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NITROGEN FERTILIZATION AND NARROW PLANT SPACING STIMULATES SUNFLOWER PRODUCTIVITY

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ABSTRACT

Plant population exerts a strong influence on growth and seed yield because of its competitive effect both on the vegetative and reproductive development. For evaluating the effect of different plant populations (83,333, 66,666 and 55,555 plants ha^{-1}) and N rates (90, 120 and 150 kg N ha^{-1}) on sunflower hybrid (Hysun-33) a field experiment was conducted during spring seasons of 2012 and 2013 using split plot design with three replications at Agronomic Research Area, University of Agriculture, Faisalabad. Results revealed that each N increment enhances the total dry matter, achene yield and its components while oil contents were undesirably affected. During both years, total dry matter, achene yield and harvest index were detected from 83, 333 plants ha^{-1}. Contradictorily, yield components (head diameter, number of achenes per head and 1000-achene weight) were highest in 55,555 plants ha^{-1} treatment. Application of 150 kg N ha^{-1} in 83,333 plants ha^{-1} plant population was best treatment to attain maximum achene yield.

Keywords: correlation, nitrogen, plant population, regression, achene, sunflower, yield.

INTRODUCTION

Pakistan has been facing a persistent shortage of vegetable oils for many years (Munir*et al*., 2007) due to increasing population (Iqbal*et al*., 2007) and many other critical factors. The native edible oil production does not equal to increasing demand of population. Thus country is forced to import edible oil in massive quantities involving giant expenditure in foreign exchange. Pakistan will have to seem away from the traditional oilseed crops (cottonseed, rapeseed and mustard and groundnut) to appreciably increase local production of vegetable oil (Khaliq and Cheema, 2005). Rapeseed and mustard oil cannot be used (more than 5%) for ghee formation (P.O.D.B., 2006) as it contains higher concentration of erucic acid. Similarly, cotton oil contents and its fiber are negatively correlated, as is generally grown for its fiber (Govt. of Pakistan, 2009b). The most important non-conventional oil seed crops are sunflower, soybean and safflower (Khaliq and Cheema, 2005). Among different non-conventional oilseed crops sunflower has appeared as an important crop (Badar *et al.,* 2002; Khaliq and Cheema, 2005; Ahmad *et al*., 2009) that can reduce edible oil import (Khan *et al*., 2003; Hu *et al*., 2008). Sunflower can be grown nearly all over Pakistan (Khaliq and Cheema, 2005). In Pakistan area under sunflower crop was 0.28 million hectares with oilseed production of 0.378 million tons and oil production 0.14 million tons(Govt. of Pakistan, 2013).

Reduction in sunflower production was due to many factors like improper plant density, nitrogen fertilizer level and irrigation application etc. Availability of different nutrients is the main factor that controls the sunflower yield (Habib *etal*., 2006). Fertilizer application boosts the fertility status of soil; enhance the nutrients uptake by the plant that finally increase crop yield (Adediran*et al.*, 2004). However in intensive agriculture, nitrogen is the major nutrient determining sunflower yield (Habib *et al.*, 2006; Abdel-Motagally and Osman, 2010). Nitrogen, the most deficient element in our soils, being an integral part of structural and functional protein, chlorophyll and nucleic acid plays a vital role in crop development. Increased supply of nitrogen results in faster rate of plant growth, productivity and photosynthetic capacity of leaves (Fayyaz-Ul-Hassan *et al*., 2005). Leaf area, leaf production, light interception and photosynthesis rate were reduced by the nitrogen deficiency (Toth*et al*., 2002; Nasim*et al*., 2011). Increased rates of nitrogen reduced the oil contents of sunflower (Ali *etal*., 2004; Osman and Awed, 2010; Bakht*et al*., 2010a; Nasim*et al*., 2011; Hussain*et al*., 2011) but the reduction was relatively small, and it was over compensated by increase in seed yield (Scheiner*et al*., 2002). Higherachene weight and number of achene per head were obtained from the application of 150 or 225 kg N ha^{-1} (Ali *et al*., 2011).Plant population has a crucial significance for achieving highest yield potential of a sunflower crop. Plant population affects the radiation interception, evapotranspiration and finally water use efficiency of growing crop (Saleem*et al.*, 2008; Yasin*et al*., 2011). Killi, (2004) reported that head diameter, total number of seeds per head, seed yield per head and 1000–seed weight were highest with highest plant population (71420 plants ha^{-1}).

The aim of the present study was to determine effect of different plant population and N rates on growth and yield of sunflower under agro environmental conditions of Faisalabad, Pakistan.

MATERIALS AND METHODS

Field experiment was conducted to study the response of sunflower to different plant populations and N rates. Investigation was carried out for two consecutive years i.e. during 2012 and 2013 at the Agronomic Research Area, University of Agriculture, Faisalabad, Pakistan. The climate of Faisalabad (31°26' N, 73°06' E) region is subtropical and arid to semi-arid at an altitude of 184 meters. The experimental field was quite uniform and its soil was sandy clay loam. The soil was analyzed for its physio-chemical properties; each year before sowing the crop (Table 1).

