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Research Paper

Physiology, growth and productivity of staggered sown spring sunflower (*Helianthus annuus*) in response to varying intra-row spacing and applied nitrogen in the Indo-Gangetic Plains

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ABSTRACT

An experiment was conducted during *spring* seasons of 2014 and 2015 at Ludhiana, Punjab, to investigate the effect of intra-row spacing and nitrogen application to sunflower (*Helianthus annuus* L.) sown on different dates on growth, photosynthetic parameters, root density, yield forming traits and sink development. Treatments comprised combinations of 3 sowing dates (20 January, 10 February and 2 March), 2 intra-row spacings (24 cm and 30 cm) as main factor and 4 nitrogen doses (0, 45, 60 and 75 kg/ha) as sub-factor in split-plot design with 3 replications. The early sowing resulted in higher total dry-matter accumulation (DMA) (4.84 t/ha) and DM partitioning to seed (2.03 t/ha). The results indicate that higher DMA under earlier-sown crop could be associated with the higher chlorophyll content, chlorophyll fluorescence (Fv/Fm ratio), optimal dry-matter partitioning (%) to leaf with consequent reduction in DM partitioning to stem. Early-sown crop also recorded higher root mass density than late-sown crop at 0–15, 15–30 and 30–45 cm soil depth. Closer intra-row spacing resulted in higher DMA by all the plant parts except seed. Each graded N dose led to improved DMA, but the improvement in dry-matter partitioning to seed was significant up to 60 and 75 kg N/ha during 2014 and 2015, respectively, owing to higher chlorophyll content, Fv:Fm ratio, chlorophyll content index, root density and dry matter partioning to leaf under respective treatments.

Key words : Chlorophyll content, Dry-matter accumulation and its partitioning, Fv:Fm ratio, Root density, Sunflower, Yield attributes, Yield

Sunflower is an important oilseed crop owing to its high yield potential and quality oil with ready acceptance of the consumers. Its short duration enables its cultivation in the intensive cropping systems. Cultivation of sunflower in spring season is in vogue in the north India owing to prevalence of favourable climatic conditions such as abundant sunshine, long days and significant honey-bee activity. Crop productivity is an outcome of complex interactions between genetic, environmental and input management (Sheoran *et al.,* 2014). Sowing time influences the crop growth and productivity by altering various physiological processes and morphological developments mainly through temperature. Earlier studies have revealed progressive reduction in productivity of sunflower in this region with delay in sowing beyond January. However under intensive cropping systems especially after potato and peas, sowing of sunflower is often delayed to end February or even up to early March, where higher temperature conditions right from germination stage adversely affect the crop productivity through desiccation of pollen-grains, drying of stigmas, inhibition of pollen germination and pollen tube growth (Kakani *et al.,* 2002).

Maintaining optimum plant density is much more important for non-tillering/non-branching crops such as sunflower than other crops to harness its potential productivity. Yield losses due to sub-optimal population or overcrowding can be minimized by maintaining the optimum plant spacing (Ali *et al.,* 2012). Increased plant population may compensate for the reduced yield of individual plant in non-tillering/ non-branched crop, especially under delayed sowing conditions. Nitrogen (N) application aids in better early stage growth, more rapid leaf-area development, improved leaf-area duration, better assimilation of carbohydrates and synthesis of proteins (Nasim *et al.,* 2012). Optimum dose of N fertilizer is likely to vary in response to sowing date and plant density. Limited studies

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have addressed the interactive effects of sowing date, intra-row spacing and N doses on physiological parameters, growth and productivity of sunflower grown in Indo Gangetic Plains. Hence this study was conducted to find out optimum intra-row spacing and nitrogen dose for sunflower sown on different dates during the spring season.

MATERIALS AND METHODS

A field experiment was conducted during the spring 2014 and 2015 at research farm of Punjab Agricultural University, Ludhiana, [30°56' N, 75°52' E, 247 m], India on Typic Ustipsamment (Fatehpur sandy-loam) soils. Mean monthly meteorological data during the crop seasons of 2014 and 2015 are given in Table 1. The field experiment was conducted at different sites during 2014 and 2015. Soil of experimental field during 2014 was medium in organic carbon (0.61%) and available N (285.7 kg/ha) but during 2015, it was low in organic carbon (0.36%) and available N (175.4 kg/ha). However, at both sites, the soil was high in available P (68.2 and 64.8 kg/ha during 2014 and 2015 respectively) and medium in available K status (194.0 and 184.8 kg/ha during 2014 and 2015 respectively). The soil *p*H and electrical conductivity of both the locations were within the normal range.

