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NARROW PLANT SPACING AND NITROGEN APPLICATION ENHANCES SUNFLOWER (*Helianthus annuus* L.) PRODUCTIVITY

Muhammad Awais[1*], Aftab Wajid[1], Ashfaq Ahmad[1] and Allah Bakhsh[2]

[1]Department of Agronomy, University of Agriculture, Faisalabad-38040, Pakistan;
[2]Department of Irrigation & Drainage, University of Agriculture, Faisalabad-38040, Pakistan
Corresponding author's e-mail: mauaf26@gmail.com

Appropriate nitrogen application and optimum plant population ensure economic crop yield. For assessing the response of sunflower hybridHysun-33 to different plant populations, i.e. 83,333, 66,666 and 55,555 plants ha^{-1}at different N rates of 90, 120 and 150 kg ha^{-1}, a field experiment was undertaken using RCBD in split plot arrangement with three replications at Agronomic Research Area, University of Agriculture, Faisalabad. Results demonstrated that each successive N dose increased the crop biomass, yield and its components although sunflower oil contents were negatively affected. Maximum plant growth and achene yield (3115.4 kg ha^{-1}) were observed at 83, 333 plants ha^{-1}. Conflictingly days to flowering (64.5), achene formation (73.73), physiological maturity (95.98), head diameter (19.16 cm), thousand achene weight (43.53 g) and number of achenes per head (1138.8) were maximum in 55,555 plants ha^{-1}. Application of 150 kg N ha^{-1} in 83,333 plants ha^{-1} plant population was found to be best treatment to attain maximum achene yield.
Keywords: Plant population, nitrogen, achene yield, sunflower, productivity, *Helianthus annuus* L.

INTRODUCTION

Pakistan is persistently scarce in the production of edible oil (Munir *et al*., 2007) and condition is getting most horrible day by day with alarming increase in population growth rate (Asif *et al*., 2001; Iqbal *et al*., 2007). The graph of population and urbanization is constantly expanding, outstretching the deviation between demand and indigenous oilseed production. The quick increase of local oil production has been the main concern for decision makers because of rising import bills.

Sunflower is chief non-conventional oilseed crop that has the ability to fulfill the gaps that exist among the domestic demands and production (Hu *et al*., 2008). It is a widely distributed oil seed crop of the world (Allam *et al*., 2003; Nasim *et al*., 2011) as it has broad range of adaptability (Koutroubas *et al*., 2008) and high oil contents of about 43% (Nasim*et al*., 2011). Among different factors, optimum application of nitrogen fertilizer is the effective approach to maximize growth and yield of sunflower (Ghani *et al*., 2000; Ali *et al*., 2004; Ozer *et al*., 2004; Abdel-Motagally and Osman, 2010). Nitrogen is essential element (Abdel-Motagally and Osman, 2010; Ali *et al*., 2012) for boosting the domestic production of edible oils to meet its mounting demand (Nasim *et al*., 2011). Photosynthetic rate, leaf area and leaf area index increased with the application of nitrogen fertilizer (Rouphael *et al*., 2007). Oyinlola *et al*. (2010) reported that 100 kg N ha^{-1} was suitable for sunflower and the higher rate (150 kg N ha^{-1}) indicates a negative effect on the oil contents and yield. On the other hand according to Wajid *et al*. (2011), application of 180kg N ha^{-1} was optimum to attain maximum sunflower yield, while Hussain *et al.* (2011) reported that 80 kg N ha^{-1} was sufficient for sunflower fertilization. But, nitrogen application rate varies according to the environmental conditions and quantity of nitrogen previously present in the soil (Laureti *et al*., 2007). Plant density is important factor upsetting sunflower growth and yield (Allam *et al*., 2003; Osman and Awed, 2010). Maximum seed and oil yield was obtained from the planting density of 71420 plants ha^{-1} at the N application of 60 kg ha^{-1} (Killi, 2004). Higher planting density in sunflower crop reflected a considerable decline in plant height however, 1000-seed weight and head diameter increased with decreasing planting density (Basha, 2000). Increasing planting density to a certain level (85000 ha^{-1}) increased the sunflower seed yield and further increase in density imposed a negative impact on the crop (Mojiri and Arzani, 2003). Seed oil contents and oil yield were increased as planting density increased (Killi, 2004) contrary to Al-Thabet (2006) who reported that planting density has no significant effect on oil contents. Optimum plant population depends on cultivar, cultural, field management and environmental factors (Ali *et al*., 2011).In present study, it was attempted to explore most appropriate plant population and N rate in sunflower production under agro environmental conditions of Faisalabad.