Table 1. Physiochemical properties of soil (0-30 cm)

Soil characteristics	2012	2013
Physical		
Sand (%)	59	63
Silt (%)	17	15
Clay (%)	24	22
Chemical		
pH	7.8	7.62
Organic matter (%)	1.07	1.09
Total soluble salt (%)	12.31	12.27
Nitrogen (%)	0.05	0.06
Available P (ppm)	6.7	6.8
Available K (ppm)	189	195

Weather summary of experimental site was presented in Fig. 1. The experiment was laid out in a randomized complete block design with split plot arrangement keeping plant population (83333, 66666 and 55555) in main plots and N rates (90, 120 and 150 kg ha^{-1}) in sub plots. The experiment was replicated thrice; measuring a net plot size of 3.6 m × 5 m. Sunflower hybrid (Hysun-33) was sown on 1st March during both the years. In each season the experimental field was wetted by heavy irrigation (locally called *rouni*) and seedbed was prepared by one deep ploughing and two cultivations, each followed by planking. Planting was done on 60 cm apart ridges in both experiments. Plant to plant distance was kept according to plant population treatments (20 cm for 83,333, 25 cm for 66,666 and 30 cm for 55,555plants ha^{-1}). Phosphorus and potassium was used @ 60 kg ha^{-1} each in all plots. Nitrogen, phosphorus and potassium were applied in the form of Urea, DAP and SOP. One third dose of nitrogen and full of the P and K was applied at sowing. Remaining N was used in two splits; 1/3 at first irrigation and 1/3 at the flowering stage. All other cultural practices such as hoeing, earthing up and plant protection measures were kept normal for the crop. Table 2 describes the crop husbandry operations during both years. Growth sampling was conducted at a ten days interval. In each plot, four plants were harvested at the ground level. The plants that were cut were separated into leaves and stems. A sub-sample (50 g) of each fraction was taken and dried in forced draft oven at 70ºC for at least 48 h up to constant weight to calculate total dry weight (g m^{-2}) at each harvest. The crop growth rate (CGR) was calculated as suggested by Hunt (1978) at each sampling date.

$$CGR = (W2-W1) / (T2- T1)$$

Where, W_1 and W_2 were the total dry weights harvested at times T_1 and T_2, respectively. Mean CGR was calculated by averaging all CGR values calculated at each destructive harvest. At final harvest, two rows with a length of 5 m for each plot were harvested. A subsample of 10 plants was obtained to measure the yield components. All the heads including subsample were threshed mechanically to estimate achene yield of entire plot and converted into kg ha^{-1}. For the measurement of achene moisture, the subsample of 500 g was weighed, dried and then weighed again, so the final yield was corrected to 10 % moisture. The sunflower head diameter was measured from the 10 randomly taken plants and average head diameter was determined. Five heads per plot were threshed, their grains counted and average grains per head was computed. Five samples each of thousand achenes were taken from each plot, weighed with an electric balance and averaged. The total dry matter was determined and for this purpose whole plot was harvested, weighed and converted into kg ha^{-1}.Harvest index (HI) was measured as the ratio of achene yield to biological yield, and expressed in percentage.

$$HI = (Achene\ yield / Biological\ yield) \times 100$$

Data collected were analyzed statistically by employing the Fisher's analysis of variance technique and significance of treatments means was tested using least significance difference (LSD) test at 5% probability level (steel *et el*., 1997).

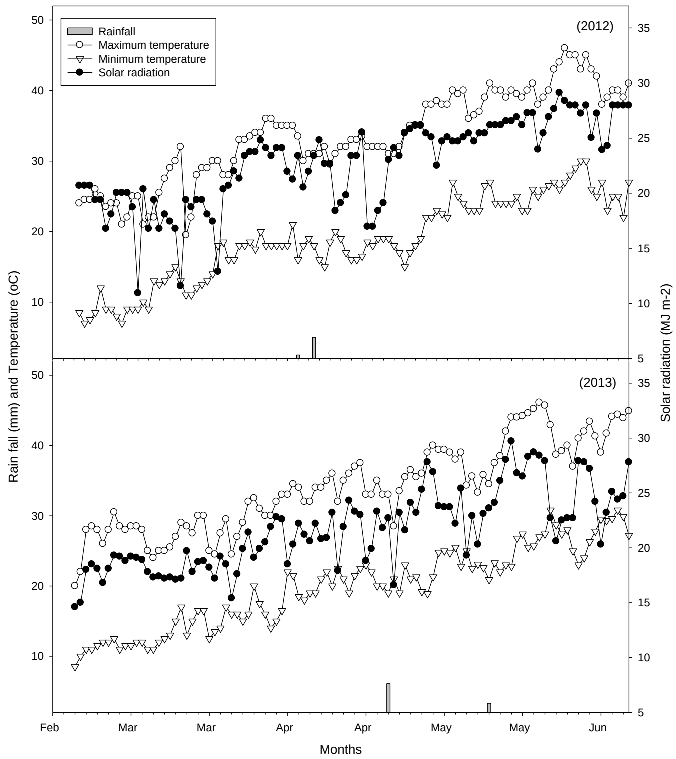

Figure 1. Mean climatic conditions of agro-ecological conditions of Faisalabad.

