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Influence of Different Methods and Levels of Nano Fertilizers Application on Growth and Growth Indices of Maize (*Zea mays*)

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Abstract

The field experiment was conducted at Agronomy Field Unit, ZARS, UAS-B, GKVK, Bengaluru during *kharif* 2022 to study the influence of different methods and levels of nano fertilizers on growth and growth indices of maize (*Zea mays*). The experiment was composed of two main factors (A_1 - Soil application and A_2 - Foliar application), three sub factors (N_1 - Nano urea @ 2 ml L^{-1}, N_2 - Nano urea @ 4 ml L^{-1} and N_3 - Nano urea @ 6 ml L^{-1}) and three sub-sub factors (P_1 - Nano DAP @ 2 ml L^{-1}, P_2 - Nano DAP @ 4 ml L^{-1} and P_3 - Nano DAP @ 6 ml L^{-1}) with total of 18 treatment combinations replicated thrice and laid out in split-split plot design. The results indicated that, foliar application of nano fertilizers recorded higher plant height (248 cm), number of photosynthetically active leaves $plant^{-1}$ (8.27), leaf area $plant^{-1}$ (2560 cm^2), leaf area index (1.42), leaf area duration (83.02 days), total dry matter production $plant^{-1}$ (444 g) and SPAD values (44.26) over soil application at harvest. Among different levels of nano urea, application of nano urea @ 6 ml L^{-1} recorded higher plant height (247 cm), number of photosynthetically active leaves $plant^{-1}$ (8.20), leaf area $plant^{-1}$ (2563 cm^2), leaf area index (1.42) and leaf area duration (82.84 days) which is on par with nano urea @ 4 ml L^{-1} compared to nano urea @ 2 ml L^{-1} at harvest. Among the various levels of nano DAP, application of nano DAP @ 6 ml L^{-1} recorded higher plant height (246 cm), number of photosynthetically active leaves $plant^{-1}$ (8.11), leaf area $plant^{-1}$ (2492 cm^2), leaf area index (1.38) and leaf area duration (82.03 days) which is on par with application of nano DAP @ 4 ml L^{-1} over nano DAP @ 2 ml L^{-1} at harvest.

Keywords : Nano urea, Maize, Foliar application, Soil application, Photosynthetically active leaves $plant^{-1}$

Maize widely known as the 'Queen of cereals' is the world's third most important cereal crop, widely adaptable and cultivated globally for both grain and fodder. It is referred to as the 'Queen of cereals' due to its superior yield potential compared to other cereal crops. Maize is a crop that has the higher productivity when compared to other cereal crops (Malhotra, 2017). Primarily grown as a *kharif* crop, maize is sown from the last week of May to the end of June and harvested between September and October. Maize has a yield potential of 10 t ha^{-1}, which can be significantly increased to 18 t ha^{-1} with improved field management practices. Global demand for maize is projected to double by 2050. Improper nutrient management is one of the main reasons for the low productivity. Therefore, it is essential to increase maize productivity by implementing innovative and sustainable nutrient management practices. No single nutrient source can fully satisfy the complete nutritional requirements of a plant. To address this issue, a new class of fertilizers called nano fertilizers can be utilized, which enhance crop production and support sustainable agriculture. Soil fertility, which refers to the soil's ability to produce crops, is crucial for increasing agricultural output, food security and rural income. Without maintaining the soil fertility, it will become difficult to cultivate crops on that soil. Achieving this requires not only proper fertilizer application but also the use of a variety of fertilizer types. This approach includes the use of specialized formulations, micronutrient fertilizers, and organic fertilizers. By adopting a multi dimensional approach, farmers can enhance soil structure, optimize nutrient availability and promote sustainable farming practices, leading to increased yields, improved livelihoods and more resilient food systems (Mahmood *et al.*, 2017). Excessive use of synthetic fertilizers leads to pollution of the air, water and land, while also causing financial challenges. The sustainable application of nano-fertilizers in enhancing soil fertility and crop productivity has shown considerable potential with little to no environmental trade-offs.

Material and Methods

A field experiment was carried out at the Agronomy Field Unit of the Zonal Agricultural Research Station, University of Agricultural Sciences, Gandhi Krishi Vigyan Kendra, Bengaluru. The experimental site is located in the Eastern Dry Zone (Agro Climatic Zone V) of Karnataka, situated at 13º 05' North latitude and 77º 34' East longitude, with an elevation of 924 meters above mean sea level. The study area received 513 mm of precipitation during the *kharif* 2022. The experiment involved in eighteen treatment combinations consisting of a main plot with two factors, sub plot with three factors and sub-sub plot with three factors replicated thrice in the split-split plot design and soil was red sandy loam in texture and it was acidic in reaction (pH 5.64) with normal electrical conductivity of 0.30 dS m^{-1} and organic carbon (0.48%) content was low. The seeds of the MAH 14-5 maize variety, developed by the All India Co-ordinated Research Project on Maize, V.C. Farm, Mandya during 2017 were dibbled at the rate of one seed per hill, maintaining a spacing of 60 cm between rows and 30 cm within the rows, with a seed rate of 15 kg ha^{-1}. After sowing, the seeds were covered with a thin layer of soil firmly and the field was irrigated immediately. The farmyard manure was applied 15 days prior to sowing at the rate of 10 t ha^{-1} across all plots uniformly. The fertilizers were applied according to recommendations (150:75:40 kg of $N:P_2O_5:K_2O$ ha^{-1}), with 50 per cent of nitrogen (N) and the full doses of phosphorus (P_2O_5) and potassium (K_2O) applied as basal, while the remaining 50 per cent of nitrogen was applied in two equal split doses as top dressing at 30 and 60 days after sowing (DAS). First irrigation was given immediately after sowing for uniform germination. Subsequent irrigations were given as per the crop requirement based on the soil moisture content and rainfall. All the plots were kept weed free by spraying of pre-emergent herbicide atrazine @ 1.5 kg a.i. ha^{-1} and earthing up was done at 30 days after sowing to all the plots. The treatments included main factors consists of methods of nano fertilizer application (A) are A_1 (Soil application) and A_2 (Foliar application), sub factors consists of levels of nano urea fertilizer (N) includes N_1 (Nano urea @ 2 ml L^{-1}), N_2 (Nano urea @ 4 ml L^{-1}) and N_3 (Nano urea @ 6 ml L^{-1}), whereas, sub-sub factors consists of levels of nano DAP fertilizer (P) are P_1 (Nano DAP @ 2 ml L^{-1}), P_2 (Nano DAP @ 4 ml L^{-1}) and P_3 (Nano DAP @ 6 ml L^{-1}). Biometric observations on growth parameters were recorded on randomly selected five plants at 30, 60, 90 days after sowing and at harvest in the net plot. The various growth parameters such as plant height, number of leaves $plant^{-1}$, leaf area $plant^{-1}$, leaf area index (LAI), leaf area duration (LAD), total dry matter production $plant^{-1}$ and SPAD values were recorded and calculated from five randomly selected and labelled plants at different growth stages of crop (30, 60, 90 DAS and at harvest). The data recorded on various parameters were subjected to Fisher's method of analysis of variance and interpretation of the data was made as given by Gomez and Gomez (1984). The level of significance used in 'F' and 't' test was P = 0.05. Whenever F-test was significant for comparison among the treatments means, an appropriate value of critical differences (CD) was worked out. Otherwise against CD values abbreviation 'NS' (Non-significant) is indicated.

Results and Discussion

Plant Height

The experiment was conducted during *kharif* 2022, data pertaining to plant height at different growth stages of maize as influenced by different methods and levels of nano fertilizers in maize is presented in Table 1.

The plant height of maize did not vary significantly at 30 DAS in *kharif* 2022, but numerically higher plant height (22.01 cm) was observed with the foliar application over the soil application (18.81 cm). However, at the later stages plant height varied significantly among different treatments. The foliar application of nano fertilizers resulted in significantly greater plant height (206 cm, 243 cm and 248 cm at 60 DAS, 90 DAS and harvest, respectively) compared to soil application. Among the different levels of nano urea, the application of nano urea at 6 ml L^{-1} recorded a higher plant height of 20.84 cm, 206 cm, 242 cm and 247 cm at 30 DAS, 60 DAS, 90 DAS and harvest, respectively, which was comparable to nano urea at 4 ml L^{-1} (20.63 cm, 201 cm, 237 cm and 242 cm at 30 DAS, 60 DAS, 90 DAS and harvest, respectively) but superior to nano urea at 2 ml L^{-1}. Similarly, the treatment with nano DAP at 6 ml L^{-1} recorded a higher plant height of 20.93 cm, 204 cm, 241 cm and 246 cm

Table 1

Effect of different methods and levels of nano urea and nano DAP application on plant height at different growth stages of maize

Treatments	Plant height (cm)											
	30 DAS			60 DAS			90 DAS			At harvest		
Methods of application (A)												
A_1: Soil application	18.81			183			222			227		
A_2: Foliar application	22.01			206			243			248		
F-test	NS			*			*			*		
SEm±	0.53			0.60			1.43			2.83		
CD at 5%	-			3.63			8.67			17.24		
Levels of nano urea (N)												
N_1: Nano urea @ 2 ml L^{-1}	19.77			176			218			223		
N_2: Nano urea @ 4 ml L^{-1}	20.63			201			237			242		
N_3: Nano urea @ 6 ml L^{-1}	20.84			206			242			247		
F-test	NS			*			*			*		
SEm±	0.27			2.62			3.89			1.66		
CD at 5%	-			8.54			12.68			5.42		
Levels of nano DAP (P)												
P_1: Nano DAP @ 2 ml L^{-1}	19.82			179			220			225		
P_2: Nano DAP @ 4 ml L^{-1}	20.49			200			236			242		
P_3: Nano DAP @ 6 ml L^{-1}	20.93			204			241			246		
F-test	NS			*			*			*		
SEm±	0.31			3.09			3.56			3.18		
CD at 5%	-			9.02			10.38			9.30		
Interaction	F-test	SEm±	CD at 5%	F-test	SEm±	CD at 5%	F-test	SEm±	CD at 5%	F-test	SEm±	CD at 5%
A × N	NS	0.38	-	NS	3.70	-	NS	5.50	-	NS	2.35	-
A × P	NS	0.44	-	NS	4.37	-	NS	5.03	-	NS	4.50	-
N × P	NS	0.54	-	NS	5.35	-	NS	6.16	-	NS	5.52	-
A × N × P	NS	0.76	-	NS	7.57	-	NS	8.71	-	NS	7.80	-

Note : CD = Critical difference; NS = Non-Significant; SEm± = Standard error of mean

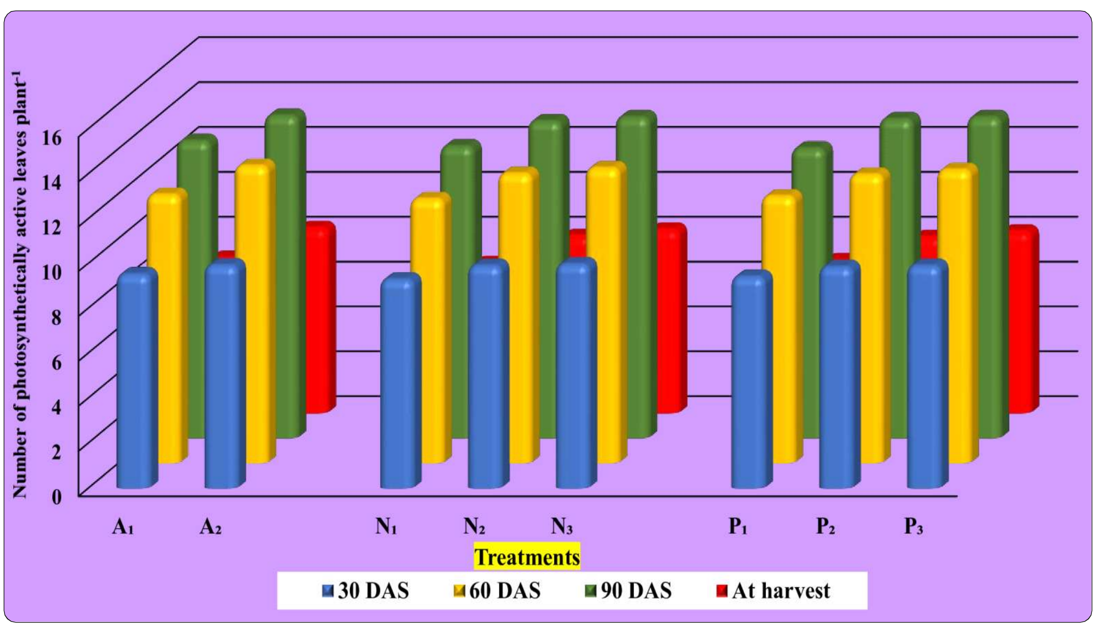
at 30 DAS, 60 DAS, 90 DAS and harvest, respectively, which was on par with nano DAP at 4 ml L^{-1} (20.49 cm, 200 cm, 236 cm and 242 cm at 30 DAS, 60 DAS, 90 DAS and harvest, respectively) but outperformed nano DAP at 2 ml L^{-1}.

The significant increase in plant height could be attributed to the combined application of traditional fertilizers as basal dose and nano fertilizers via foliar spray at higher doses. This combination boosted enzyme activities and auxin metabolism promoting cell growth and elongation which resulted in taller plants. Yasser *et al.* (2020), Reddy *et al.* (2022), Rashmi & Prakash (2023), Singh *et al.* (2023) and Parameshnaik *et al.* (2024) also reported similar findings.

Number of Photosynthetically Active Leaves Plant^{-1}

The total number of photosynthetically active leaves plant^{-1} of maize did not vary significantly at 30 DAS in *kharif* 2022, but numerically the higher number of photosynthetically active leaves plant^{-1} (9.93) was observed with the foliar application over the soil application (Fig. 1).

However, at the later stages number of photosynthetically active leaves plant^{-1} of maize varied significantly among different treatments. The foliar application recorded significantly higher number of photosynthetically active leaves plant^{-1} (13.26, 14.39 and 8.27 at 60, 90 DAS and at harvest, respectively) than the soil application. The treatment with application of nano urea @ 6 ml L^{-1} recorded higher number of photosynthetically active leaves plant^{-1} of 9.98, 13.16, 14.32 and 8.20 at 30, 60, 90 DAS and at harvest, respectively which is statistically at par with application of nano urea @ 4 ml L^{-1} (9.91, 12.91, 14.14 and 7.91 at 30, 60, 90 DAS and at harvest, respectively) compared to the application of nano urea @ 2 ml L^{-1}. Among the different levels of nano DAP, application of nano DAP @ 6 ml L^{-1} recorded higher number of photosynthetically active leaves plant^{-1} of 9.91, 13.08, 14.32 and 8.11 at 30, 60, 90 DAS and at harvest, respectively which is on par with nano DAP @ 4 ml L^{-1} (9.86, 12.87, 14.23 and 7.87 at 30, 60, 90 DAS and at harvest, respectively) in comparison to nano DAP @ 2 ml L^{-1}.



A_1 = Soil application
A_2 = Foliar application
N_1 = Nano urea @ 2 ml L^{-1}
N_2 = Nano urea @ 4 ml L^{-1}
N_3 = Nano urea @ 6 ml L^{-1}
P_1 = Nano DAP @ 2 ml L^{-1}
P_2 = Nano DAP @ 4 ml L^{-1}
P_3 = Nano DAP @ 6 ml L^{-1}

Fig. 1 : Effect of different methods and levels of nano urea and nano DAP application on number of photosynthetically active leaves plant^{-1} at different growth stages of maize

By 30 and 60 DAS, the rapid absorption and availability of nitrogen led to the production of more number of leaves. As nitrogen is a key component of chlorophyll, rubisco enzyme, antioxidant enzyme system, nitrate reductase and several essential amino acids increased the number of photosynthetically active leaves produced plant^{-1}. Similar results also observed by Uma (2019), Rajesh (2021) and Chandan (2023).

Leaf Area Plant^{-1}

Various methods of nano fertilizer application directly influenced the leaf area plant^{1} in maize. The foliar application treatment resulted in significantly higher leaf area plant^{-1} at all stages of crop growth, except at 30 DAS. The data indicated that the leaf area plant^{-1} in maize increased up to 90 DAS and then gradually declined as the crop approached maturity.

The maize crop grown with foliar application had recorded significantly higher leaf area plant^{-1} at 60 DAS (6647 cm^2), 90 DAS (7417 cm^2) and at harvest (2560 cm^2) over the soil application (Table 2). Among the different levels of nano urea, application of nano urea @ 6 ml L^{-1} recorded higher leaf area plant^{-1} of 948, 6638, 7378 and 2563 cm^2 at 30, 60, 90 DAS and at harvest, respectively followed by the application of nano urea @ 4 ml L^{-1} (948, 6537, 7232 and 2401

TABLE 2

Effect of different methods and levels of nano urea and nano DAP application on leaf area plant^{-1} at different growth stages of maize

Treatments	Leaf area plant^{-1} (cm^2) 30 DAS			60 DAS			90 DAS			At harvest		
Methods of application (A)												
A_1: Soil application	921			6189			6609			1803		
A_2: Foliar application	941			6647			7417			2560		
F-test	NS			*			*			*		
SEm±	26			25			75			24		
CD at 5%	-			91			227			72		
Levels of nano urea (N)												
N_1: Nano urea @ 2 ml L^{-1}	897			6080			6430			1581		
N_2: Nano urea @ 4 ml L^{-1}	948			6537			7232			2401		
N_3: Nano urea @ 6 ml L^{-1}	948			6638			7378			2563		
F-test	NS			*			*			*		
SEm±	14			34			89			70		
CD at 5%	-			103			291			229		
Levels of nano DAP (P)												
P_1: Nano DAP @ 2 ml L^{-1}	905			6049			6449			1697		
P_2: Nano DAP @ 4 ml L^{-1}	938			6581			7213			2356		
P_3: Nano DAP @ 6 ml L^{-1}	949			6624			7378			2492		
F-test	NS			*			*			*		
SEm±	12			121			113			82		
CD at 5%	-			357			330			238		
Interaction	F-test	SEm±	CD at 5%	F-test	SEm±	CD at 5%	F-test	SEm±	CD at 5%	F-test	SEm±	CD at 5%
A × N	NS	8	-	NS	48	-	NS	126	-	NS	99	-
A × P	NS	12	-	NS	171	-	NS	160	-	NS	115	-
N × P	NS	14	-	NS	209	-	NS	196	-	NS	141	-
A × N × P	NS	20	-	NS	296	-	NS	277	-	NS	200	-

Note : CD = Critical difference; NS = Non-Significant; SEm± = Standard error of mean

cm^2 at 30, 60, 90 DAS and at harvest, respectively) in comparison to the application of nano urea @ 2 ml L^{-1}. The treatment with nano DAP @ 6 ml L^{-1} recorded higher leaf area plant^{-1} of 949, 6624, 7378 and 2492 cm^2 at 30, 60, 90 DAS and at harvest, respectively which is at par with nano DAP @ 4 ml L^{-1} (938, 6581, 7213 and 2356 cm^2 at 30, 60, 90 DAS and at harvest, respectively) compared to nano DAP @ 2 ml L^{-1}.

The increase in leaf area plant^{-1} can be attributed to nitrogen application which enhances the production of tryptophan an amino acid that promotes cell elongation (Yadegari, 2013), thereby expanding the leaf area.

Leaf Area Index

The observation on leaf area index recorded at 30, 60, 90 DAS and at harvest as influenced by different methods and levels of nano urea and nano DAP application during *kharif* 2022 are presented in Table 3.

Different methods of nano fertilizers application had a direct effect on leaf area index of maize. The treatment with foliar application recorded

TABLE 3

Effect of different methods and levels of nano urea and nano DAP application on leaf area index (LAI) at different growth stages of maize

Treatments	Leaf area index (LAI)			
	30 DAS	60 DAS	90 DAS	At harvest
Methods of application (A)				
A_1: Soil application	0.512	3.44	3.67	1.00
A_2: Foliar application	0.523	3.69	4.12	1.42
F-test	NS	*	*	*
SEm±	0.083	0.01	0.04	0.005
CD at 5%	-	0.03	0.12	0.03
Levels of nano urea (N)				
N_1: Nano urea @ 2 ml L^{-1}	0.498	3.38	3.57	0.88
N_2: Nano urea @ 4 ml L^{-1}	0.527	3.63	4.02	1.33
N_3: Nano urea @ 6 ml L^{-1}	0.527	3.69	4.10	1.42
F-test	NS	*	*	*
SEm±	0.008	0.02	0.05	0.04
CD at 5%	-	0.06	0.16	0.13
Levels of nano DAP (P)				
P_1: Nano DAP @ 2 ml L^{-1}	0.503	3.36	3.58	0.94
P_2: Nano DAP @ 4 ml L^{-1}	0.521	3.66	4.01	1.31
P_3: Nano DAP @ 6 ml L^{-1}	0.527	3.68	4.10	1.38
F-test	NS	*	*	*
SEm±	0.007	0.07	0.06	0.05
CD at 5%	-	0.20	0.18	0.13

Interaction	F-test	SEm±	CD at 5%	F-test	SEm±	CD at 5%	F-test	SEm±	CD at 5%	F-test	SEm±	CD at 5%
A × N	NS	0.011	-	NS	0.03	-	NS	0.07	-	NS	0.06	-
A × P	NS	0.010	-	NS	0.09	-	NS	0.09	-	NS	0.07	-
N × P	NS	0.012	-	NS	0.12	-	NS	0.11	-	NS	0.08	-
A × N × P	NS	0.017	-	NS	0.16	-	NS	0.15	-	NS	0.11	-

Note : CD = Critical difference; NS = Non-Significant; SEm± = Standard error of mean

significantly higher leaf area index at all the stages of crop growth except at 30 DAS.

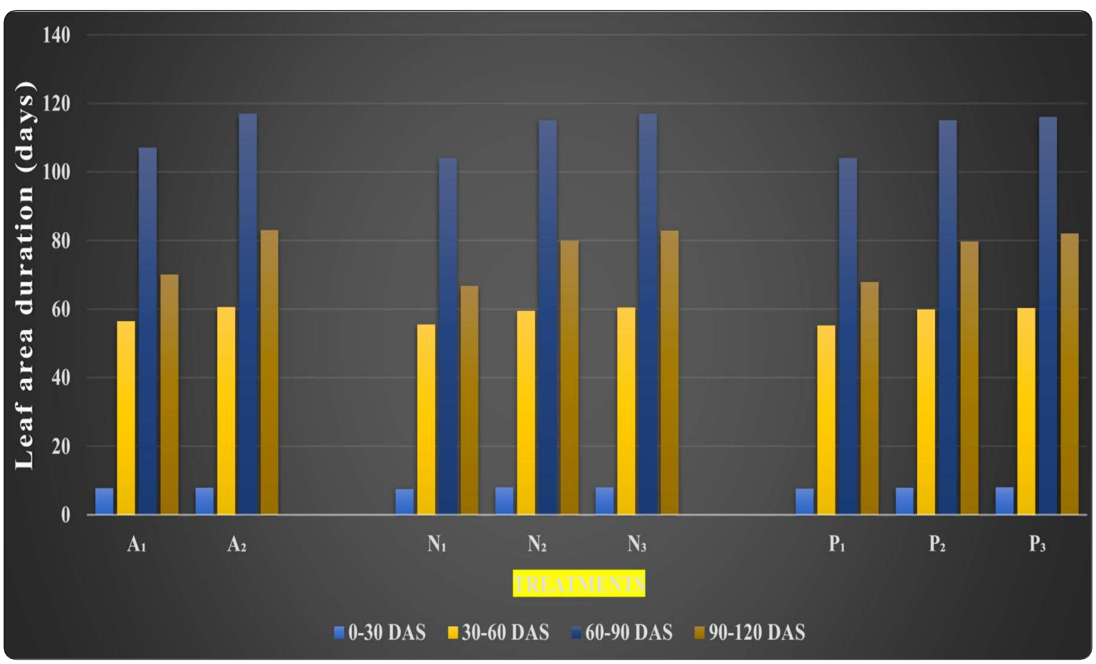
The maize plants grown with foliar application of nano fertilizers recorded significantly higher LAI at 60 DAS (3.69), 90 DAS (4.12) and at harvest (1.42) over the soil application. At 30 DAS, no significant difference was recorded in LAI of maize. Application of nano urea @ 6 ml L^{-1} recorded significantly higher LAI of 3.69, 4.10 and 1.42 at 60, 90 DAS and at harvest, respectively which is on par with nano urea @ 4 ml L^{-1} (3.63, 4.02 and 1.33 at 60, 90 DAS and at harvest, respectively) compared to nano urea @ 2 ml L^{-1}. Significantly higher LAI of 3.68, 4.10 and 1.38 at 60, 90 DAS and at harvest, respectively was obtained with application of nano DAP @ 6 ml L^{-1} followed by nano DAP @ 4 ml L^{-1} (3.66, 4.01 and 1.31 at 60, 90 DAS and at harvest, respectively) than nano DAP @ 2 ml L^{-1}.

As the crop duration increases, the leaf area index (LAI) of the crop rises reaching its peak at 90 DAS before declining towards harvest. The higher LAI at 90 DAS is primarily due to the plant achieving greater leaf area at that stage. However, after 90 DAS the LAI decreases as the leaves dry with maturity. The foliar application of nano urea and nano DAP allows for quicker absorption by the leaves compared to conventional nitrogen sources owing to their larger surface area. The adequate availability of nitrogen during the vegetative stage results in increased number of leaves as well as greater leaf area and leaf area index. Similar findings were reported by Reddy *et al.* (2022) and Sannathimmappa *et al.* (2023).

Leaf Area Duration

The data on leaf area duration was significantly influenced at 30-60, 60-90 and 90-120 DAS of maize. The observations on LAD were recorded at 0-30, 30-60, 60-90 and 90-120 DAS as influenced by different methods and levels of nano urea and nano DAP during *kharif* 2022 are presented in Fig. 2.

The foliar application of nano fertilizers recorded significantly longer LAD (60.49, 117 and 83.02 days



A_1 = Soil application
A_2 = Foliar application
N_1 = Nano urea @ 2 ml L^{-1}
N_2 = Nano urea @ 4 ml L^{-1}
N_3 = Nano urea @ 6 ml L^{-1}
P_1 = Nano DAP @ 2 ml L^{-1}
P_2 = Nano DAP @ 4 ml L^{-1}
P_3 = Nano DAP @ 6 ml L^{-1}

Fig. 2 : Effect of different methods and levels of nano urea and nano DAP application on leaf area duration at different growth stages of maize

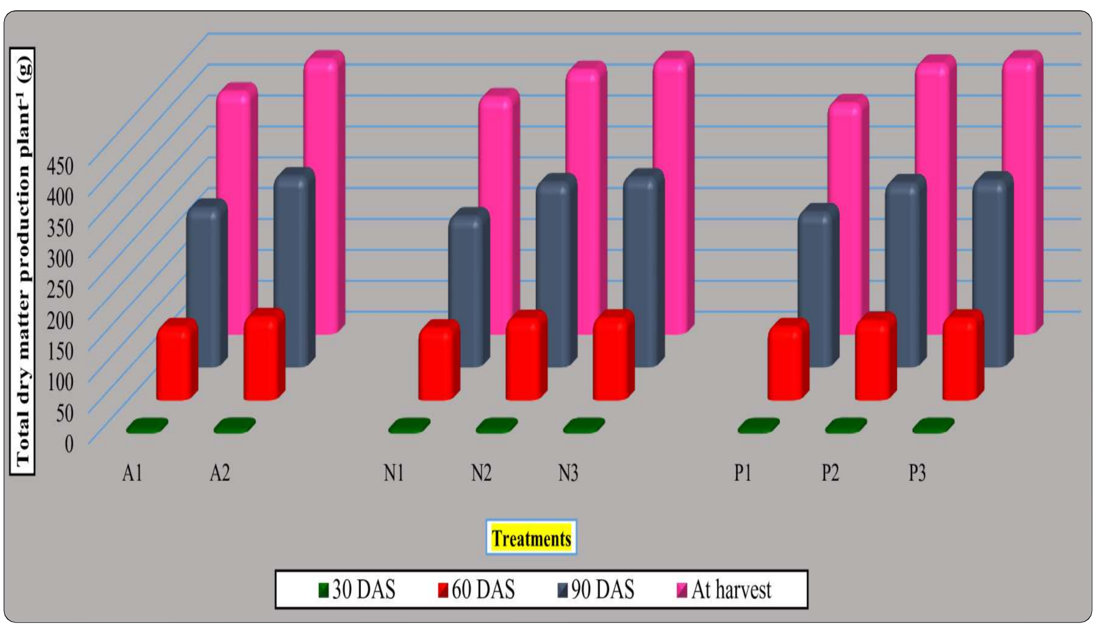
at 30-60, 60-90 and 90-120 DAS, respectively) compared to the soil application. Whereas, application of nano urea @ 6 ml L^{-1} was obtained significantly higher LAD (60.34, 117 and 82.84 days at 30-60, 60-90 and 90-120 DAS, respectively) as compared to nano urea @ 4 and 2 ml L^{-1}. However, treatment with nano DAP @ 6 ml L^{-1} was recorded significantly higher leaf area duration (60.24, 116 and 82.03 days at 30-60, 60-90 and 90-120 DAS, respectively) when compared to nano DAP @ 4 and 2 ml L^{-1}.

The leaf area duration of a crop directly influenced on yield. The longer duration allows a crop more time for photosynthesis, sink development and the accumulation of photosynthates in the sink. Leaf area duration refers to the capacity of crop plants to produce and sustain green leaf area for the longest duration per unit of land area, hence it is also known as the photosynthetic potential of the crop (Hunkova *et al.*, 2016). Treatments involving the foliar application of nano urea and nano DAP recorded significantly higher LAD. This increased LAD enhanced crop growth parameters and led to higher yields. Similar findings were also reported by Ajithkumar *et al.* (2021) and Mallikarjuna (2021). The interaction effect of different methods and levels of nano urea and nano DAP application were found non-significant on leaf area duration at all the growth stages of maize.

Total Dry Matter Production Plant^{-1}

The observation on total dry matter production plant^{-1} recorded at 30, 60, 90 DAS and at harvest as influenced by different methods and levels of nano urea and nano DAP application during *kharif* 2022 are furnished in Fig. 3.

The total dry matter production plant^{-1} was significantly higher (133, 308 and 444 g at 60, 90 DAS and at harvest, respectively) in maize grown with foliar application at all the crop growth stages compared to soil application. The treatment with nano urea @ 6 ml L^{-1} recorded significantly higher total dry matter production plant^{-1} at 60 DAS (131 g), 90 DAS (306 g) and at harvest (443 g) followed by the application of nano urea @ 4 ml L^{-1} (130, 298 and 427 g at 60, 90 DAS and at harvest, respectively) over nano urea @ 2 ml L^{-1}. Among the different levels of nano DAP



A_1 = Soil application
A_2 = Foliar application
N_1 = Nano urea @ 2 ml L^{-1}
N_2 = Nano urea @ 4 ml L^{-1}
N_3 = Nano urea @ 6 ml L^{-1}
P_1 = Nano DAP @ 2 ml L^{-1}
P_2 = Nano DAP @ 4 ml L^{-1}
P_3 = Nano DAP @ 6 ml L^{-1}

Fig. 3 : Effect of different methods and levels of nano urea and nano DAP application on total dry matter production plant^{-1} at different growth stages of maize

application, the treatment with nano DAP @ 6 ml L^{-1} obtained significantly higher total dry matter production $plant^{-1}$ of 131 g at 60 DAS, 301 g at 90 DAS and 444 g at harvest, which is on par with nano DAP @ 4 ml L^{-1} (127, 297 and 437g at 60, 90 DAS and at harvest, respectively) over nano DAP @ 2 ml L^{-1}.

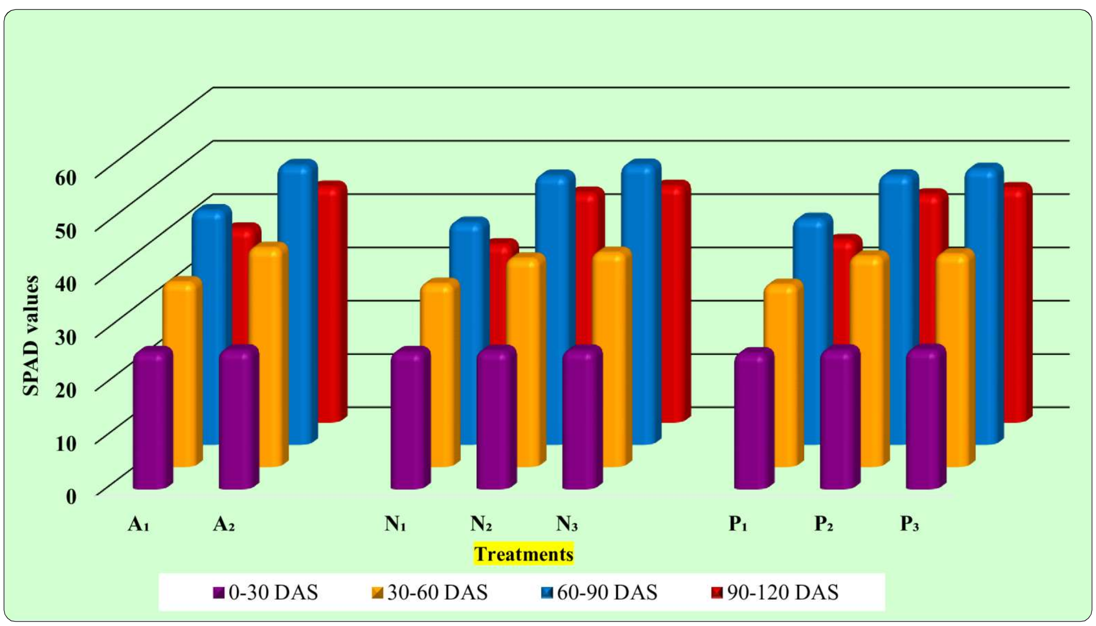
The higher total dry matter accumulated at the harvest due to nano-size of the nutrients which offers a higher surface and reactive area. This is primarily due to the smaller particle size providing more sites that facilitate various metabolic processes within the plant system leading to increased photosynthesis and consequently higher growth and yield (Yasser *et al.,* 2020).

SPAD Values

SPAD value indicates the greenness *i.e.,* chlorophyll content of leaves. The observation on chlorophyll content recorded at 30, 60, 90 DAS and at harvest as influenced by different methods and levels of nano urea and nano DAP during *kharif* 2022 are presented in Fig. 4.

Maize plants grown with foliar application of nano fertilizers was recorded significantly higher chlorophyll content at 60 DAS (41.24), 90 DAS (52.53) and at harvest (44.26) over the soil application. At 30 DAS, no significant difference was recorded in chlorophyll content of maize. Application of nano urea @ 6 ml L^{-1} obtained significantly higher chlorophyll content of 40.32, 52.59 and 44.44 at 60, 90 DAS and at harvest, respectively which is on par with nano urea @ 4 ml L^{-1} (39.24, 50.54 and 43.14 at 60, 90 DAS and at harvest, respectively) when compared to nano urea @ 2 ml L^{-1} (Fig. 4). The treatment with nano DAP @ 6 ml L^{-1} recorded significantly higher chlorophyll content of 40.05, 51.82 and 43.98 at 60, 90 DAS and at harvest, respectively which is on par with nano DAP @ 4 ml L^{-1} (39.66, 50.58 and 42.79 at 60, 90 DAS and at harvest, respectively) in comparison to nano DAP @ 2 ml L^{-1}.

The application of 6 ml L^{-1} concentration of nano urea and nano DAP provides a greater amount of nutrients to the plant compared to the lower concentration of 2 ml L^{-1} in soil application. This higher concentration



A_1 = Soil application
A_2 = Foliar application
N_1 = Nano urea @ 2 ml L^{-1}
N_2 = Nano urea @ 4 ml L^{-1}
N_3 = Nano urea @ 6 ml L^{-1}
P_1 = Nano DAP @ 2 ml L^{-1}
P_2 = Nano DAP @ 4 ml L^{-1}
P_3 = Nano DAP @ 6 ml L^{-1}

Fig. 4 : Effect of different methods and levels of nano urea and nano DAP application on SPAD values at different growth stages of maize

supports enhanced chlorophyll production and better overall plant health. Similar results were observed by Dhlamini *et al.* (2020).