The study was conducted in factorial split-plot design with 3 replications. Combinations of 3 sowing dates (20 January, 10 February and 2 March) and 2 intra-row spacing (30 cm and 24 cm) comprised the main plot treatments, whereas 4 nitrogen doses (control, 45 kg, 60 kg and 75 kg/ha) were allocated to sub pots. Gross plot size was 25.2 m^2. Sunflower hybrid 'PSH 996' was sown as per treatments by dibbling 3 seeds/hill at row spacing of 60 cm. One plant/hill was maintained by thinning extra plants at 3 weeks after sowing. Phosphorus @ 30 kg P_2O_5/ha and potassium @ 30 kg K_2O/ha were applied at sowing. Nitrogen was applied as per treatments through urea in 2 splits-half as basal and half at thinning. All other recommended management practices were adopted.

Plant height, number of green leaves/plant and stem girth were recorded from 10 randomly tagged plants in middle 3 rows of each experimental unit. Leaf-area index was recorded with Canopy Analyser (Sun Scan Canopy Analyzer Model CI-110/CI-120). For determining leaf thickness, leaves were collected at seed-filling stage and were fixed in FAA (formalin-acetic acid-ethyl alcohol) solution immediately after collection. FAA was prepared by mixing 85 ml of 50% ethyl alcohol, 5 ml of glacial acetic acid and 10 ml of 40% formaldehyde. The fixed materials were thoroughly washed with distilled water before cutting free hand sections. Thin free hand sections were stained with safranin and fast green. The sections were examined under Leica bright field research microscope fitted with digital camera and computer imaging systems. The leaf thickness was measured from these transverse sections using ocular micrometer.

Dry-matter partitioning (leaf, stem, thalamus and seed) was determined at physiological maturity from 5 randomly selected plants. For recording root density, soil core samples were taken layer wise (0–15, 15–30 and 30–45 cm) with the help of root sampling pipe having internal diameter of 15 cm, by keeping the plant stump in the centre of the core. The roots were collected by washing soil core samples in thin nylon mesh of 1 mm sieve in running water. The roots were dried at 65°C$\pm$ 2°C in an oven till constant weight. The root density was expressed as weight of roots per unit volume of soil and, was calculated as follows:

$$\text{Rooting density (g/cm}^3\text{)} = \frac{\text{Total root weight in particular depth (g)}}{\text{Total soil volume from which roots were collected (cm}^3\text{)}}$$

Chlorophyll fluorescence and chlorophyll content index (CCI) were measured periodically from fully expanded apical leaves, using a portable chlorophyll fluorometer (Model - OS-30p, Opti-Sciences, Inc.) and portable chlorophyll content meter (Model–CCM-200, Opti-Sciences, Inc.) respectively. Chlorophyll content was determined spectro-photometricaly using chloroform extract. Data were subjected to analysis of variance (ANOVA) using statistical analysis software (SAS 9.3. North Carolina) to evaluate differences between treatments. Treatment means were compared at $P \leq 0.05$.

RESULTS AND DISCUSSION

Sowing dates

Sowing dates significantly influenced various growth attributes (Table 2). Plant height increased but leaf-area index (LAI), stem girth, number of green leaves/plant and leaf thickness decreased with delay in sowing from 20 January to 2 March through 10 February. Increase in plant height in 2 March-sown crop was significant over 10 February and 20 January sown crop. Sun *et al.* (2012) reported increase in auxin biosynthesis with increase in temperature. Increase in plant height under delayed sowing may be ascribed to increased biosynthesis of auxins during early vegetative growth stage owing to favourable temperature conditions (Table 1). Early-sown crop entered into reproductive phase at an early stage and, competition between vegetative and reproductive parts restricted its growth and development. Sheoran *et al*. (2014) reported similar findings in the spring sunflower. Crop sown on 10 February and 2 March recorded significantly lower LAI than the crop sown 20 January. The DMA by various plant parts (leaf, seed, thalamus and their total) except stem decreased progressively with each delay in sowing (Figs. 1 and 2). The longer crop duration of earlier-sown crop enabled the plants to accumulate more photosynthates than later sown crop. Poor DMA by various plant parts of late-sown crop may be attributed to early leaf senescence and inhibited vegetative growth of crop due to higher temperature in comparison to early sown crop. Fetri *et al.* (2013) reported significant reduction in stem girth and leaf area with delay in sowing.

Root mass density was higher at ray floret-opening stage than at maturity (Fig. 3). Delay in sowing lowered the root mass density at both these stages at all soil depths (0–15, 15–30 and 30–45 cm). Irrespective of sowing date, majority of roots (85–90%) were confined in 0–15 cm soil layer. However, proportion of roots at lower soil depths (15–30 and 30–45 cm) was higher in early sowing date, indicating better proliferation of roots in sub-soil than late sowing date. The higher root mass density of early-sown

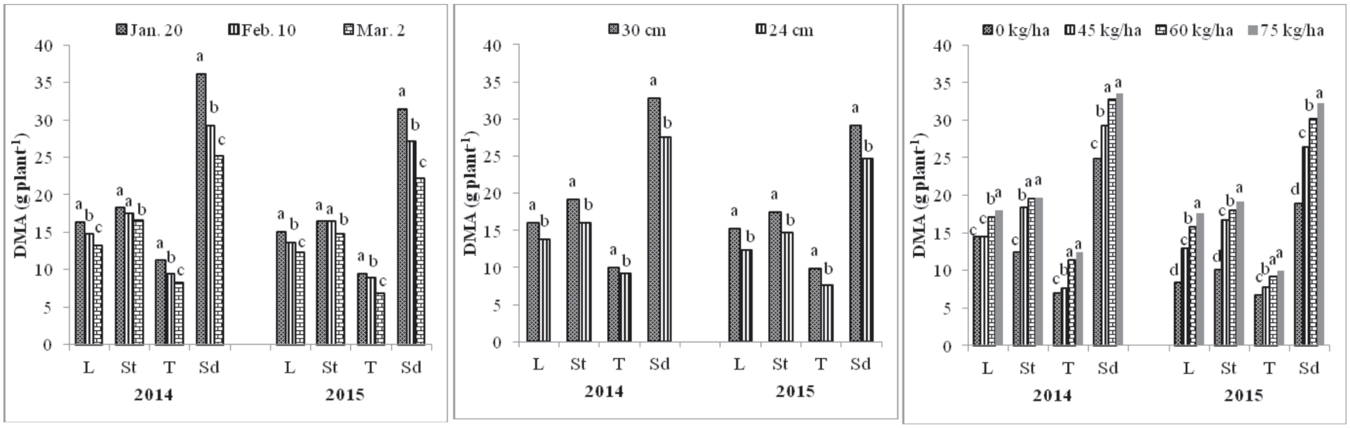

Fig. 1. Effect of sowing dates, intra-row spacing and N doses on dry-matter accumulation (DMA) per plant (Note: bars with different letter differ significantly) spring in sunflowers

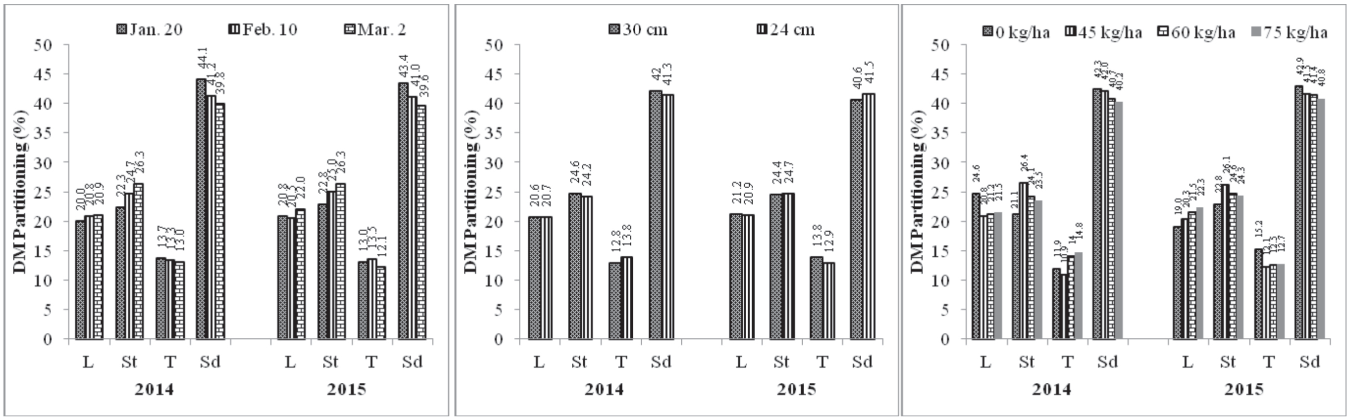

Fig. 2. Effect of sowing dates, intra-row spacing and N doses on dry-matter (DM) partitioning (%) into various plant parts of spring sunflower

Table 1. Mean monthly meteorological data during the crop seasons

Month	2014				2015			
	Air temperature (˚C)			Total rainfall (mm)	Air temperature (˚C)			Total rainfall (mm)
	Max	Min	Mean		Max	Min	Mean	
January	17.5	7.0	12.2	55.5	15.6	7.0	11.3	24.6
February	19.4	8.2	13.9	36.7	20.2	10.5	15.3	38.6
March	25.3	12.5	18.9	35.0	25.5	13.3	19.4	84.6
April	32.7	16.7	24.7	31.0	32.6	17.5	25.0	29.4
May	37.6	22.9	30.2	26.2	38.6	23.8	31.2	17.0
June	40.6	27.1	33.8	30.2	37.7	26.1	31.7	17.9

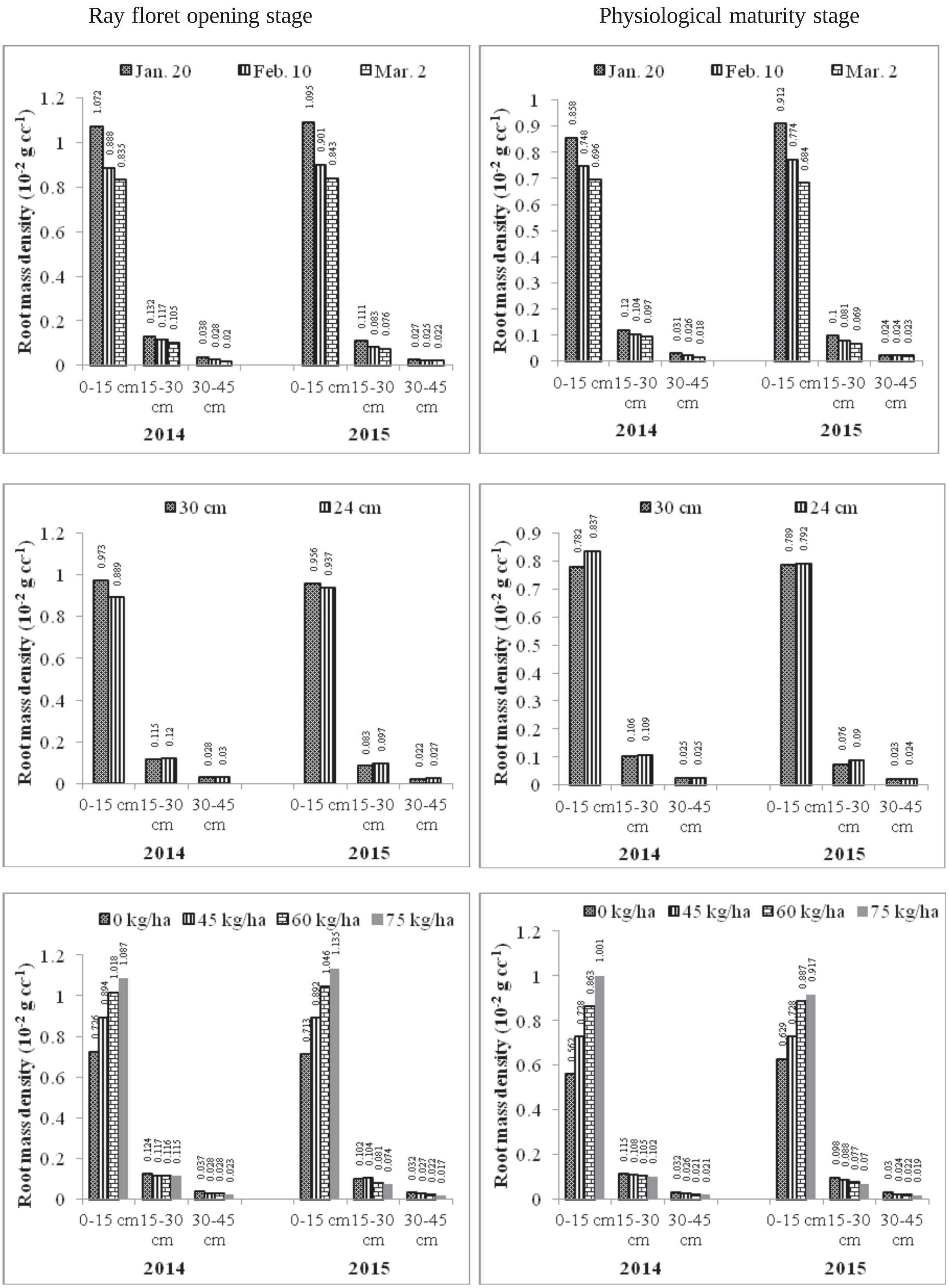

Fig. 3. Effect of sowing dates, intra-row spacing and N doses on root mass density (10^{-2} g cc^{-1}) at ray floret opening and maturity stage in spring sunflower

crop can be ascribed to longer growth period of the crop. The crop took 120 and 113 days for maturity when raised on 20 January, 106 and 99 days when raised on 10 February and 92 and 87 days when sown on 2 March during 2014 and 2015 respectively. Early-sown crop experienced low to mild temperature during initial phases of crop growth, which might have slowed down the shoot growth but allowed roots activity to continue because the fluctuation in soil temperature is often less compared to air temperature. This might have resulted in partitioning of more photosynthates to roots under early sowing dates.

Effect of dates of sowing on total chlorophyll content, chlorophyll content index (CCI) and Fv:Fm ratio was significant at all growth stages, viz. 25, 50 and 75 DAS (Table 3). At 25 DAS, 10 February sowing date resulted in the highest chlorophyll content and 20 January sowing date in the highest CCI, and such increases were significant over 2 March sowing date. Increase in Fv:Fm ratio with delay in sowing to 10 February and 2 March sowing date over 20 January sowing date was significant. At 50 and 75 DAS, total chlorophyll content, CCI and Fv:Fm ratio registered consistent and significant reduction with successive delay in sowing date except the differences in chlorophyll content and Fv:Fm ratio between 20 January and 10 February sowing dates at 50 DAS were not significant. Temperature of 20–25^{o}C during the growing period is the most ideal for sunflower production. Significantly higher chlorophyll fluorescence recorded in 25 days old crop sown on 2 March may be associated with the favourable temperature prevailing during that growth period of crop as compared to very low temperature experienced by the crop at this stage in case of early sowing dates (20 January and 10 February). Higher temperature within the optimum range might have favourably affected the photosynthesis. Hence, at later stages favourable temperature conditions experienced by the crop sown on 20 January and 10 February contributed to higher chlorophyll content than the crop sown on 2 March, where higher temperature at corresponding growth stage might have degraded the chlorophyll content. Each delay in sowing from 20 January to 2 March through 10 February caused significant and progressive reduction in yield-contributing characters such as head diameter, thalamus weight, number of seeds/head, seed weight/head, seed filling and 1,000-seed weight (Table 4). However, hectoliter weight was statistically similar in 20 January and 10 February sowing dates (Table 4). Similarly, delay in sowing resulted in progressive reduction in seed, biological yield and harvest index (Table 5). Crop sown on 20 January gave 22.2% higher seed yield than 10 February-sown crop. Likewise, 10 February sown crop gave 19.3% higher seed yield than 2 March sown crop.

Higher seed yield under 20 January sowing date can be ascribed to favourable environmental conditions at all pheno-phases, which resulted in better development of yield attributing traits such as head diameter, head weight, seed weight/head, number of seeds/head, 1,000-seed weight and seed filling percentage, than later sowing dates (Table 4). Moreover, higher chlorophyll content and dry matter (Table 3 and Fig. 1) as well as more number of days

Table 2. Effect of sowing dates, intra-row spacing and nitrogen doses on growth attributes of sunflower at maturity (pooled data of 2 years)

Treatment	Plant height (cm)	Stem girth (cm)	Leaf area-index	Number of leaves/plant	Leaf thickness (micro metre)
Sowing date					
20 January	156.7	2.00	3.11	19.1	63.2
10 February	155.4	1.81	2.67	16.7	52.9
2 March	167.5	1.61	2.44	15.4	46.1
SEm±	2.3	0.04	0.10	0.3	0.5
CD (P=0.05)	7.2	0.16	0.31	0.9	4.1
Intra row spacing (cm)					
30	158.0	1.86	2.70	17.2	54.8
24	161.7	1.75	2.81	16.9	53.4
SEm±	2.0	0.03	0.10	0.2	0.4
CD (P=0.05)	NS	0.7	NS	NS	1.9
N dose (kg/ha)					
0	146.7	1.56	2.19	15.8	44.0
45	158.7	1.79	2.57	16.85	48.7
60	164.7	1.88	2.91	17.45	57.4
75	169.3	1.98	3.34	18.15	66.3
SEm±	2.2	0.04	0.07	0.2	0.6
CD (P=0.05)	6.1	0.07	0.21	0.7	3.2

taken for various pheno-phases by crop sown on 20 January contributed to formation of larger sink to efficiently utilize the assimilates. The prolonged reproductive period of crop sown on 20 January (59.4 and 51.7 days) over 10 February (51.9 and 46.0 days) and 2 March (48.0 and 41.7 days) also ensured proper development of seed and consequently in achieving higher seed yield.

Air temperature (Table 1) and canopy temperature at various phenological stages (data not given) indicated that later-sown crop experienced higher air temperature and canopy temperature at all phases of crop growth and development. Higher temperature at flowering stage inhibited pollen germination and pollen-tube growth and resulted in poor seed setting and lower seed yield (Kakani *et al.,* 2002). The higher night temperature has detrimental effect on seed yield as it increases the rate of respiration in absence of photosynthesis. Under late-sown conditions, more photosynthates were probably utilized in respiration resulting in the reduction in proportion of photosynthates for sink development. Sheoran *et al*. (2014) observed decline in growth, leaf area and forced early maturity of the crop due to higher temperature (terminal heat stress) encountered by late-sown crop and ultimately led to lower seed yield.

Intra-row spacing

Wider intra row spacing (30 cm) resulted in significantly more leaf thickness and stem girth, whereas narrow intra-row spacing (24 cm) resulted in significant increase in DMA by leaf, stem, thalamus and total DMA per unit area due to higher plant population. Increased plant population under 24 cm intra- row spacing might have increased competition for space and resources leading to reduced stem girth and leaf thickness but increased DMA. Sarmah *et al.* (1992) and Ali *et al.* (2012) reported similar effect of spacing on stem girth.

Wider intra-row spacing (30 cm) registered more root mass density at 0–15 cm soil depth due to less spatial competition between plants (Fig. 3). Increase in root mass density at 15–30 and 30–45 cm soil depths, in closer- over wider-intra row spacing may be ascribed to forced proliferation of roots in to deeper soil layers due to constraint in upper soil layer owing to of higher plant population. Wider intra-row spacing resulted in significantly higher Fv:Fm ratio at 75 DAS, whereas the effect of row spacing on chlorophyll content, CCI and Fv:Fm ratio at all stages were inconspicuous (Table 3).

Crop sown with 30 cm intra-row spacing resulted in significantly more head diameter, seed weight/head, thalamus weight, number of seeds/head and 1,000-seed weight (Table 4). However, the seed yield and harvest index was not significantly influenced by intra row spacing (Table 5). Sunflower is a non-tillering and non-branching crop. Hence seed yield solely depends on the ability of an indi-

Table 3. Effect of sowing dates, intra-row spacings and nitrogen doses on periodic chlorophyll content (mg/g FW), chlorophyll content index (CCI) and chlorophyll fluorescence (Fv:Fm ratio) of sunflower leaves (pooled data of 2 years)

Treatment	Chlorophyll content (mg/g FW)			Chlorophyll content index (CCI)			Chlorophyll fluorescence (Fv:Fm ratio)		
	25 DAS	50 DAS	75 DAS	25 DAS	50 DAS	75 DAS	25 DAS	50 DAS	75 DAS
Sowing date									
20 January	1.17	2.79	2.00	20.9	22.2	20.0	0.678	0.733	0.721
10 February	1.19	2.69	1.82	19.8	20.2	17.9	0.715	0.731	0.674
2 March	1.02	2.47	1.55	17.8	17.6	15.4	0.750	0.672	0.643
SEm±	0.02	0.06	0.03	0.3	0.3	0.7	0.011	0.007	0.006
CD (P=0.05)	0.08	0.19	0.10	0.9	1.9	2.0	0.034	0.022	0.021
Intra-row spacing (cm)									
30	1.15	2.68	1.81	19.5	20.0	17.9	0.717	0.713	0.693
24	1.10	2.62	1.77	19.5	20.0	17.6	0.711	0.710	0.669
SEm±	0.02	0.04	0.02	0.3	0.4	0.4	0.09	0.06	0.05
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	0.014
N dose (kg/ha)									
0	0.94	2.40	1.59	17.4	17.6	16.1	0.664	0.661	0.626
45	1.10	2.64	1.77	19.1	19.0	17.4	0.711	0.698	0.664
60	1.17	2.75	1.84	19.9	21.3	18.6	0.738	0.740	0.697
75	1.28	2.86	1.95	21.6	22.1	18.8	0.745	0.748	0.737
SEm±	0.02	0.05	0.02	0.3	0.2	0.5	0.08	0.05	0.05
CD (P=0.05)	0.05	0.11	0.07	0.8	0.8	1.0	0.019	0.026	0.025

DAS, Days after sowing

vidual plant to produce a single large head.

Nitrogen

Application of nitrogen resulted in significant and consistent increase in growth attributes (Table 2). The stem girth, LAI and leaf thickness increased linearly up to the highest N dose (75 kg/ha). Plant height and number of green leaves/plant also increased up to 60 kg/ha of N application, but differences between 45 and 60 kg/ha as well as 60 and 75 kg/ha were not significant. The DMA by leaf and total DMA increased with each increment of N dose up to 75 kg/ha (Figs. 1 and 2). Increased availability of N to plants under higher N application rates might have delayed leaf senescence by prolonging the N absorption from soil and translocation of assimilates to vegetative parts. These results are in line with those reported by Yadav *et al.* (2009) and Wabekwa and Degri (2012). Nasim *et al.* (2012) reported an increase in LAI, stem girth and plant height due to increased rate of N application.

Application of each higher dose of N resulted in progressive increase in root mass density at 0–15 cm soil depth owing to easy access and more availability of N in upper soil layers, whereas under N starvation (control or lower doses) conditions, plant tended to proliferate its roots to lower layers. The reduction in root mass density at maturity as compared to ray floret opening stage may be ascribed to decaying of root hairs and increased mortality of roots due to ageing of plant, especially in the reproductive phase of the crop.

Nitrogen application resulted in improvement in all the photosynthetic parameters at all stages (Table 3). The differences between successive doses of N were significant except between 60 and 75 kg/ha of N for CCI at 25 and 75 DAS. Nitrogen is involved in synthesis of chlorophyll, a pigment responsible for photosynthesis, induces vegetative and generative growth and prevents premature senescence leading to enhanced metabolic processes of plant (Legha and Giri, 1999). Decrease in photosynthetic parameters at later growth stages might be due to ageing and senescence of plant with advancement in age.

Thalamus weight and seed filling (%) (age) increased significantly due to application of N up to 60 kg N/ha but head diameter, seed weight/head, number of seeds/head and 1,000-seed weight increased significantly with each successive higher dose of applied N up to 75 kg/ha, leading to significant response of N up to 75 kg/ha in terms of seed yield (Tables 4 and 5). Since N is a major constituent of chlorophylls and proteins, its adequate supply through fertilizer encourages photosynthesis and leads to better crop growth, development and consequently yield. Nitrogen application improved vegetative and generative growth and delayed premature leaf senescence and thereby, enhanced yield of sunflower (Legha and Giri, 1999; Suryavanshi *et al.*, 2015). The reduced harvest index with the application of higher level of N was due to greater increase in biological yield due to N application than seed yield. The results revealed that the dry matter partitioning to sink (seed) was lower to the extent of 21.2,

Table 4. Effect of sowing dates, intra row spacing and N doses on yield contributing characters of sunflower (pooled data of 2 years)

Treatment	Head diameter (cm)	Seed weight/head (g)	Thalamus weight (g)	Seeds/ head	Unfilled seeds/ head	Seed-filling (%)	1,000-seed weight (g)	Hectolitre weight (kg/hl)
Sowing date								
20 January	19.3	33.7	10.3	736	58	92.4	53.6	46.4
10 February	17.4	28.1	9.2	642	73	89.1	49.3	46.1
2 March	14.8	23.5	7.5	562	86	86.2	45.2	39.4
SEm±	0.2	0.7	0.4	14	2.6	0.5	0.4	0.4
CD (P=0.05)	0.5	2.1	1.1	37	6.0	0.9	1.1	0.9
Intra row spacing (cm)								
30	17.5	30.9	9.5	672	72	89.7	50.2	43.7
24	16.8	26.1	8.5	621	73	88.8	48.6	44.2
SEm±	0.2	0.7	0.4	12	2.2	0.4	0.3	0.4
CD (P=0.05)	0.4	1.2	0.9	30.0	NS	0.8	0.9	NS
N dose (kg/ha)								
0	14.4	21.8	6.9	519	101	83.0	46.0	43.0
45	16.6	27.9	7.6	634	85	87.8	48.4	44.4
60	18.5	31.5	10.2	701	53	92.6	50.8	44.4
75	19.1	32.9	11.2	733	50	93.5	52.5	44.0
SEm±	0.2	0.6	0.5	10.0	2.0	0.4	0.4	0.3
CD (P=0.05)	0.5	1.4	1.2	32	7.0	1.0	1.4	1.0

8.6 and 11.6% with application of 45, 60 and 75 kg N/ha, respectively, as compared to biological yield. Nasim *et al.* (2012) also reported increase in total dry-matter and seed yield owing to increased rate of N application at Gujranwala, Pakistan.