Table 2. Crop husbandry operations in experiment during 2012 and 2013

Operations	**2012**	**2013**
Sowing dates	01.03.2012	01.03.2013
Crop establishment	11.03.2012	11.03.2013
Fertilizer application		
P (DAP) @ 60 kg ha^{-1}	01.03.2012	01.03.2013
K (SOP) @ 60 kg ha^{-1}	01.03.2012	01.03.2013
N (Urea)	N application in three splits according to treatments	
1st Dose	01.03.2012	01.03.2013
2nd Dose	20.03.2012	20.03.2013
3rd Dose	21.04.2012	18.04.2013
Thinning	19.03.2012	19.03.2013
Earthing Up	18.04.2012	15.04.2013
Irrigations		
1	20.03.2012	20.03.2013
2	07.04.2012	05.04.2013
3	21.04.2012	18.04.2013
4	11.05.2012	06.05.2013
5	25.05.2012	21.05.2013
Sampling dates		
1	20.03.2012	20.03.2013
2	30.03.2012	30.03.2013
3	09.04.2012	09.04.2013
4	19.04.2012	19.04.2013
5	29.04.2012	29.04.2013
6	09.05.2012	09.05.2013
7	19.05.2012	19.05.2013
Harvesting	12.06.2012	08.06.2013

RESULTS AND DISCUSSION

Plant population significantly affected the crop growth rate (CGR) during both experimental years (Table 3). The sunflower achieved more CGR (15.11 and 15.32 g m^{-2} d^{-1} in 2012 and 2013, respectively) when plant population was maintained at 83,333 plants ha^{-1}. Lowest mean CGR (13.54 and 13.77 g m^{-2} d^{-1} during 2012 and 2013, respectively) was noted from 55,555 plants ha^{-1} treatment. The treatment P_2 (66,666 plants ha^{-1}) was statistically similar to P_1 (83,333 plant ha^{-1}) in both study years. The effect of N rates on CGR was also significant (Table 3). More CGR (14.85 g m^{-2} d^{-1}) was observed in plots where N was applied @ 150 kg ha^{-1} in 2012 and it was statistically at par with plots fertilizes with 120 kg N ha^{-1}. Same trend was noted in next study year and N_2 treatment remained at par with N_3 treatment. The minimum CGR of 13.93 g m^{-2} d^{-1} was recorded in N_1 (90 kg ha^{-1}) during both experimental years. However, this treatment was also at par with N_2 (120 kg N ha^{-1}). Increased vegetative growth due to N application finally leads to enhancement in CGR.Nitrogen effects on sunflower mean CGR has been described by Nasim*et al*. (2011) who recorded 16.01 g m^{-2} d^{-1} mean CGR with application of 180 kg N ha^{-1}. Increase in CGR with nitrogen increment also authenticated the results of Iqbal*et al.* (2008) who also described positive effects of nitrogen on CGR. The CGR association with total dry matter (R^2= 1 in both years) and achene yield (R^2= 0.98 in 2012 and 0.96 in 2013) was also positive (Fig. 4).

Table 3. Influences of plant population and nitrogen on growth and yield components of sunflower hybrid

Treatments plants ha^{-1}	Crop growth rate (gm-2d-1) 2012	2013	Mean	Head diameter (cm) 2012	2013	Mean	Number of achenes per head 2012	2013	Mean	Thousand achene weight 2012	2013	Mean
83,333	15.11 a	15.32 a	15.22	15.2 b	15.0 b	15.1	971.0 b	942.1 b	956.5	39.3 b	38.3 b	38.78
666,666	14.51 a	14.77 a	14.64	17.4 ab	17.0 a	17.16	1030 ab	1009 a	1020	42.6 a	40.1 ab	41.32
55,555	13.54 b	13.77 b	13.66	18.8 a	18.2 a	18.48	1071 a	1024 a	1047.9	42.7 a	41.1 a	41.89
LSD 0.05	0.96	0.96		2.66	1.57		65.71	41.26		2.87	2.09	
Significance	*	*		*	*		*	*		*	*	
N rates kg ha^{-1}												
90	13.9 b	13.4 b	13.7	15.8 b	15.7 b	15.7	976.4 b	946.4 b	961.4	38.1 b	37.9 b	38
120	14.4 ab	14.7 ab	14.6	17.5 a	16.9 ab	17.2	1034 ab	996 ab	1015.7	42.4 a	40.3 ab	41.32
150	14.9 a	15.2 a	15.1	18.1 a	17.6 a	17.8	1061.8 a	1032 a	1047.3	44.1 a	41.3 a	42.69
LSD 0.05	0.7	0.81		1.26	1.42		65.74	57.17		3.95	2.72	
Significance	*	*		**	*		*	*		*	*	
Interaction	NS	NS		NS	NS		NS	NS		NS	NS	
Year mean	14.38	14.62	14.5	17.1	16.72	16.91	1024.4	991.9	1008.1	41.52	39.82	40.67

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

Highly significant increase in plant height was recorded with increasing plant population during both study seasons (Table 5). P_1 (83,333 plants ha^{-1}) produced taller plants (187.3 cm) as compared to P_2 (66,666 plants ha^{-1}) and P_3 (55,555 plants ha^{-1}) that attained a plant height of 181.2 and 177.0 cm during season 2012. A similar trend was also seen during 2013. Decreased number of plants per unit area may increase the crop canopy ability to receive the radiation due to more light penetration than denser plants. Increased light intensity disturbs the level of auxin in plants that finally decreased plant height (Allam*et al*., 2003). Amjad*et a*l. (2011) observed 191 cm tall plants with a plant population of 83,333 plants ha^{-1}. Positive effects of increasing plant population on plant height were also reported by killi (2004). Our results are not consistent with xiao*et al.* (2006) who described a negative effect of increasing plant population on plant height. Plant height highly significantly increased with increasing N rates (Table 5). Maximum plant height (191.1 cm and 186.4 cm) was observed with the 150 kg ha^{-1} N rate in 2012 and 2013, respectively. Minimum plant height (172.5 and 171.3 cm in 2012 and 2013, respectively) was obtained with the application of 90 kg N ha^{-1}. While the effect of N_2 (120 kg ha^{-1}) on plant height was statistically at par with N_1 and N_3. Nitrogen is an important component of nucleic acid, nucleotide and protein that play a vital role in metabolism. So increase in plant height may be due to the role of N in enhancing vegetative growth (Al-thabet, 2006). These findings also in concur with Poonia (2000) and Ozer (2004) who reported that nitrogen application increased sunflower plant height.

Head size contributes considerably to achene yield as it affects number of achenes per head. The different plant populations significantly affected the head diameter (Table 3). Maximum head diameter (18.76, 18.19 cm) was noted for 55,555 plants ha^{-1} plant population during 2012 and 2013 respectively. More photosynthetic products are available for sunflower head development due to reduced plant height in plots where plant population of 55,555 plants ha^{-1} was maintained. Head diameter for 66,666 plants ha^{-1} plant population was statistically similar with the plant population of 55,555 plants ha^{-1} during both experimentation years. The head diameter was minimum (15.20 cm in 2012 and 14.99 cm in 2013) in plots where 83,333 plants ha^{-1} plant population was maintained. However, this treatment was at par with P_2 (66,666 plants ha^{-}) in 2012. Increase in spacing between plants enhanced head diameter (Ali and Osman, 2004). Similar findings were documented by Amjad*et al*. (2012) who attained 16.43 cm head size with 83,333 plants ha^{-1} plant population. Among N rates, plots fertilized with 150 kg N ha^{-1} produced maximum head diameter (18.08 cm) in 2012. The situation was similar in 2013 and treatment 150 kg N ha^{-1} attained a head diameter of 17.55 cm. A regular reduction in head diameter was seen with decreasing N rates from 150 to 90 kg N ha^{-1}. The treatment N_1 (90 kg N ha^{-1}) produced minimum head diameter (15.77 and 15.70 cm in 2012 and 2013, respectively) and this treatment was statistically at par with N_2 (120 kg N ha^{-1}) in 2013. Nitrogen rate of 150 kg ha^{-1} produced a head diameter of 20.13 cm (Amjad*et al*., 2012).

Number of achenes per head was significantly affected by plant population and N levels (Table 3). Maximum number of achenes per head was observed from 55,555 plants ha^{-1} plant population (1071.6 and 1024.1) in 2012 and 2013 against minimum attained from 83,333 plants ha^{-1} plant population (971.0 and 942.1) in 2012 and 2013 respectively. Plant population of 55,555 plants ha^{-1} produced 9.39% and 8% more number of achenes per head as compared to 83,333 plants ha^{-1} plant population during both experimental years. The treatment P_2 (66,666 plants ha^{-1}) was statistically at par with P_1 and P_3 in 2012. Denser plants compete more with each other for light, water and nutrition (Amjad*et al*., 2011) that compel sunflower to produce long plants with small achene number (Iqbal and Ashraf, 2006), head diameter (Tenebe*et al*., 2008) and achene production (Beg *et al*., 2007). Number of achenes per head was increased regularly with increasing N rates from 90 to 150 kg N ha^{-1} (Table 3). Maximum number of achenes per head (1061.8 in 2012 and 1032.8 in 2013) was attained from N_3 (150 kg N ha^{-1}) that was statistically at par with N_2 (120 kg N ha^{-1}) that produced 1034.9 and 996.50 achenes per head in 2012 and 2013, respectively. The lowest number of achenes per head (976.4 and 946.4) was noted from N_1 (90 kg N ha^{-1}) and this treatment was also statistically similar to N_2 during both study years. Nitrogen contribution towards improvement in source, sink and number of achenes per head was also described by Rondanini*et al.* (2006). The biomass production characters like light capture, leaf area and radiation use efficiency was reduced with N deprivation (Khan *etal.*, 1999) that finally produced less number of achenes per head (Iqbal and Ashraf, 2006). Our results collaborate with findings of Malik *et al.* (2004); Khaliq and Cheema (2005); Beg *et al*. (2007) andAmjad*et al*. (2011).

Different plant populations significantly influenced the 1000-achene weight in our study (Table 3). Thousand achene weight did not coincide with the achene yield as with increasing plant population thousand achene weight decreased gradually in order of P_3>P_2>P_1 treatment. The lowest plant population (55,555 plants ha^{-1}) produced maximum 1000-achene weight (42.68 and 41.10 g) during 2012 and 2013, respectively. While minimum-1000 achene weight (39.27 and 38.29 g in 2012 and 2013, respectively) was attained from P_1 (83,333 plants ha^{-1}). Reduction in 1000-achene weight with increasing plant population was also confirmed from previous studies (El-Mohandes*et al*., 2005; Al-thabet, 2006). Differences in 1000-achene weight among different N levels were also significant (Table 3). Thousand achene weight was increased with increasing N rates and maximum 1000-achene weight (44.09 g) was obtained from 150 kg N ha^{-1} in 2012. The trend was similar in 2013. The minimum 1000-achene weight of 38.07 in 2012 and 37.92 in 2013 was noted from 90 kg N ha^{-1}. The optimum N supply ensures the improvement in source efficiency and sink capacity. Nasim*et al*. (2012) recorded a 1000-achene weight of 49 g with 180 kg N ha^{-1}. Increase in 1000-achene weight in response to N application was also described by Anwar-ul-Haq*et al.* (2006).

Table 4 illustrated that different plant populations have highly significant effect on achene yield during two years experiment (2012 and 2013). Maximum achene yield (3164.4 kg ha^{-1} in 2012 and 3030.1 kg ha^{-1} in 2013) was attained from the plant population of 83,333 plants ha^{-1} and it was followed by the 66,666 plants ha^{-1} plant population that produced achene yield of 2890.3 and 2711.1 kg ha^{-1} in 2012 and 2013, respectively. The minimum achene yield (2413.2 and 2289.6 kg ha^{-1}) was produced by 55,555 plants ha^{-1} plant population in 2012 and 2013 respectively. A regular increase in achene yield with increasing plant population (55,555 to 83,333 plants ha^{-1}) was mainly due to increase in number of plants at harvest as described byAllam*et al*. (2003). Amjad*et al*. (2012) attained achene yield of 3662 kg ha^{-1} with plant population of 83333 plants ha^{-1}.Highly significant and significant enhancement in achene yield was observed with increasing N rates during 2012 and 2013, respectively (Table 4). Application of 150 kg N ha^{-1} gave maximum (3066 and 2859.8 kg ha^{-1} in 2012 and 2013, respectively) achene yield. Minimum achene yield of 2537.5 kg ha^{-1} in 2012 and 2451.6 kg ha^{-1} in 2013 was resulted from 90 kg N ha^{-1}. The treatment N_2 produced achene yield (2864.4 kg ha^{-1} in 2012 and 2719.4 kg ha^{-1} 2013) statistically similar with N_3. Significant increase in growth (TDM, CGR) and yield components (head diameter and number of achenes per head) with nitrogen increment ultimately produced significant increase in achene yield (Osman and Awed, 2010). Al-Thabet*et al*. (2006) and Awais*et al*. (2013) recorded a seed yield of 3952 kg ha^{-1} and 3196.8 kg ha^{-1} from the 150 kg N ha^{-1} application, respectively. The regression lines drawn revealed a positive association of total dry matter with achene yields (Fig. 3).

Table 4. Influences of plant population and nitrogen on growth and yield of sunflower hybrid

Treatments	Achene yield (kg ha^{-1})			Total dry matter (kg ha^{-1})			Harvest index (%)			Oil contents (%)		
Plants ha^{-1}	2012	2013	Mean	2012	2013	Mean	2012	2013	Mean	2012	2013	Mean
83,333	3164 a	3030 a	3097	10197 a	9930 a	10064	31.2 a	30.5 a	30.86	40.63	39.71	40.17
666,666	2890 b	2711 b	2800	9670 a	9460 a	9565	29.9 a	28.8 ab	29.36	40.69	39.81	40.25
55,555	2413 c	2289 c	2351	8824 b	8636 b	8730	27.4 b	26.6 b	26.98	40.74	40.01	40.38
LSD 0.05	244.12	244.12		832.69	798.83		2.23	2.37		1.67	2.0	
Significance	**	**		*	*		*	*		NS	NS	
N rates kg ha^{-1}												
90	2537 b	2451 b	2494	9167 b	8760 b	8963	27.6 b	28.0	27.8	41.8 a	41.2 a	41.52
120	2864 a	2719 a	2791	9552 ab	9425 a	9488	30.2 a	28.8	29.5	41.1 ab	39.7 ab	40.39
150	3066 a	2859 a	2962	9971 a	9842 a	9907	30.7 a	29.1	29.9	39.2 b	38.6 b	38.89
LSD 0.05	210.88	262.06		612.92	664		2.44	3.58		2.12	2.04	
Significance	**	*		*	*		*	NS		*	*	
Interaction	NS	NS		NS	NS		NS	NS		NS	NS	
	2822.6	2676.9	2749.8	9564	9342.5	9453.3	29.49	28.63	29.07	40.69	39.84	40.27

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

TDM accumulation was less upto 2nd harvest (30 DAS) then a rapid increase in TDM was observed until physiological maturity (Fig. 2). The total dry matter (TDM) was significant among different plant population and N rates (Table 4). The data revealed that TDM followed the same pattern for plant population in the whole study. P_1 (83,333 plants ha^{-1}) achieved maximum TDM of 10197.7 kg ha^{-1} in 2012 and 9930.6 kg ha^{-1} in 2013. However P_1 (83,333 plants ha^{-1}) was statistically at par with P_2 (66,666 plants ha^{-1}) in producing TDM (9670.4 and 9460.4 kg ha^{-1} in 2012 and 2013, respectively). The plant population (83,333 plants ha^{-1}) gained 13.46 % and 13.03 % more TDM over 55,5555 plants ha^{-1} plant population in 2012 and 2013, respectively. During both experimentation years, P_3 (55,5555 plants ha^{-1}) produced minimum TDM (8824.1 and 8636.5 kg ha^{-1}). Diepenbrock*et al*. (2001) attained 9850 kg ha^{-1} TDM from 80,000 plants ha^{-1}. Similar results were recorded by Nasrollahi*et al*. (2011).In the year 2012, N rate of 150 kg ha^{-1} produced higher TDM (9971.8 kg ha^{-1}) which was statistically similar with 120 kg N ha^{-1} with a mean TDM of 9552.8 kg ha^{-1} (Table 4). Lowest mean TDM (9167.6 kg ha^{-1}) was noted in N_1 treatment where N was applied @ 90 kg ha^{-1}. However N_1 and N_2 were also at par with each other in producing TDM. Almost similar situation was recorded in 2013 and maximum (9842.6 kg ha^{-1}) and minimum (8760.0 kg ha^{-1}) TDM was found in the same treatments as in 2012. However N_1 and N_2 were statistically different with each other in 2013. Similarly N_2 and N_3 were also statistically at par with each other during 2012 and 2013.

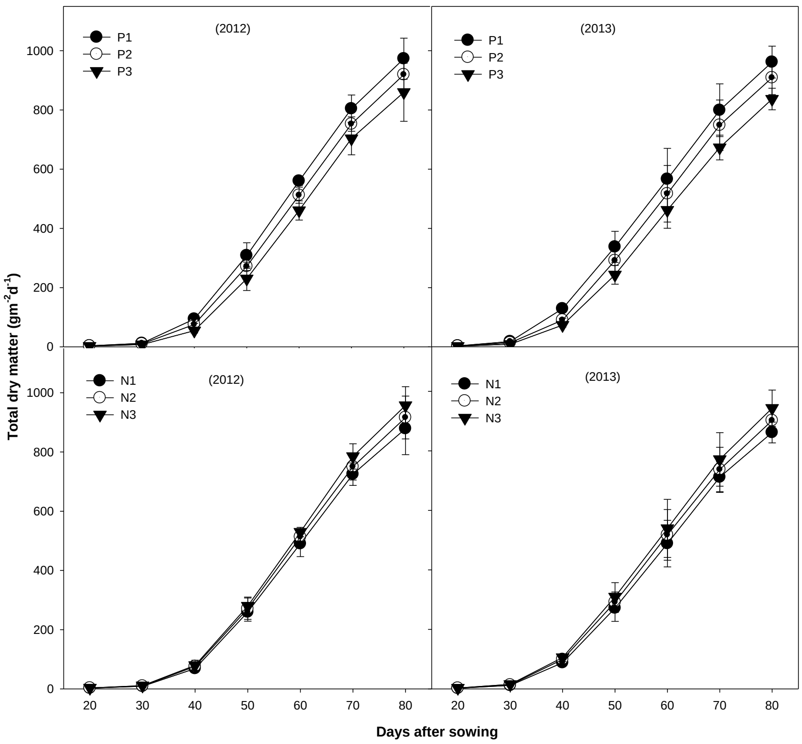

Figure 2. Total dry matter during the crop cycle as affected by various plant populations and N rates

