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Agronomic measures to improve thermal energy utilization by *spring* sunflower (*Helianthus annuus* L.)

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ABSTRACT

Investigations were conducted to study the thermal energy utilization by sunflower during *spring* 2014 and 2015 at Punjab Agricultural University, Ludhiana, Punjab, India. Experiments were laid out with three sowing dates (January 20, February 10 and March 2), two intra rowspacing (30 and 24 cm) and four nitrogen doses (0, 45, 60 and 75 kg ha^{-1}). The results indicated that early sowing and application ofnitrogen significantly increased number of days to attain physiological maturity. The thermal units required to attain various phenological stages also increased progressively as the sowing was delayed. However, effect of sowing date was not conspicuous onaccumulated growing degree days (AGDD) to attain physiological maturity. Widely sown crop required slightly more AGDD than closely sown for attaining physiological maturity. Application of nitrogen also increased the AGDD. Heat use efficiency followed the descending order with each successive delay in sowing.Seed filling duration had highly significant ($P<0.01$) positive correlation and regression with seed yield, indicating that with each unit increase in seed filling duration, seed yield increased by 91.3 units.

Key words: GDD, Helianthus annuus., HUE, Sunflower

The ability of the crop to utilize heat energy for dry matter accumulation is determined by environmental conditions in addition to genetic factors (Rao*et al.,* 1999). Agronomic practices such as sowing time, plant spacing and fertilizer requirement are the important factors influencing the crop growth and yield. Coinciding the crop phenology with favorable environment by selecting the appropriate sowing time is crucial for attaining higher yield. Sowing date is thus, an important non-monetary input that can be adjusted to avail the congenial environment. An appropriate plant stand helps in harnessing the renewable resources in an efficient manner. Maintenance of optimum plant population is therefore, important for achieving high yield of all crops in general and non-tillering /branching crops such as sunflower in particular. Nitrogen is the most important nutrient for plants which increase the total biomass production, yield components and yield as plant metabolic processes need proteins to support vegetative and reproductive growth of crop. Optimum nitrogen nutrition results in rapid leaf area development, prolongs life of leaves, improves leaf area duration and overall crop assimilation, thus leading to yield enhancement (Nasim *et al.,* 2011). Nitrogen is also known to alter the phasic development of crop by maintaining the required nutritional status of the plant and by altering the rate of dry matter accumulation (Copeland and Mcdonald., 1995).

Agronomic practices cause variation in the thermal energy utilization by altering the crop growth and development. Growing degree days (GDD),which determine occurrence of various phenological events in the life cycle of a plant, is the most common agro-climatic index used to estimate phenological development of a plant (Gouri*et al.*, 2005, Bonhomme 2000). Temperature, solar radiation and sunshine duration are major weather variables having significant influence on phenological, physiological and morphological expression of sunflower (Zheljazkov*et al.,* 2009). Nutritional status of plant is another important factor as floral induction in many crop is highly dependent on dry matter accumulation, rate of which is governed by availability of essential nutrients (Copeland and Mcdonald., 1995.). Keeping these in view, present investigations were conducted to study thermal energy utilization by *spring* sunflower under variable sowing times, intra row spacing's and N supply.

MATERIALS AND METHODS

The field experiments were conducted during *spring* 2014 and 2015 at the Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana, (30°56' N latitude, 75°52' E longitude and an elevation of

Table 1: Effect of sowing dates, intra row spacing and N dose on phenology of sunflower hybrid PSH 996 (Mean of two years ± SD)

Treatment	Days taken for attainment of						
	Star bud stage	Ray floret stage	Flower initiation	50 % flowering	100 % flowering	Seed filling stage	Physiological maturity
Sowing date							
Jan., 20	60.7± 0.6	70.8± 0.8	74.4± 1.0	79.8± 2.7	85.2± 3.6	91.3± 3.4	116.3± 4.9
Feb., 10	53.2± 0.8	63.8± 1.4	67.2± 1.6	70.7± 1.1	75.2± 2.3	80.6± 2.5	102.2± 5.0
March,2	44.9± 1.3	55.0± 0.3	58.3± 0.5	61.3± 0.4	65.8± 0.5	71.1± 1.2	89.8± 3.2
Intra row spacing (cm)							
30 cm	53.2± 0.4	63.4± 0.5	66.8± 0.5	70.7± 0.7	75.5± 2.1	81.3± 2.5	103.2± 4.4
24 cm	52.8± 0.4	63.0± 0.8	66.5± 0.9	70.5± 1.6	75.2± 2.1	80.8± 2.2	102.3± 4.3
N doses (kg ha^{-1})							
0	51.6± 0.1	64.5± 1.2	67.9± 0.0	72.7± 0.8	77.3± 2.3	83.1± 2.3	100.0± 4.2
45	52.6± 0.4	62.4± 0.3	66.0± 0.1	70.1± 0.8	74.8± 2.1	80.4± 2.3	102.7± 4.2
60	53.4± 0.5	62.7± 0.3	65.9± 0.7	70.0± 1.3	74.9± 1.6	80.4± 1.9	103.7± 4.5
75	54.2± 0.3	63.2± 1.0	66.1± 1.3	70.2± 1.0	74.5± 2.5	80.2± 3.0	104.6± 4.5

247 metres above the mean sea level), India. Ludhiana has sub-tropical and semi-arid climate with cold winters and hot-dry summers. Data on rainfall, maximum and minimum temperatures during the study period were collected from agro–meteorological observatory of PAU, Ludhiana, situated at a distance of 300 metre from the experimental site.

The field experiment was laid out in factorial split plot design with 24 treatment combinations consisting of three sowing dates (D_1-January 20, D_2-February 10 and D_3-March 2) and two intra row spacing's(S_1-30 cm and S_2-24 cm) in main plots and four nitrogen doses (N_0-0, N_{45}-45, N_{60}-60, N_{75}-75 kg ha^{-1}) in sub plots. Sunflower hybrid PSH 996 was sown as per treatmentsreplicated thriceby dibbling 3 seeds per hillat row spacing of 60 cm. One plant per hill was maintained after crop establishment denoted by 2- 4 leaf stage. Phosphorous @ 30 kg P_2O_5 ha^{-1}and potassium @ 30 kg K_2O ha^{-1} were applied at sowing. Nitrogenwas applied as per treatments through urea in two splits, half as basal and half at thinning (3 weeks after sowing). Irrigations were applied as per crop requirement. Earthing up was done 6-7 weeks after sowing to prevent crop lodging. