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Response of Specific Leaf Area (SLA), Leaf Area Index (LAI) and Leaf Area Ratio (LAR) of Maize (*Zea mays* L.) To Plant Density, Rate and Timing of Nitrogen Application

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Abstract: Nitrogen is considered as one of the most important inputs needed for increasing productivity of field crops. Balanced amount of N application at proper time according to the need of the maize decreases N losses, increases yield and quality. There is also a need to understand how levels and timing of N application affect the physiology of maize is an attempt to explore further avenues for proper nutrient management for improving yield on sustainable basis. Thus the experiment was designed and planted at the Agriculture Research Farm of the NWFP Agricultural University, Peshawar for two consecutive years (summer 2002 and summer 2003) with a an objective to study the effect of plant density, N rates and timing on SLA, LAI and LAR of maize. All the three parameters i.e. SLA, LAI and LAR enhanced to a maximum with increasing plant density, N rate and number of splits for N application. SLA, LAI and LAR enhanced at the rate of 0.152 $cm^2\ g^{-1}$, 0.0065 and 0.023 $cm^2\ g^{-1}$, respectively with one kg increase in N rate. The highest SLA (324.8 $cm^2\ g^{-1}$), LAI (4.59) and LAR (63.03 $cm^2\ g^{-1}$) was recorded in those plots to which N was applied in five splits with greater proportion at later stages, while the minimum SLA (275.70 $cm^2\ g^{-1}$), LAI (3.66) and LAR (53.46 $cm^2\ g^{-1}$) was recorded in the plots which received N only in three splits with greater proportion at the sowing time. Plots maintained at a high density (100,000 plants ha^{-1}) produced the higher SLA, LAI and LAR than the plots maintained at low density (60,000 plants ha^{-1}).

Key words: maize · nitrogen · plant density · SLA · LAI and LAR

INTRODUCTION

Maize (*Zea mays* L.) is an important cereal crop of Pakistan and based on area and production it ranks third in cereals next to wheat and rice. In the North West Frontier Province (NWFP) maize is the second most important crop after wheat. According to the recent Agric. Statistics of Pakistan, maize was grown on a total area of 941.6 thousands ha, with a total production of 1664.4 thousand tones and yield 1768 kg ha^{-1} in Pakistan. In NWFP it was grown on a total area of 540.82 thousand ha, with a total production of 916.4 thousand tones and average yield of 1696 kg ha^{-1} [1]. In too thick plant population of maize canopy photosynthesis is negatively affected due to less light penetration in the crop canopy and more competition for available nutrients which adversely affect plant growth and development resulting in low yield. On the other hand in too thin population there is less light interception due to lower leaf area index and more weeds germinate and grow rapidly which also result in lower yield [2]. Nitrogen in the intensive cropping systems of Pakistan is of major practical importance because of the large quantities of N removed by the harvestable portion of crop [3]. Deficiency of N reduces cell division and enlargement due to inadequate protein synthesis while excess of N prolongs the growth period with consequent delay in crop maturity [4]. Nitrogen losses to the atmosphere in the farm of ammonia are more than 20% [5]. Nitrogen is deficient in Pakistani soils because they are calcareous with high base saturation and pH ranging from 8 to 9 [6]. To maintain crop yields and reduce losses of N and increase the profit of our farmers it is important to utilize N applied to crops as efficiently as possible. The best agricultural technique to

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reduce losses of N is the split application of N fertilizer at farm level [2]. Nitrogen uptake during the vegetative stage is used primarily for vegetative growth and during late vegetative periods for reproductive organs initiation, whereas the N applied after silking and tasseling is mainly directed towards the synthesis of grain proteins [7]. Specific leaf area, leaf area index and leaf area ratio are important factors in the estimation of canopy photosynthesis in crop growth simulation models that compute dry matter accumulation from temporal integration of canopies photosynthesis. In addition to total leaf area per plant, single leaf area per leaf or the vertical distribution of leaf area is also required when the calculation of canopy photosynthesis is based on sunlit and shaded leaf area across various layers in the crop canopy [8]. In the model MAIS [9], a process based crop growth model for maize grown under non limiting soil conditions, the growth of each individual leaf on the stem of the maize plant is estimated. Leaf area is computed from the time of it appearance based on the relationship between rate of leaf tip appearance and temperature [10] and [11]. Leaf area and LAI increase with increase in N level [12]. There is significant variation in number of leaves per plant of tropical maize [13]. Leaf area is greater under normal plant density in different hybrids of maize [14]. Increasing plant density has significant effect on grain yield and has no significant effect on leaf area [15]. Maize crop differs in its ability to maintain LAI, CGR and above ground dry matter production at different levels of N application [16]. Experiment to determine the response of maize to different nitrogen rates at different growth stages and different plant populations is very important part of research in Pakistan. Balanced amount of nitrogen application at proper time and optimum plant population will improve the physiological characteristics of maize that will result in the higher yield. Keeping this fact in view the experiment was therefore conducted with an objective to study the response of SLA, LAI and LAR of maize to different plant densities (60,000 and 100,000 plants ha^{-1}) and levels of N (60, 120 and 180 kg ha^{-1}) applied at different growth stages from planting to late grain filling stage.

MATERIALS AND METHODS

In order to study the effect of plant density, rate and timing of nitrogen application on physiological characteristics of maize, an experiment was designed and planted at the Agriculture Research Farm of the NWFP Agricultural University, Peshawar in 2002 and 2003. The experimental farm is located at 34.01°N latitude, 71.35°E longitude at an altitude of 350 m above sea level in Peshawar valley. Peshawar is located about 1600 km north of the Indian Ocean and has continental type of climate. The research farm is irrigated by Warsak canal from river Kabul. Soil was analyzed before sowing the experiment. The analysis showed that soil is clay loam, low in N, P, K and organic matter and alkaline with high pH and is calcareous in nature (Table 1). The meteorological data of the research farm is given in Table 2. The experiment was conducted in RCB design with split-plot arrangement using four replications. A sub-plot size of 4.2 m by 6 m, having 6 rows, 6 m long and 70 cm apart, was used. A uniform basal dose of 60 kg ha^{-1} P_2O_5 and 50 kg ha^{-1} K_2O was applied and mixed with the soil during seedbed preparation. Azam variety of maize was used for the study. The plots were planted at thicker seed rate by drill and the two desired plant densities of 60,000 and 100,000 plants ha^{-1} were maintained in the different experimental units by thinning at the early vegetative growth stages of maize. Nitrogen was applied at different stages, sowing and with 1st, 2nd, 3rd & 4th irrigations in different proportions as given above. The crop was irrigated at two weeks interval i.e. 14, 28, 42 and 56 days after emergence. Data was collected on specific leaf area (SLA), leaf area index (LAI) and leaf area ratio (LAR).

Table 1: Physiochemical soil (30 cm depth) properties of the Agriculture Research Farm, NWFP Agricultural University, Peshawar

S.No.	Soil Properties	Level/Type
1	Textural Class	Clay Loam
2	Calcareousness	Calcareous
3	pH	8.2
4	CaCo3	10.37%
5	Organic Matter	0.87%
6	Available K_2O	121 ppm
7	Available P_2O_5	6.57 ppm
8	Total Soluble Salts (TSS)	0.06%
9	Electrical Conductivity	0.90 dSm^{-1}

April 7, 2007At silking 10 plants were randomly harvested from one of the four middle rows. Leaves were counted and then average was worked out. Length and width of the top, middle and bottom leaves of each plant was measured for calculating average leaf area. Leaves, stem, ears and tassels were separated, dried and weighed to record data on dry weight of leaf, stem, ears and tassel $plant^{-1}$. Dry weight of leaf, stems, ears and tassels were added to calculate data on total weight $plant^{-1}$.

Table 2: Meteorological data of the Agriculture Research Farm during the experiment

	2002			2003		
Name of Climatic Parameter	July	Aug.	Sep.	July	Aug.	Sep.
Total Precipitation (mm)	1	116.6	14.9	73.2	51.6	45.2
Precipitation Days	3	8	5	11	12	4
Mean Max. Temperature (°C)	39.7	34.7	33	37	35.6	34.3
Mean Min. Temperature (°C)	26	25.5	21.3	26.5	25	23.4
Absolute Max. Temperature (°C)	43.6	40.6	34.6	42.2	38.5	38.4
Absolute Min. Temperature (°C)	22.8	15.6	17.1	23.9	22.5	15.5
Mean Relative Humidity (%) 1200 GMT	41	64	58	57	60	57
Mean Daily Relative Humidity (%)	54	75	72	69	73	72
No of Days with Max. Temp. = 35 °C	31	15	NIL	26	21	17
No of Days with Max. Temp. = 40 °C	14	2	NIL	4	NIL	NIL
Pan Evaporation (mm)	174	97.2	85.2	143	112.8	82.1
Total Sunshine hours	276.8	191.4	240.1	264.4	241.1	197

Derived physiological parameters of maize were calculated using the following formulae:

$$\text{Specific Leaf Area} = \frac{\text{Leaf area per plant}}{\text{Leaf weight per plant}} \ (cm^2\,g^{-1})$$

$$\text{Leaf Area Index} = \text{Leaf area per plant x No of plants } m^{-2}$$

$$\text{Leaf Area Ratio} = \frac{\text{Leaf area per plant}}{\text{weight per plant}} \ (cm^2\,g^{-1})$$

Data were statistically analyzed as combined over years and LSD test was used to test the significance of difference among stages of N application. Trend analysis was used to quantify the effect of levels of N. For interactions involving stages of N application LSD test was used. For interaction involving N levels, trend analysis was used [17].

RESULTS AND DISCUSSION

The data recorded on various physiological characteristics of maize in the experiment are presented in tables and where appropriate in the form of figures of appropriate type. Where the higher order interactions are not significant their means are averaged and presented as main effects and low order interaction. The results are described and discussed in the light of present pool of knowledge and the relevant review of the work published in scientific journals.

Specific Leaf Area ($cm^2\,g^{-1}$ leaf weight): Specific leaf area is a measure of leaf thickness. Combined statistical analysis of 2 years data indicated that only stages of N application had significant effects on SLA, while years, plant density and rates of N application had no significant effects on the SLA (Table 3).The SLA of maize was slightly greater in the year 2002 than the SLA of maize in the year 2003 which might be due to the fluctuation in the rain fall of both years. Although N rates had no significant effect on specific leaf area yet it increased at the rate of 0.152 $cm^2\,g^{-1}$ with one kg increase in the rate of N (Fig. 1). Maximum SLA of 324.8 $cm^2\,g^{-1}$ was recorded in those plots to which N was applied in five splits with greater proportion at later stages, followed by 319.75 $cm^2\,g^{-1}$ in the plots which received N in five equal splits (S5), while the SLA of 275.70 $cm^2\,g^{-1}$ was recorded in the plots which received nitrogen only in three splits with greater proportion at the sowing time. These results are in confirmation with those of [12] who reported that leaf area, LAI and grain yield increased with increase in the level of N. Maize crop differs in its ability to maintain LAI, CGR and above ground dry matter production at different levels of N supply [16]. Plant density had no significant effect on SLA. However, SLA was higher in the thinner density as compared to that in thicker density. These results are in confirmation with those of [14] and [15]. Plant density had least effect on leaf area [15], but [14] reported greater leaf area in normal plant density than dense plants.

Leaf Area Index (LAI): Leaf area index is a measure of leafiness per unit ground area and denotes the extent of

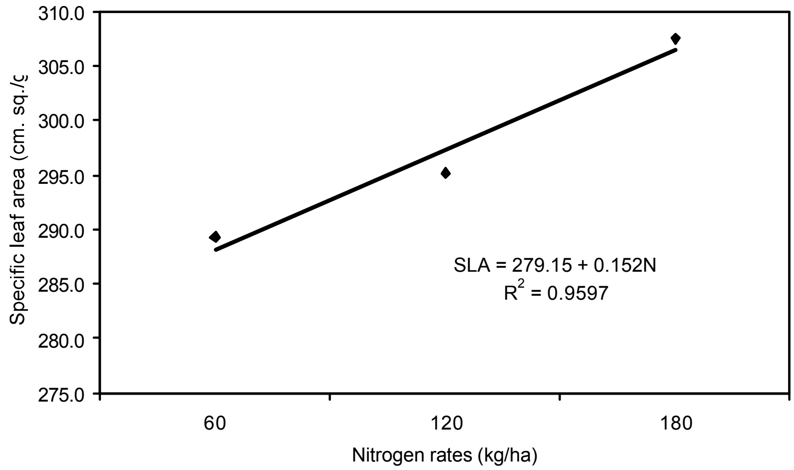

Fig. 1: Specific Leaf Area (SLA) of maize as affected by rate of N application

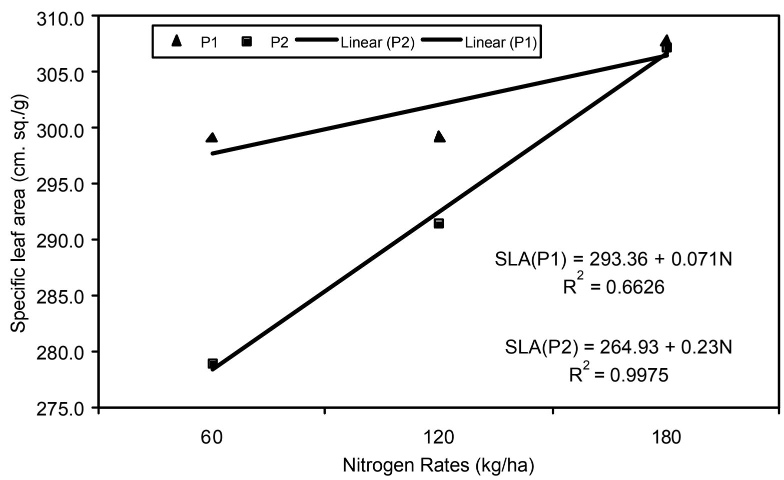

Fig. 2: Specific Leaf Area (SLA) of maize as affected by rate of N application in plots maintained at the two plant densities (P1 = 60,000 plants ha^{-1}, P2 = 100,000 plants ha^{-1})

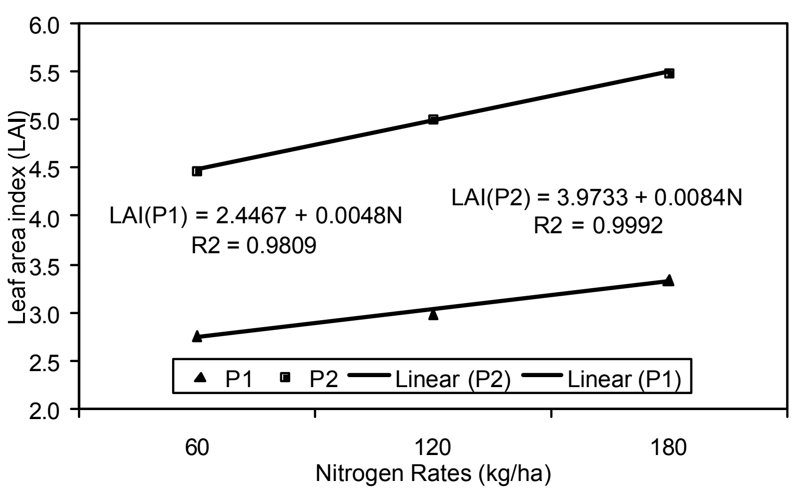

Fig. 3: Leaf Area Index (LAI) of maize as affected by rate of N application

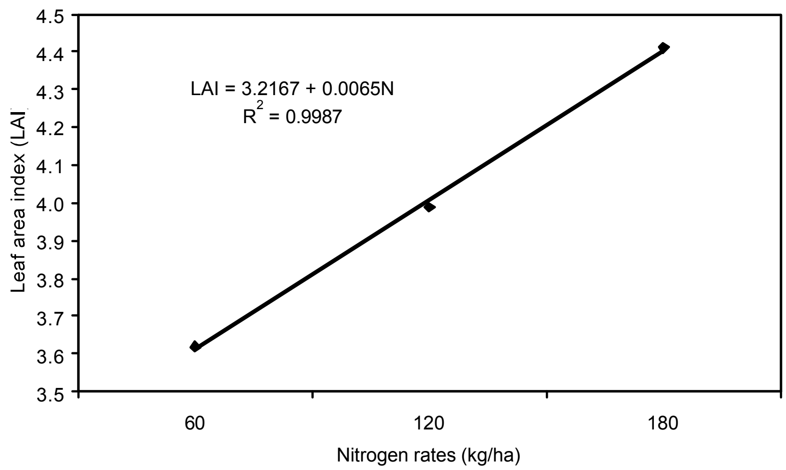

Fig. 4: Leaf Area Index (LAI) of maize as affected by rate of N application in plots maintained at the two plant densities (P1 = 60,000 plants ha^{-1}, P2 = 100,000 plants ha^{-1})

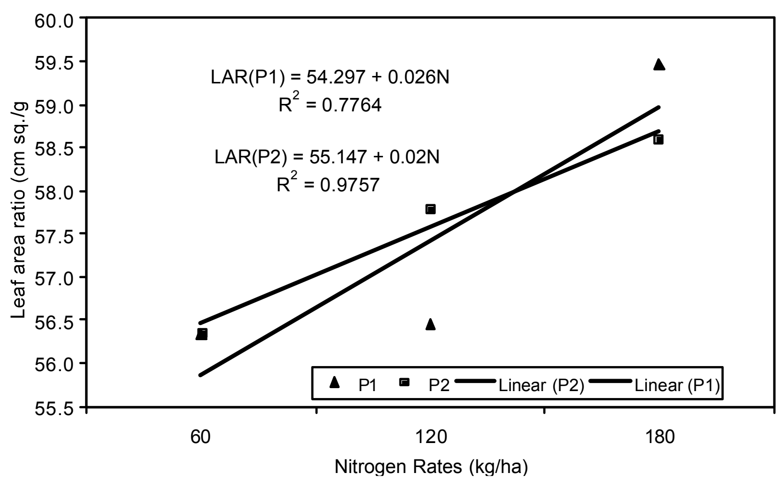

Fig. 5: Leaf Area Ratio (LAR) of maize as affected by rate of N application

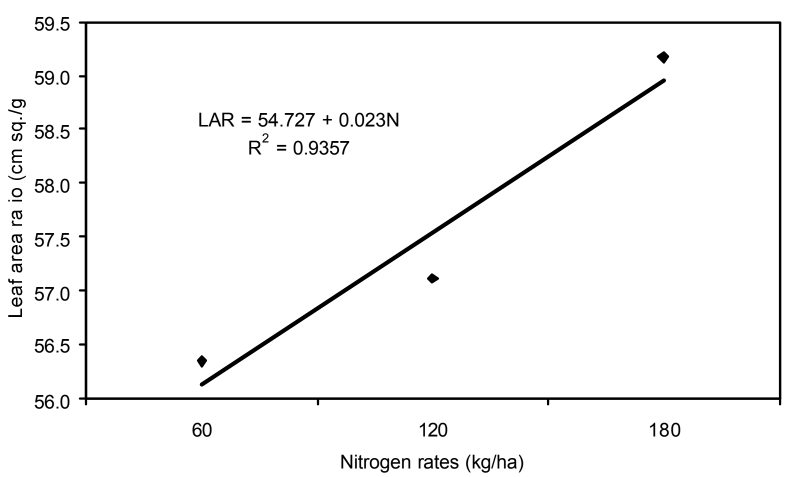

Fig. 6: Leaf area ratio (LAR) of maize as affected by rate of N application in plots maintained at the two plant densities (P1 = 60,000 plants ha^{-1}, P2 = 100,000 plants ha^{-1})

Table 3: Specific leaf area (cm^2 g^{-1} leaf weight) of maize at silking as affected by year, plant density, rate and timing of nitrogen application

Plant density (P) (Plants ha^{-1})	Timing of Nitrogen application (S)	Nitrogen levels (N) 60 kg ha^{-1}	120 kg ha^{-1}	180 kg ha^{-1}	Mean
			N x P x S		P x S
60,000	S1	281.82	296.07	302.21	293.37
	S2	269.09	290.31	286.36	281.92
	S3	327.54	314.03	307.86	316.48
	S4	283.50	295.44	306.45	295.13
	S5	313.79	288.97	319.26	307.34
	S6	320.36	305.26	324.81	316.81
100,000	S1	257.24	263.68	281.34	267.42
	S2	240.72	272.25	295.51	269.49
	S3	254.99	261.18	285.49	267.22
	S4	267.40	289.81	306.01	287.74
	S5	318.34	346.43	331.71	332.16
	S6	336.93	318.64	342.79	332.79
		N x S	Mean (S)		
	S1	269.53	279.87	291.78	280.39b
	S2	254.90	281.28	290.93	275.70b
	S3	291.26	287.60	296.68	291.85b
	S4	275.45	292.62	306.23	291.43b
	S5	316.06	317.70	325.48	319.75a
	S6	328.64	311.95	333.80	324.80a
	Year 2002	320.70	320.39	315.49	
	Year 2003	275.91	269.95	299.47	
	Mean (N)	289.31	295.17	307.48	
		Plant Density (Plants ha^{-1})			
		60,000	100,000	Mean (Y)	
	Year 2002	322.61	363.11	342.86	
	Year 2003	281.07	282.49	281.78	
	Mean (P)	301.84	292.80		
		Year 2002	Year 2003		
	S1	296.09	264.69		
	S2	287.69	263.72		
	S3	312.73	270.97		
	S4	298.81	270.31		
	S5	322.18	307.32		
	S6	335.94	313.65		

Where S1 =Two splits (50-50-0-0-0)S2 =Three splits (50-25-25-0-0)
S3 =Three splits (33.3-33.3-33.3-0-0)S4 =Four splits (25-25-25-25-0)
S5 =Five splits (20-20-20-20-20)S6 =Five splits (8.3-16.6-25-33-16.6)
Means of the same category followed by different letters are significantly different using LSD test ($p \leq 0.05$)

Table 4: Leaf area index (LAI) of maize at silking as affected by year, plant density, rate and timing of nitrogen application

Plant density (P) (Plants ha^{-1})	Timing of Nitrogen application (S)	Nitrogen levels (N) kg ha^{-1} 60	120	180	Mean
			N x P X S		P x S
60,000	S1	2.54	2.86	2.99	2.79
	S2	2.37	2.86	2.92	2.72
	S3	2.82	2.83	3.31	2.99
	S4	2.80	2.92	3.30	3.01
	S5	2.99	3.16	3.67	3.27
	S6	3.03	3.27	3.84	3.38

Table 4: Continued

100,000	S1	4.19	4.53	4.89	4.54
	S2	3.98	4.71	5.37	4.69
	S3	3.97	4.54	5.08	4.53
	S4	4.29	4.93	5.47	4.90
	S5	5.02	5.51	5.85	5.46
	S6	5.39	5.76	6.21	5.79
		N x S	Mean (S)		
	S1	3.36	3.69	3.94	3.66d
	S2	3.17	3.78	4.15	3.70a
	S3	3.40	3.68	4.20	3.76cd
	S4	3.54	3.93	4.38	3.95c
	S5	4.00	4.33	4.76	4.37b
	S6	4.21	4.52	5.03	4.59a
	Year 2002	3.73b	4.30a	4.46a	
	Year 2003	3.50b	3.68b	4.19a	
	Mean N	3.62c	3.99b	4.41a	
		Plant Density (Plants ha^{-1})			
		60,000	100,000	Mean (Y)	
	Year 2002	3.26	5.17	4.22a	
	Year 2003	2.79	4.79	3.79b	
	Mean (P)	3.02b	4.98a		
		Year 2002	Year 2003		
	S1	3.83	3.50		
	S2	3.96	3.45		
	S3	4.09	3.43		
	S4	4.23	3.67		
	S5	4.49	4.24		
	S6	4.72	4.25		

Where S1 =Two splits (50-50-0-0-0%)S2 =Three splits (50-25-25-0-0%)
S3 =Three splits (33.3-33.3-33.3-0-0%)S4 =Four splits (25-25-25-25-0%)
S5 =Five splits (20-20-20-20-20%)S6 =Five splits (8.3-16.6-25-33-16.6%)
Means of the same category followed by different letters are significantly different using LSD test ($p \leq 0.05$)

Table 5: Leaf area ratio (cm^2 g^{-1}) of maize at silking as affected by year, plant density, rate and timing of nitrogen application

Plant density (P) (Plants ha^{-1})	Timing of Nitrogen application (S)	Nitrogen levels (N) kg ha^{-1} 60	120	180	Mean
		N x P x S	P x S		
60,000	S1	55.67	60.86	57.95	58.16
	S2	48.18	56.20	52.87	52.42
	S3	60.22	53.82	58.41	57.49
	S4	56.28	54.41	57.88	56.19
	S5	58.93	55.48	64.65	59.68
	S6	58.79	57.93	64.98	60.57
100,000	S1	52.74	50.99	56.28	53.34
	S2	50.39	54.01	59.14	54.51
	S3	51.34	51.25	53.14	51.91
	S4	53.17	57.59	58.27	56.34
	S5	63.98	67.25	62.18	64.47
	S6	66.52	65.61	64.36	65.50

Table 5: Continued

	N x S	Mean (S)		
S1	54.20	55.92	57.12	55.75b
S2	49.28	55.11	56.00	53.46b
S3	55.78	52.54	55.78	54.70b
S4	54.72	56.00	58.07	56.27b
S5	61.45	61.36	63.41	62.08a
S6	62.65	61.77	64.67	63.03a
Year 2002	57.63	62.02	63.43	
Year 2003	55.07	52.21	54.92	
Mean (N)	56.35	57.12	59.17	
	Plant Density (Plants ha^{-1})			
	60,000	100,000	Mean (Y)	
Year 2002	61.75	60.30	61.02a	
Year 2003	53.08	55.05	54.06b	
Mean (P)	57.42	57.67		
	Year 2002	Year 2003		
S1	58.53	52.97		
S2	57.81	49.12		
S3	58.92	50.48		
S4	61.71	50.82		
S5	64.64	59.51		
S6	64.55	61.51		

Where S1 =Two splits (50-50-0-0-0%)S2 =Three splits (50-25-25-0-0%)
S3 =Three splits (33.3-33.3-33.3-0-0%)S4 =Four splits (25-25-25-25-0%)
S5 =Five splits (20-20-20-20-20%)S6 =Five splits (8.3-16.6-25-33-16.6%)
Means of the same category followed by different letters are significantly different using LSD test ($p \leq 0.05$)

photosynthetic machinery. Data concerning leaf area index of maize as affected by year, plant density, rate and timing of N application are reported in Table 4. Combined statistical analysis of the data revealed that year and stages of N application had significant and N rates and plant density had non significant effect on leaf area index. Leaf area index was higher in 2002 than in 2003. The variation in LAI of both years might be due to the fluctuation in the rainfall of both years. Leaf area index increased at the rate of 0.0065 with one kg increase in N rate. Plots maintained thicker density of 100,000 plants ha^{-1} gave the higher LAI than the plots maintained at lower plant density of 60,000 plants ha^{-1}. Increase in the number of split application for significantly increased LAI. The maximum LAI of 4.59 was recorded in those plots to which N was applied in five splits with greater proportion applied at later stages, followed by 4.37 in the plots to which N was applied in the same number of five splits but in equal amounts, while the minimum LAI of 3.66 was recorded in plots which received N in two equal splits at sowing and first irrigation as recommended for maize. This suggest that split application of N in later stages of maize increased leaf size in an attempt to maximize light interception and maximize the overall plant economy for acquisition of resources needed for growth and development. These results are in confirmation with those of several workers. Breadth of the area per leaf profile decreased under high soil nitrogen level and high plant density but leaf area, LAI and grain yield increased with higher rate of N [12], leaf area was greater under normal plant density than dense plants [14], increasing plant density significantly affected grain yield while leaf area was least affected by plant density [15] and maize crop differs in its ability to maintain LAI, CGR and above ground dry matter production at different levels N supply [16].

Leaf area ratio (cm^2 g^{-1}): Leaf area ratio is the ratio of leaf area to the total weight. It is also a measure of photosynthetic machinery per unit of plant biomass. Data on LAR of maize as affected by years, plant density, rate and timing of N application is presented in Table 5. Combined statistical analysis of the data revealed that N rate and plant density had no significant effects on LAR, while year and stages of N application had significant effects on LAR. The LAR of maize increased at the rate of

0.023 cm^2 g^{-1} due to one kg increase in the rate of N (Fig.5). The highest LAR of 63.03 cm^2 g^{-1} was noted in those plots to which N was applied in five split with high proportion applied at stages, followed by 62.08 cm^2 g^{-1} in the plots which received N in five splits at each of the five stages, while the minimum LAR of 53.46 cm^2 g^{-1} was recorded in the plots to which N was applied in three splits, 50% at sowing and 25% each at 1st and 2nd irrigation, i.e. 15 and 30 days after emergence respectively. Interaction between plant density and the stages of N application was significant for LAR, while other interactions were not significant. Plots maintained at high density (100,000 plants ha^{-1}) with application of N in five unequal splits resulted in the maximum LAR of 65.50 cm^2 g^{-1}, followed by LAR of 64.47 cm^2 g^{-1} in the plots to which N was applied in five equal split, while the minimum LAR of 52.42 cm^2 g^{-1} was recorded in the low density (60,000 plants ha^{-1}). Increase splits for N application increased LAR much more in higher plant density than in lower plant density. Leaf area ratio increased with increase in the rate and splits of N in late stages of maize. This suggests that split application increased leaf size is an attempt to maximize light interception and maximize the plant economy for acquisition of resources needed for growth and development. These results are in confirmation with those of several workers. Breadth of the area per leaf profile decreased under high soil nitrogen level and high plant density but leaf area, LAI and grain yield increased with higher rate of N [12], leaf area was greater under normal plant density than dense plants [14], increasing plant density significantly affected grain yield while leaf area was least affected by plant density [15] and maize crop differs in its ability to maintain LAI, CGR and above ground dry matter production at different levels N supply [16].

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