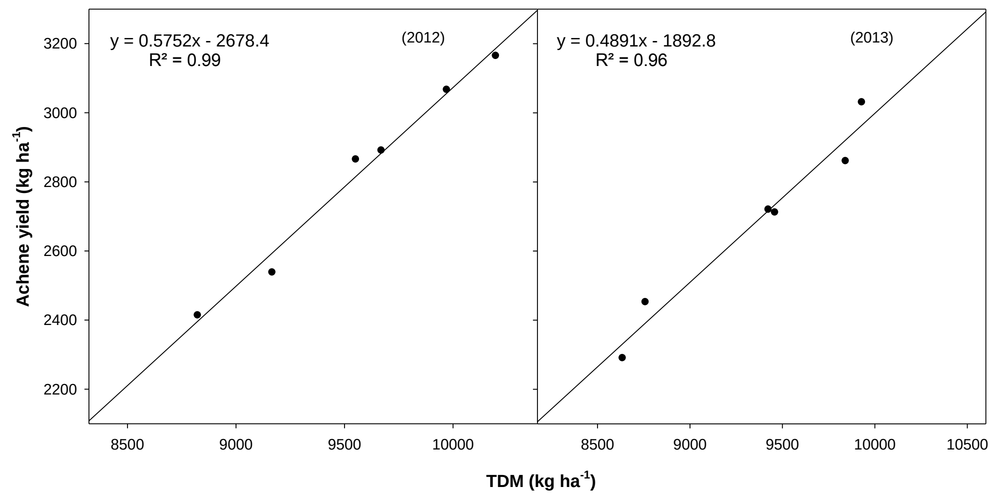

Figure 3. Relationship of sunflower total dry matter with its achene yield

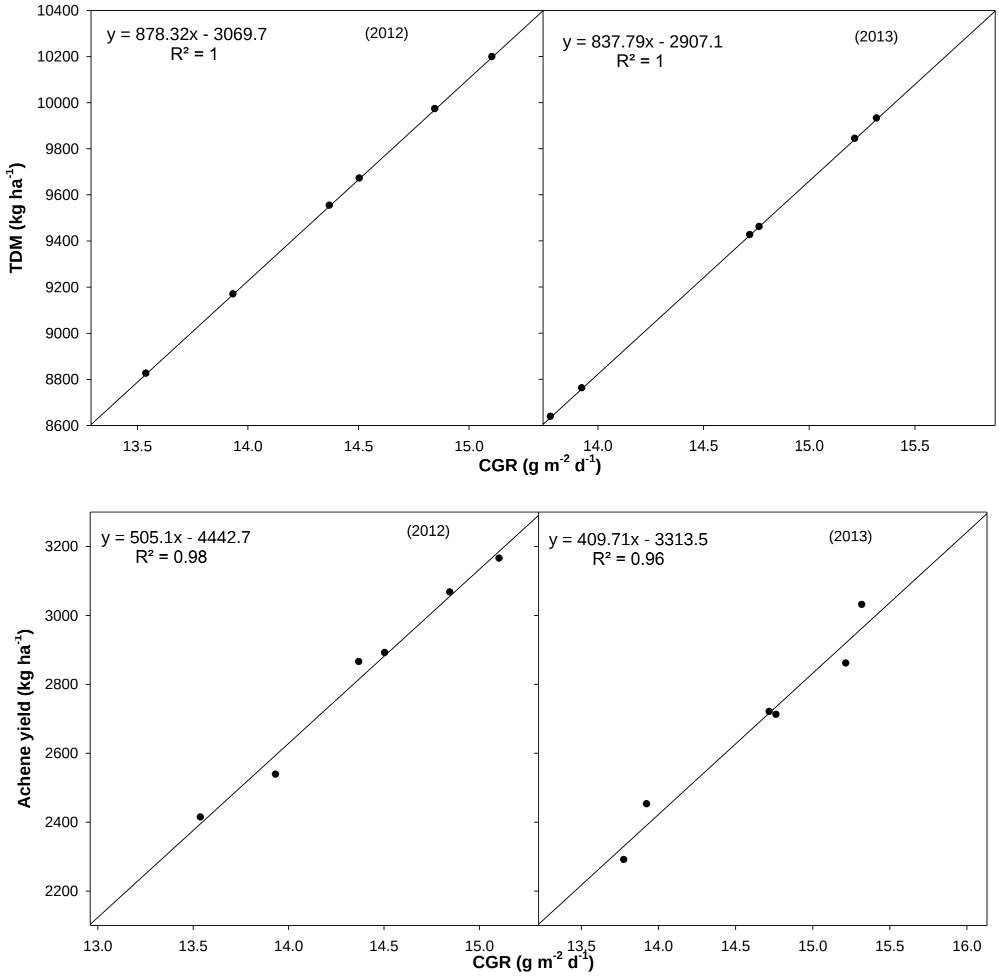

Figure 4. Relationship of sunflower crop growth rate with its total dry matter and achene yield

Harvest index was calculated to estimate efficiency of sunflower to translocate assimilates into economic yield. According to table 4 different plant populations have significant effect on harvest index in both years of study (2012 and 2013). In 2012 highest harvest index (31.21 %) was recorded when 83,333 plants ha^{-1} plant population was maintained but it did not vary significantly with the harvest index gained by the crop having a population of 66,666 plants ha^{-1} (29.92 %). The statistically lowest harvest index (27.36 %) was calculated from 55,555 plants ha^{-1} plant population. In 2013 maximum (30.51 %) and minimum harvest index (26.60 %) was calculated with the same plant population as in 2012. However in 2013 P_2 (66,666 plants ha^{-1}) achieved a harvest index of 28.79 % which was statistically similar with P_1 and P_3. Harvest index of 34.68 % was obtained at 10,0000 plants ha^{-1} plant population (Nasrollahi*et al*., 2011).Nitrogen effects on harvest index were significant in 2012 but non-significant in 2013 (Table 4). During 2012, statistically maximum (30.66 %) and minimum harvest index (27.57 %) was attained when sunflower was supplied with 150 and 90 kg N ha^{-1}, respectively. Same treatments gave maximum (29.12 %) and minimum harvest index (27.97 %) in 2013 but these two treatments did not differ significantly. Khaliq and Cheema (2005) calculated harvest index of 33.32 % from 200 kg N ha^{-1}.