Table 5. Effect of sowing dates, intra-row spacing and nitrogen doses on biological yield, seed yield and harvest index of sunflower (pooled data of 2 years)

Treatment	Biological yield (t/ha)	Seed yield (t/ha)	Harvest index (%)
Sowing date			
20 January	4.84	2.03	42.1
10 February	4.25	1.66	39.4
2 March	3.74	1.39	37.3
SEm±	0.051	0.033	0.7
CD(P=0.05)	0.10	0.09	2.0
Intra-row spacing (cm)			
30	4.18	1.66	40.1
24	4.37	1.73	39.1
SEm±	0.050	0.035	0.7
CD (P=0.05)	0.08	NS	NS
N dose (kg/ha)			
0	3.06	1.28	41.6
45	4.23	1.67	39.2
60	4.79	1.89	39.2
75	5.02	1.94	38.5
SEm±	0.042	0.020	0.5
CD (P=0.05)	0.08	0.05	1.2

Year × nitrogen

The data in Table 6 indicate that seed yield varied significantly due to year × nitrogen interaction. Data indicate that seed yield increased linearly up to 75 kg N/ha during 2015 but during 2014, increase in seed yield was significant only up to 60 kg N/ha. Data also indicate that the preceding lower level of N during 2014 outyielded the next higher level of N during 2015. The response of sunflower to higher dose of N during 2015, compared to 2014 may be ascribed to the higher available nitrogen and organic carbon status of soil during 2014.

Dates of sowing × nitrogen

The crop sown on 20 January with the application of 75 kg N/ha gave significantly higher seed yield than all the other treatment combinations. Seed yield obtained from crop sown on 20 January without application of N was at par with that given by 2 March sown crop with application of 60 kg N/ha. Application of 45 kg N/ha to 10 February-sown crop gave seed yield at par with 2 March sown crop applied with 75 kg N/ha. Similarly, crop sown on early date provided higher biological yield with lower N dose than that given by late sown-crop with higher dose of N (Table 7).

Intra-row spacing × nitrogen

Both intra row spacing resulted in similar seed yield in the absence of applied N, whereas with application of N (45, 60 and 75 kg/ha) the crop sown at closer intra-row

Table 6. Interaction effects of year and nitrogen doses on seed yield (t/ha) of sunflower (pooled data of 2 year)

Nitrogen (kg/ha)	Year	
	2014	2015
0	1.48	1.09
45	1.79	1.55
60	1.98	1.80
75	2.02	1.87
SEm±	0.029	
CD (P=0.05)	0.07	

Table 8. Effect of N doses on seed yield (t/ha) of sunflower sown at different intra-row spacing (pooled data of 2 years)

Nitrogen (kg/ha)	Intra-row spacing (cm)	
	30	24
0	1.27	1.29
45	1.62	1.72
60	1.84	1.94
75	1.90	1.98
SEm±	0.028	
CD (P=0.05)	0.07	

Table 7. Effect of nitrogen application on seed yield (t/ha) and biological yield (t/ha) of sunflower sown on different dates (pooled data of 2 years)

Nitrogen (kg/ha)	Seed yield			Biological yield		
	20 January	10 February	2 March	20 January	10 February	2 March
0	1.49	1.30	1.06	3.41	3.06	2.70
45	2.02	1.59	1.39	4.82	4.18	3.68
60	2.30	1.84	1.53	5.43	4.76	4.19
75	2.32	1.91	1.59	5.67	4.98	4.40
SEm±		0.042			0.034	
CD (P=0.05)		0.09			0.14	

spacing gave significantly higher seed yield than wider intra-row spacing (Table 8). This indicates that more N was required for increased number of plants under reduced intra-row spacing for yield enhancement.

On the basis of study, it was concluded that early sowing of the spring sunflower by 20 January, intra-row spacing of 24 cm, and applied-N dose of 60–75 kg N/ha depending on native soil-N status were optimum for higher productivity in alluvial soil of Indo-Gangetic Plains.

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