MATERIAL AND METHODS

Present investigations were conducted to assess behavior of sunflower to various plant populations (P_1= 83333, P_2 = 66666 and P_3 = 55555 plants ha^{-1}) and N rates (N_1 = 90, N_2 =

120 and N_3 = 150 kg ha^{-1}) at the Agronomic research area, University of Agriculture, Faisalabad during spring, 2012. Soil of experimental site, with a sandy clay loam texture, had1.08 % organic matter, 7.73 pH, 12.31 % total soluble salts, 0.06 %N, 186 ppm $K_2O$and 6.7 ppm P_2O_5.Triplicated Randomized Complete Block Design was used in split plot arrangement with a net plot size of 3.6m x 5m.

Plant populations and N rates were kept in main and sub plot, respectively. Sunflower hybrid Hysun-33 was sown on March 1, 2012in 75 cm wide rows with different P x P distances (20, 25 and 30 cm) to get required plant population. One third N dose, all phosphorus (60 kg ha^{-1}) and potassium (60 kg ha^{-1}) fertilizers were applied at sowing, while remaining two third N was splitted, at first irrigation and at flowering stage. Seven harvests were taken starting from20 days after sowing with an interval of 10days. Three plants from a row were harvested from each plot at ground level. Fresh and dry weight of leaves and stem were noted; leaf area was determined by leaf area meter (CI-202). Leaf area index (LAI) was determined by formula assumed by Watson (1952):

$$LAI = \text{Leaf area} / \text{Ground area}$$

Net assimilation rate and crop growth rate were computed by using the formulae given by Hunt (1978).

$$CGR = (W_2-W_1) / (t_2-t_1)$$

Where W_1 and W_2 are the total dry weights of samples at times t_1 and t_2, respectively

$$NAR = TDM / LAD$$

Where TDM =Total Dry Matter, LAD = Leaf Area Duration

Data on days to germination, flowering and achene formation were recorded from each plot when seed germination, flowering and achene formation was about 75 %.Data on days to physiological maturity were noted when greenish backside of 75 % heads changed to yellow and external brackets became brownish. All the plants form the experimental plot was harvested for recording yield components and yield. All the data attained were analyzed by using the Fisher's analysis of variance technique. Treatments' differences were compared by employing least significant difference (LSD) test at 0.05 probability level (Steel *et al*., 1997).

RESULTS

***Phenology*:** Plant population and N rates showed non-significant difference for days to germination (Table 1). Significant differences were recorded in number of days to flowering with changing plant population and nitrogen rates (Table 1).Maximum days to flowering (65.75) were seen with lowest plant population (55,555 plants ha^{-1}) that was statistically at par with the number of days to flowering (65.31) with 66,666 plants ha^{-1} plant population, while statistically minimum days to flowering (64.20) were recorded with highest plant population (83,333 plants ha^{-1}). The sunflower took more days to flowering (66.58) when it was supplied with 150 kg N ha^{-1}, followed by N_2 (120 kg N ha^{-1}), while less days to flowering (63.80)was noted with N_1(120 kg N ha^{-1}). In the same way, both plant population and N rates significantly influenced the days to achene formation (Table 1). Treatment P_3 (66,666 plants ha^{-1}) took maximum days (77.73) to achene formation while the treatment P_2 (66,666 plants ha^{-1}) and P_1 (55,555 plants ha^{-1}) were statistically same in days to achene formation that took 76.68 and 76.01 days, respectively. Nitrogen rates also showed highly significant effect on number of days to achene formation. The treatment N_3 (150 kg N ha^{-1}) took more days (77.43) for achene formation while minimum days (76.09) to achene formation were found at 90 kg N ha^{-1}. Significant differences were also recorded between N_1 and N_2 for number of days to achene formation. Significantly

Table 1. Nitrogen and plant population effects on growth and phenology of sunflower hybrid