Higher growth and growth indices in the cultivation of maize can be achieved by foliar application of nano urea and nano DAP @ 6 ml L^{-1}. Based on the results obtained from the current investigation and the discussed potential reasons for their variability, the following conclusions were made. Foliar application of nano urea and nano DAP @ 6 ml L^{-1} in maize recorded significantly higher plant height (248 cm), number of photosynthetically active leaves $plant^{-1}$ (8.27), leaf area $plant^{-1}$ (2560 cm^2), leaf area index (1.42), leaf area duration (83.02 days), total dry matter production $plant^{-1}$ (444 g) and SPAD values (44.26) which was on par with foliar application of nano urea and nano DAP @ 4 ml L^{-1} compared to soil application of nano urea and nano DAP @ 2 ml L^{-1}.

References

Ajithkumar, K., Kumar, Y., Savitha, A. S., Ajayakumar, M. Y., Narayanaswamy, C., Raliya, R., Krupashankar, M. R. and Bhat, S. N., 2021, Effect of IFFCO nano fertilizer on growth, grain yield and managing turcicum leaf blight disease in maize. *Int. J. Plant Soil Sci*., **33** (16) : 19 - 28.

Chandan, B. M., 2023, Study on response of ragi to nano urea under irrigated condition. *M.Sc. (Agri.) Thesis*, Univ. Agric. Horti. Sci., Shivamogga, Karnataka, India.

Dhlamini, B., Paul, H. K., Katata, S. L. and Kutu, F. R., 2020, Sulphate supplemented NPK nano fertilizer and its effect on maize growth. *Mater. Res. Express,* **7** (9) : 95 - 112.

Gomez, K. A. and Gomez, A. A., 1984, Statistical procedures for agricultural research. John Wiley and Sons, New York, USA.

Hunkova, E., Marek, Z. and Katarina, O., 2016, Leaf area duration of oilseed rape (*Brassica napus* subsp. *napus*) varieties and hybrids and its relationship to selected growth and productivity parameters. *J. Cent. Eur. Agric.,* **12** (1) : 1 - 15.

Mahmood, F., Khan, I., Ashraf, U., Shahzad, T., Hussain, S. and Shahid, M., 2017, Effects of organic and inorganic manures on maize and their residual impact on soil physicochemical properties. *J. Soil Sci. Plant Nutr.*, **17** (1) : 22 - 32.

Malhotra, S. K., 2017, Diversification in utilization of maize and production. In: proceedings of Gyan Manthan conference: perspective of maize production and value chain, pp. : 49 - 57.

Mallikarjuna, P. R., 2021, Effect of nano nitrogen and nano zinc nutrition on nutrient uptake, growth and yield of irrigated maize during summer in the southern transition zone of Karnataka. *M.Sc. (Agri.) Thesis*, Univ. Agric. Horti. Sci., Shivamogga, Karnataka, India.

Parameshnaik, C., Kalyana Murthy, K. N., Hanumanthappa, D. C., Seenappa, C., Nanja Reddy, Y. A. and Prakasha, H. C., 2024, Influence of nano fertilizers on growth and yield of maize. *Mysore J. Agric. Sci.*, **58** (1) : 211 - 221.

Rajesh, H., 2021, Studies on foliar application of nano nitrogen (N) and nano zinc (Zn) in sweet corn (*Zea mays* L. saccharata). *M.Sc. (Agri.) Thesis*, Univ. Agril. Sci., Raichur, Karnataka, India.

Rashmi, C. M. and Prakash, S. S., 2023, Effect of nano phosphorus fertilizers on growth and yield of maize (*Zea mays* L.) in central dry zone of Karnataka. *Mysore J. Agric. Sci*., **57** (2) : 286 - 293.

Reddy, B. M. S., Elankavi, Kumar, M. S., Vikram, S. M. and Divya, B. V., 2022, Effects of conventional and nano fertilizers on growth and yield of maize (*Zea mays* L.). Bhartiya Krishi Anusandhan Patrika, pp. : 1 - 4.

Sannathimmappa, H. G., Patil, M., Rudragouda, Channagouda, C. and Patil, C., 2023, Effect of nano nitrogen and nano zinc nutrition on growth and yield of irrigated maize in southern transition zone of Karnataka. *Pharma Innov. J.*, **12** (1) : 1706 - 1709.

Singh, Y. K., Singh, B. V., Katiyar, D., Saikanth, D. R. K., Kumar, K., Singh, O., Verma, S. and Kumar, P., 2023, Efficacy of nano fertilizers on yield, attributes and economics of wheat. *Int. J. Environ. Clim.*, **13** (7) : 291 - 297.

UMA, V., 2019, Influence of nano - zinc oxide (ZnO) particles on growth and yield of maize *(Zea mays* L.). *M.Sc. (Agri.) Thesis*, Univ. Agric. Sci., Bangalore.

YADEGARI, M., 2013, Effect of foliar application of Fe, Zn, Cu and Mn on yield and essential oils of *Borago officinalis*. *J. Appl. Sci. Agric*., **8** (5) : 568 - 575.

YASSER, E., EL-GHOBASHY, AMIRA, A., EL-MEHY, KAMAL, A. AND EL DOUBY, 2020, Influence of intercropping cowpea with some maize hybrids and N nano-mineral fertilization on productivity in salinity soil. *Egyptian J. Agron*., **42** (1) : 63 - 78.