A sunflower crop rich in oil contents of excellent quality is the final objective of a farmer. The effect of plant population on oil contents was non-significant during both years of experimentation (Table 4). The sunflower oil contents varied from 39.71 % to 40.74 % among different plant populations. Non-significant differences for oil contents among various plant populations were also stated by Al-Thabet (2006). Our results are not consistent to outcomes of Killi (2004) and Amjad*et al*., (2012) who informed significant increase in oil concentration and also to Osman and Awed (2010) who described reduction in oil contents with increasing plant population.Negative and significant effects of N increment on oil contents are present in Table 4. The sunflower oil contents follow the same pattern for different N rates in both years (2012 and 2013). The oil contents were decreased progressively as N rates increased from 90 to 150 kg ha^{-1}. The highest oil contents (41.84 % and 41.21 %) were observed for N_1 (90 kh N ha^{-1}) and lowest (39.18 % and 38.60 %) for N_3 (150 kg ha^{-1}) during 2012 and 2013 respectively. The treatment N_2 (120 kg ha^{-1}) was statistically similar with N_1 and N_3 in providing oil contents (41.05 % in 2012 and 39.73 % in 2013). As nitrogen is an important constituent of the proteins, so increasing nitrogen rates increased protein synthesis and reduced oil contents (Hussain*et al*., 2011). Amjad*et al.* (2012) obtained 38 % oil from sunflower with 150 kg N ha^{-1}. Significant influences of different plant populations and N rates on oil yield of sunflower were presented in table 5. Maximum oil yield (1285.3 kg ha^{-1} in 2012 and 1200.6 kg ha^{-1} in 2013) was achieved from the plant population of 83,333 plants ha^{-1}. The minimum oil yield (982.2 and 914.7 kg ha^{-1}) was produced by 55,555 plants ha^{-1} plant population in 2012 and 2013 respectively.The maximum oil yield (1204.6 and 1102.7 kg ha^{-1} in 2012 and 2013, respectively) was obtained with the application of 150 kg N ha^{-1}. Minimum oil yield of 1060.8 kg ha^{-1} in 2012 and 1009.7 kg ha^{-1} in 2013 was recorded with 90 kg N ha^{-1}.

Table 5. Influences of Plant population and nitrogen on plant height and oil yield of sunflower

Treatments	Plant height (cm)			Oil yield (kg ha^{-1})		
plants ha^{-1}	2012	2013	Mean	2012	2013	Mean
83,333	187.3 a	186.3 a	186.8	1285.3 a	1200.6 a	1242.95
666,666	181.2 b	179.6 ab	180.4	1178.3 b	1077.0 b	1127.65
55,555	177.0 c	173.0 b	175.0	981.2 c	914.7 c	947.95
LSD 0.05	3.97	8.35		90.78	82.63	
Significance	*	*		*	*	
N rates kg ha^{-1}						
90	172.5 b	171.3 b	171.9	1204.6 a	1102.7 a	1153.65
120	182.0 ab	181.2 ab	181.6	1180.3 a	1079.9 a	1130.1
150	191.1 a	186.4 a	188.8	1060.8 b	1009.7 b	1035.25
LSD 0.05	12.21	10.06		108.83	63.02	
Significance	**	**		*	*	
Interaction	NS	NS		NS	NS	
Year mean	181.9	179.6	180.75	1148.6	1064.1	1106.3

Mean sharing different letters in a column differ significantly at $p \leq 0.05$
*, ** = significant and highly significant respectively; NS = Non-Significant, , LSD= least significant difference

Correlation between achene yield and components of yield

Table 6 reveals correlation co-efficients of achene yield with growth and components of achene yield. Achene yield was correlated positively and highly significantly with crop growth rate, harvest index and total dry matter and during both years (2012 and 2013). Pooled data also showed similar results. However correlation of achene yield with head diameter and number of achenes per head was negative and non-significant. Similarly correlation of 1000-achene weight with achene yield was positive and non-significant in 2012 but negative and non-significant in 2013. Pooled data also indicates a non-significant association of 1000-achene weight with achene yield.

Table 6. Correlation of sunflower achene yield with some studied parameters

Parameters	Correlation co-efficient (r)		
	2012	2013	Pooled
Crop growth rate	0.99**	0.98**	1.00**
Head diameter	-0.34 ns	-0.49 ns	-0.41 ns
Number of achenes per head	-0.22 ns	-0.22 ns	-0.22 ns
1000-achene weight	0.14 ns	-0.16 ns	0.01 ns
Total dry matter	0.99**	0.98**	1.00**
Harvest index	0.98**	0.98**	0.99**

ns= Non-significant,**,* significant at 1% and 5% probablity

CONCLUSIONS

Results in table 3,4 & 5 and figure 2,3 & 4 reveals that sunflower (Hysun-33) should be planted in highpopulationof 83,333 plants ha^{-1} (keeping row to row and plant to plant distance of 60 and 20 cm, respectively) with nitrogen level of 150 kg $ha^{-1}$to attain maximum achene yield. Increased plant populations (66,666 and 83,333 plants ha^{-1}) have a decreasing effect onyield components (head diameter, thousand achene weights and number of achene per head and) however this effect was over-compensated by more number of plants per meter square.

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