Treatments	Days to germination	Days to flowering	Days to achene formation	Days to physiological maturity	Leaf area index	CGR (g m^{-2} d^{-1})
P1	9.66	64.20 b	76.01 b	99.02 b	4.64 a	10.30 a
P2	9.44	65.31 a	76.68 b	99.90 b	4.37 b	9.55 b
P3	9.44	65.75 a	77.73 a	100.9 a	3.46 c	8.37 c
LSD	0.85	1.09	0.9	0.89	0.21	0.60
significance	NS	*	*	**	**	*
N1	9.66	63.80 c	76.09 c	99.01 c	3.85 c	8.81 b
N2	9.44	64.82 b	76.9 b	99.96 b	4.20 b	9.31 ab
N3	9.44	66.58 a	77.43 a	100.9 a	4.43 a	10.09 a
LSD	0.98	0.98	0.43	0.47	0.22	0.63
significance	NS	**	**	**	**	*
Mean	9.52	65.07	76.81	98.95	4.16	9.40
Interaction	NS	NS	NS	NS	NS	NS

Mean sharing different letters in a column differ significantly at $p \le 0.05$ *, ** = significant and highly significant respectively; NS = Non-Significant, LSD= Least Significant Difference maximum days (100.9) to physiological maturity were noted in the treatment P_3 (55,555 plants ha^{-1}) that was statistically higher than that of P_2 (66,666 plants ha^{-1}) which took 99.90 days, while P_1 (83,333 plants ha^{-1}) took minimum days (99.02) to physiological maturity (Table 1). More days to maturity (100.9) were recorded from the highest dose of N (150 kg ha^{-1}), whereas the lowest days to maturity (99.01) were observed by the application of 90 kg N ha^{-1}.

Growth**:** The data showed that plant population as well as N doses had highly significant effect on leaf area index (LAI) (Table 1). Maximum LAI (4.64) was noted at 60 DAS (Fig. 1b) when plant population of 83,333 plants ha^{-1} was maintained, while minimum LAI (3.46) was observed from the plant population (55,555 plants ha^{-1}). Maximum LAI (4.43) was detected from 150 kg N ha^{-1} application and minimum value of LAI (3.85) was achieved with the application of 90 kg N ha^{-1} at 60 days after sowing when crop achieved maximum canopy cover (Fig. 1a).The relationship of LAI with crop growth rate (CGR) and leaf area duration (LAD) was found to be highly significant. Mean crop growth rate (CGR) was statistically highly significant with plant population and N rates (Table 1). Maximum mean CGR (10.30 g m^{-2} d^{-1}) was attained from the treatment P_1 (83,333 plants ha^{-1}) that was statistically different from both treatments $P_2$and P_3. Mean CGR was reduced regularly with discount of plant population (Fig. 2b) and lowest mean CGR (8.37 g m^{-2} d^{-1}) was calculated for the lowest plant population (55,555 plants ha^{-1}).The effect of increasing nitrogen rates on mean CGR was positive and significant (Fig. 2a). Mean crop growth rate was increased up to 10.09 g m^{-2} d^{-1} with the application of 150 kg N ha^{-1}. Lowest mean CGR (8.81 g m^{-2} d^{-1}) was achieved when crop

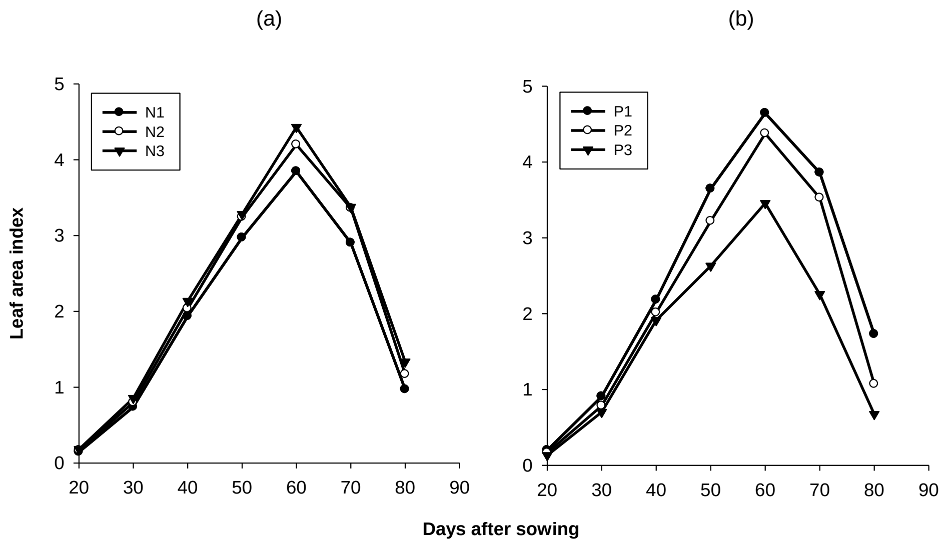

Figure 1. N application (a) and plant population (b) influences on leaf area index

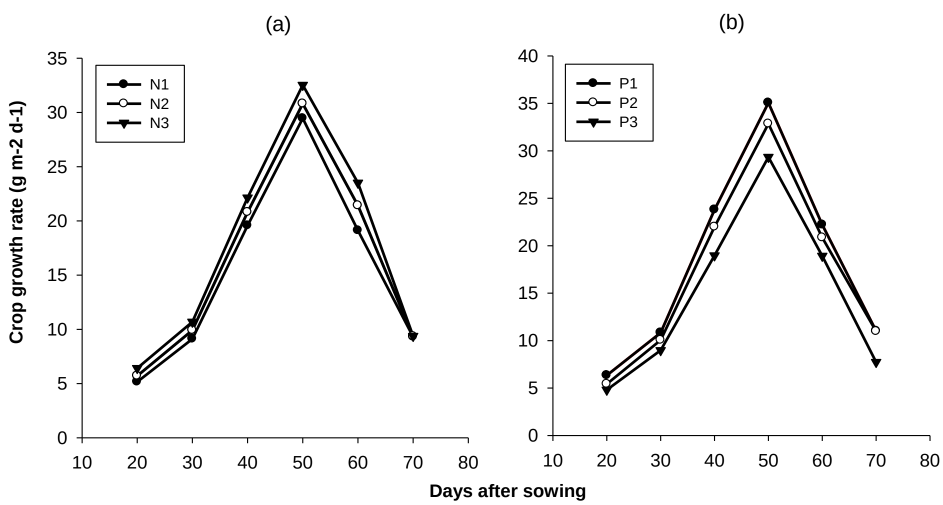

Figure 2. N application (a) and plant population (b) influence on crop growth rate

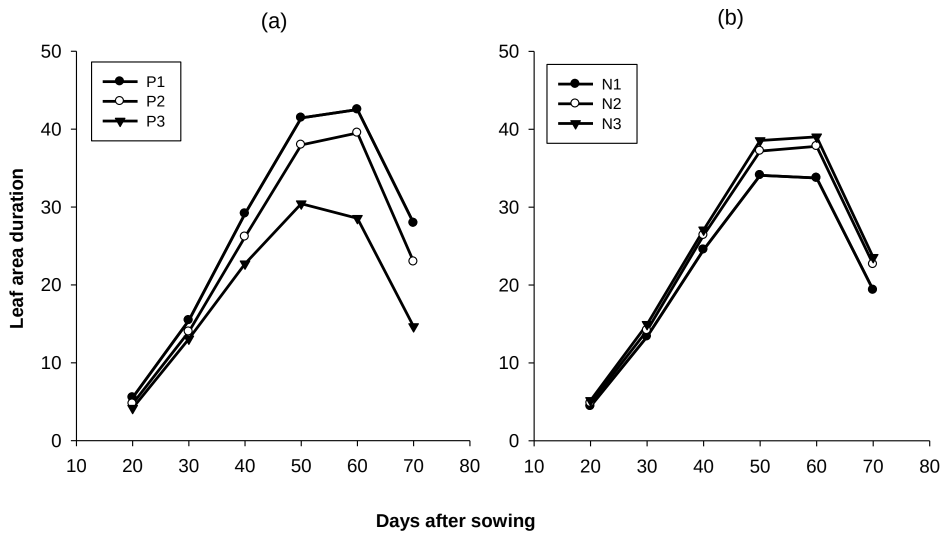

Figure 3. N application (b) and plant population (a) influence on leaf area duration

was supplied with 90 kg N ha^{-1}.The association of CGR with LAI and LAD was highly significant (Table 3).The crop achieved maximum LAD (161.9 days) with P_1 treatment (83,333 plants ha^{-1}) and minimum LAD (113.5 days) was attained from the P_3 treatment (66,666 plants ha^{-1}). Similarly response of N rates was also significant and positive. Minimum LAD (129.5 days) was observed with application of 90 kg N ha^{-1}.Each successive increase in plant population and N rates increased plant height, linearly and significantly (Fig. 3a & 3b). Maximum plant height (187.28 cm) was obtained with highest plant population (83,333 plants ha^{-1}) while statistically minimum plant height (174.04 cm) was attained with lowest plant population (55,555 plants ha^{-1}). Similarly, 150 kg N ha^{-1} treatment produced taller plants (191.14 cm) as compared to 120 and 90kg N ha^{-1} treatments which produced 182.0 cm and 172.52 cm tall plants. However, 120 kg N ha^{-1} treatment was statistically at par with that of 90 kg N ha^{-1}as well as with 150 kg N ha^{-1}treatments. Association of plant height with LAI was significant whereas it was highly significant with CGR.

***Yield components and achene yield*:** Increasing plant population (55,555 to 83,333 plants ha^{-1}) progressively decreased head diameter (Table 2). Hysun-33 produced maximum head diameter (19.09 cm) at lowest plant population (55,555 plants ha^{-1}), while statistically minimum head diameter (15.20 cm) was observed at highest plant population (83,333 plants ha^{-1}).Increasing N rates imposed a positively significant effect on head diameter. Maximum head diameter (18.61 cm) was produced by highest N application (150 kg N ha^{-1}) that was statistically different with the head diameter (17.20 cm) produced from N application of 120 kg ha^{-1}. A significant correlation of head

Table 2. Nitrogen and plant population effects on yield of sunflower hybrid

Treatments	LAD (days)	Plant height (cm)	Head diameter (cm)	Achene number per head	1000-achene Wt. (g)	Achene yield (kg ha^{-1})	Oil contents (%)
P1	161.9 a	187.28 a	15.20 b	963.0 c	39.27 b	3164.2 a	39.47 a
P2	145.3 b	181.34 b	17.36 ab	1042.0 b	41.53 a	2890.1 b	39.24 a
P3	113.5 c	174.04 c	19.09 a	1086.8 a	41.68 a	2495.3 c	39.23 a
LSD	8.07	4.10	2.84	29.37	1.43	260.32	0.94
significance	**	*	*	*	*	**	NS
N1	129.5 c	172.52 b	15.84 c	976.9 c	37.54 c	2487.4 c	40.42 a
N2	143.0 b	182.0 ab	17.20 b	1036.5 b	40.94 b	2898.0 b	39.69 ab
N3	148.3 a	191.14 a	18.61 a	1078.1.9 a	44.00 a	3196.8 a	37.84 b
LSD	4.76	14.17	1.13	28.76	2.80	249.09	2.04
significance	*	**	**	*	**	**	*
Mean	140.28	181.89	17.22	1030.5	40.83	2907.0	39.31
Interaction	NS	NS	NS	NS	NS	NS	NS

Mean sharing different letters in a column differ significantly at p≤0.05 *, ** = significant and highly significant respectively; NS = Non-Significant, LSD= Least Significant Difference diameter with thousand achene weight and highly significant with number of achenes per head was found (Table 3). Different plant populations significantly affected the number of achenes per head (Table 2). A progressive increase in number of achenes per head was observed with decrease in plant population from 83,333 to 55,555 plants ha^{-1}. Plant population of 55,555 plants ha^{-1} produced significantly higher number of achenes per head (1086.8) as compared to plant population (83,333 plants ha^{-1}) which produced statistically minimum number of achenes (963.0). Similarly, each increment of nitrogen fertilizer increased the number of achenes per head significantly. Maximum number of achenes (1078.1) was noticed with the application of 150 kg N ha^{-1}, whereas, minimum number of achenes (976.9) was attained from the application of 90 kg N ha^{-1}.Significant differences were noted for thousand achene weight due to different plant populations and N application rates (Table 2). Thousand achene weight (41.68 g) was significantly high in P_3 (55,555 plants ha^{-1}) which was statistically at par with that of P_2 treatment (66,666 plants ha^{-1}) while minimum thousand achene weight (39.27 g) was produced from P_1 treatment (83,333 plants ha^{-1}).In the same way, more thousand achene weight (44.00 g) was produced from $N_3$and statistically minimum thousand achene weight (37.54 g) was recorded from N_1 treatment. Both, achene number and achene weight were positively and significantly correlated with each other (Table 3). Achene yield was considerably influenced with different plant populations (Table 2) and maximum achene yield (3164.2 kg ha^{-1}) was obtained from the treatment P_1 (83,333 plants ha^{-1}) and the treatment P_3 (55,555 plants ha^{-1}) produced minimum achene yield (2495.3 kg ha^{-1}). Overall, an increase of 21.14 % was recorded with highest plant population than lowest plant population (55,555 plants ha^{-1}). The data showed that achene yield was also significantly affected by N rates (Table 2). Achene yield was increased from 2487.4 to 2898 and 3196.8 kg ha^{-1}with increasing nitrogen application. Moreover, higher N rate (150kg ha^{-1}) improved sunflower yield by 22.19 %as compared to lower dose of nitrogen (90 kg ha^{-1}).The regression lines(Fig. 4) indicate a positive, strong and linear relation of achene yield with LAI (R^2=0.84), CGR (R^2=0.94), LAD (R^2=0.69) and plant height (R^2=0.92). Very little and non-significant differences were recorded in oil contents among different plant populations (Table 2). However, increasing nitrogen application effects on oil contents were significant and negative.

DISCUSSION

The superiority of higher plant population for growth (leaf area index, leaf area duration, crop growth rate and net assimilation rate), development (days to germination, days to flowering, days to achene formation and days to physiological maturity), yield and yield components might be due to the fact that, there may be more efficient consumption of the input resources (nutrients, space, water and light) as compared to low plant population**.** This study directed that increasing plant population had substantial effect on growth, development and all yield characters of sunflower. Seed germination is controlled by soil, environmental (Ali *et al*., 2012) as well as genetic factors, so non-significant differences were found for days to germination among different plant populations and nitrogen rates. Days taken for flowering increased with decreasing plant population. Less plant competition for water, nutrients and light in low plant population plots increased vegetative growth and delayed flowering (Iqbal *et al*., 2007).

Table 3. Correlation between Achene yield and explanatory parameters

Parameters	**Achene yield (kg ha^{-1})**	**Head diameter (cm)**	**Number of achene per head**	**1000-achene Wt. (g)**	**Plant height (cm)**	**Oil contents (%)**	**Leaf area index**	**M CGR (g m^{-2} d^{-1})**	**LAD (days)**
Achene Yield	1.00								
Head diameter	-0.13ns	1.00							
Achene per head	-0.06ns	0.99**	1.00						
1000-achene weight	0.45ns	0.82*	0.87**	1.00					
Plant height	0.96**	0.11ns	0.18ns	0.63ns	1.00				
Oil contents	-0.64ns	-0.63ns	-0.66ns	-0.92**	-0.80*	1.00			
Leaf area index	0.92**	-0.44ns	-0.36ns	0.14ns	0.77*	-0.33ns	1.00		
Mean crop growth rate	0.97**	-0.35ns	-0.28ns	0.24ns	0.87**	-0.48ns	0.97**	1.00	
Leaf area duration	0.83**	-0.59ns	-0.50ns	-0.04ns	0.66ns	-0.11ns	0.96**	0.90**	1.00

*, ** and Ns significant at the 5%, 1% probability levels and non significant respectively.

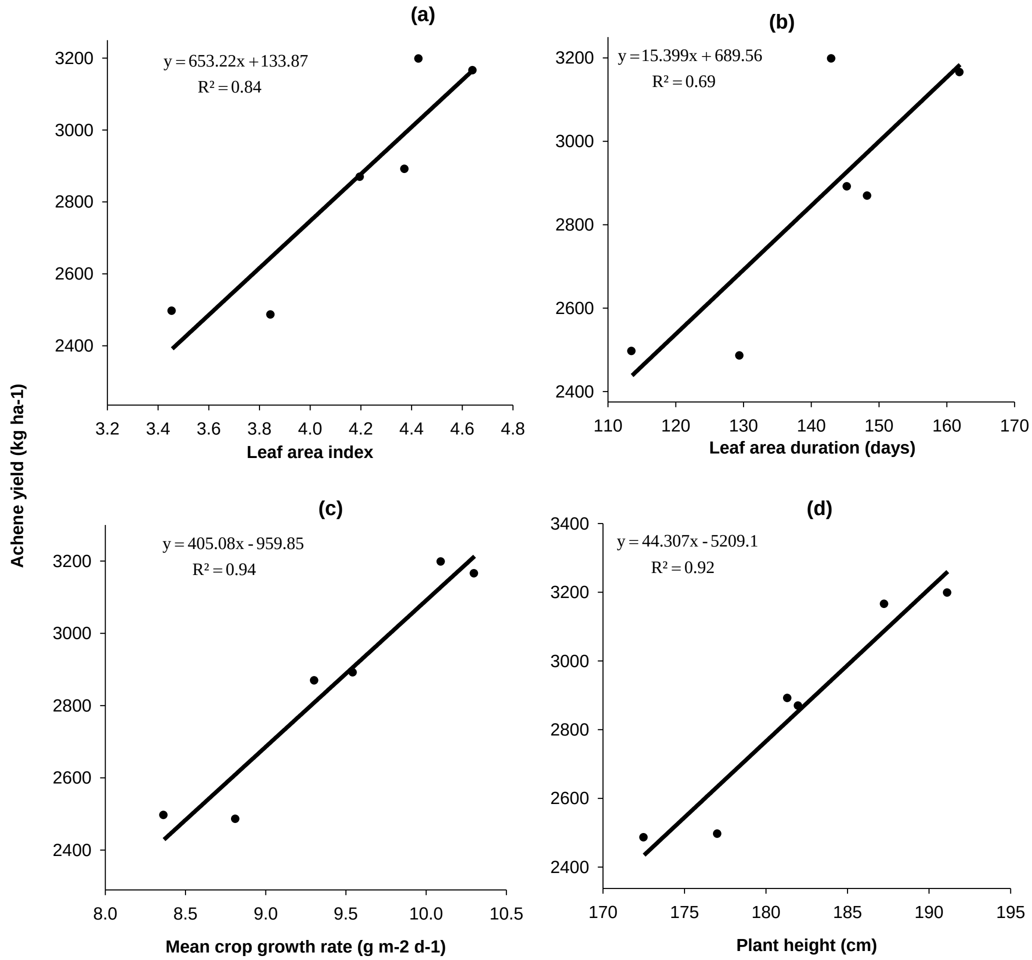

Figure 4. Relationship of achene yield with leaf area index (a), leaf area duration (b), crop growth rate (c) and plant height (d).

Phenological traits were delayed with increasing nitrogen application (Hammad *et al*., 2011). Increase in number of days to flowering with increasing rates of nitrogen might be due to more utilization of metabolites by vegetative tissues (Oyinlola *et al*., 2010) that leads to considerable increase in vegetative growth (Bakht *et al.*, 2010). More days to flowering with decreasing plant population and increasing nitrogen rates was also reported by Ali *et al*. (2012) who reported 62.33 and 62.05 days from 83,333 plants ha^{-1} plant population and 150kg ha^{-1} application. Whereas, Oyinlola *et al*. (2010) recorded 61 days for flowering with 60 kg N ha^{-1} application. A linear increase in days to achene formation was also recorded with each increment in plant population as well as nitrogen fertilizer application. These results are in agreement with those of Ali *et al*. (2012) who reported that sunflower takes 72.66 days to achene formation with the application of 150 kg N ha^{-1} and 73.27 days with a plant population of 83,333 plants ha^{-1}. An increasing trend in days to physiological maturity with decreasing plant population and increasing nitrogen application agrees the findings of Ali *et al.* (2012) who observed that sunflower took 95.83 and 95.05 days to maturity with 83,333 plants ha^{-1} plant population and 150 kg N ha^{-1}, respectively. Increasing nitrogen application caused extension in days to physiological maturity (Mujiri and Arzani, 2003). Increasing nitrogen application increased the photosynthesis rate (Oikeh *et al.*, 1997) and leaf durability that finally delayed crop physiological maturity (Gungula *et al*., 2003). Leaf area can be regarded as the consequence of the duration and rate of leaf expansion, and leaf expansion rate was found to be very sensitive to nitrogen availability (Trapani *et al*., 1999). Leaf area index (LAI) has crucial significance in increasing the crop yield (Hammad *et al*., 2011).More number of plants m^{-2} in P_1 treatment might be the possible reason for maximum leaf area index. More assimilates production and its exploitation in leaf expansion with increasing nitrogen availability (Hammad *et al*., 2011) ultimately lead to more leaf area index. Nasim *et al*. (2011) recorded a LAI value of

4.6 with the application of 180 kg N ha^{-1}. An increase in LAI with increasing nitrogen application up to 150 kg ha^{-1} was also noted by Murad *et al*. (2000). Moreover, Bange *et al*. (2000) also explained more leaf expansion in sunflower due to higher rate of cell division and cell enlargement with increased N rates. LAI of sunflower increased with the application of higher rate of N (Sadras, 2006) and the decline in LAI was much prominent at low doses of N (Ali *et al*., 2000; Iqbal *et al*., 2008). CGR increased progressively up to 50 DAS then it started to decline and reached to minimum at maturity. Nitrogen effects on mean CGR in sunflower has been described by Nasim *et al*. (2011) who recorded16.1 g m^{-2} d^{-1} mean CGR with application of 180 kg N ha^{-1}. As CGR is a function of LAI and NAR (Hammad *et al*., 2011) increase in CGR with nitrogen application might be due to increase in leaf area index. Increase in CGR with nitrogen increment also authenticated the results of Iqbal *et al.,* (2008) who also described positive effects of nitrogen on CGR. In our study, more LAD was attained from highest plant population (83,333 plants ha^{-1}) and N rate (150 kg ha^{-1}). Increasing rates of nitrogen increase persistency of crop to remain vigorous for CO_2 absorption (Wajid *et al*., 2010). There is more competition for water, nutrients, light and other environmental factors between plants at high plant population (Ali *et al*., 2011), compelling the crop to grow taller plants with reduced seed production (Allam *et al*., 2003; Beg *et al*., 2007) as well as less head diameter (Tenebe *et al*., 2008; Osman and Awed, 2010). Decrease in head diameter, thousand achene weight and number of achenes with increasing plant population was also recorded by Al-thabet (2006). Biomass production was reduced with lower rates of nitrogen (Khan *et al.,* 1999) that finally produced lesser head diameter, achene weight and number of achenes per head (Iqbal and Ashraf, 2006; Nasim *et al*., 2011). The study also validates the findings of Cantagallo *et al.* (2009) who described that the growth and development of both source (leaf) and sink (seed) were very sensitive to nitrogen deficiency. A regular increase in achene yield with increasing plant population (55,555 to 83,333) was mainly due to increase in number of plants at harvest as described by Allam *et al*. (2003). Ali *et al*. (2012) attained achene yield of 3662 kg ha^{-1}with plant population of 83,333plants ha^{-1}. Significant increase in Growth (LAI, TDM, LAD, CGR) and yield components (head diameter and number of achenes per head) with nitrogen increment ultimately produced significant increase in achene yield (Ozer *et al*., 2004; Osman and Awed, 2010). Al-Thabet *et al*. (2006) and Ali *et al*. (2012) recorded a seed yield of 3952 kg ha^{-1} and 3284 kg ha^{-1} from the 150kg N ha^{-1} application, respectively. A sunflower crop rich in oil contents of excellent quality is the final objective of a farmer. Non-significant differences for oil contents among various plant populations were also stated by Al-Thabet (2006). Our results are not consistent to the outcome of Killi (2004) and Ali *et al*. (2012) who reported significant increase in oil concentration and also to Osman and Awed (2010) who described reduction in oil contents with increasing plant population. As nitrogen is an important constituent of the proteins, so increasing nitrogen rates increased protein synthesis and reduced oil contents (Hussain *et al*., 2011).

***Conclusion*:** The sunflower phenology, growth and achene yield significantly responded to different plant populations and N rates. Although yield components (head diameter, number of achene per head and thousand achene weights) were decreased with increasing plant population but overall increased yield in this study with increasing plant population was mainly attributed to more number of plants per meter square. Our findings recommend that farmers should apply 150 kg N ha^{-1} in 83,333 plants ha^{-1} plant population to attain maximum achene yield.

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