requirement of single hybrid maize (*Zea mays*)- wheat (*Triticum aestivum*) system under rainfed conditions. *The Indian Journal of AgriculturalScience*. **71(4)**. https://epubs.icar.org.in/index.php/IJAgS/article/view/39723.

Rizwan, M., Maqsood M., Rafiq M., Saeed M. and Ali Z. (2003). Maize (*Zea mays* L.) response to split application of nitrogen. *International Journal of Agriculture & Biology*. **5(1)**, 19-21.

Singh, A., Uppal R.S., Singh B. and Kaur V. (2025). Effect of split application of nitrogen on growth and yield of maize. *International Journal of Environmental Sciences.* **11(14S)**, 70–79. https://www.theaspd.com/ijes.php.

Subedi, K.D. and Ma B.L. (2005). Nitrogen uptake and partitioning in stay green and leafy maize hybrids. *Crop Science*. **45**, 740-747.

Turgut, I. (2000). Effects of plant populations and nitrogen doses on fresh ear yield and yields components of sweet corn grown under Bursa conditions. *Turkish Journal of Agriculture and Forestry.* **24**, 341-347.

Xu, X., He P., Pampolino M.F., Johnston A.M. and Zhou W. (2022). Nutrient management strategies for improving nitrogen efficiency. *Nutrient Cycling in Agro-ecosystems*. **123**, 1–15.

Yang, Y., Zhang S. and Su Z. (2023). Variation in nitrogen partitioning and reproductive stage nitrogen remobilization determines nitrogen grain production efficiency (NUEg) in diverse rice genotypes under varying nitrogen supply. *Frontiers in Plant Science*. **14**, 1093581. https://doi.org/10.3389/fpls.2023.1093581.

Zhai, J., Zhang G., Zhang Y., Xu W., Xie R., Ming B., Hou P., Wang K., Xue J. and Li S. (2022). Effect of the rate of nitrogen application on dry matter accumulation and yield formation of densely planted maize. *Sustainability.* **14(22)**, 14940. https://doi.org/10.3390/su142214940.

Zhang, X., Davidson E.A., Mauzerall D.L., Searchinger T.D., Dumas P. and Shen Y. (2018). Managing nitrogen for sustainable crop production. *Nature.* **528**, 51–59.

Zhang, Z., Zhang Y., Shi Y. and Yu Z. (2020). Optimized split nitrogen fertilizer increases photosynthesis, grain yield, nitrogen use efficiency and water use efficiency under water-saving irrigation. *Scientific Reports*. **10**, 20310. https://doi.org/10.1038/s41598-020-75388-9.

Zhao, B., Ata-Ul-Karim S.T., Liu Z., Zhang J., Xiao J., Liu Z. and Zhang Y. (2019). Split nitrogen application increases maize yield and efficiency. *Agricultural Systems*. **176**, 102–110.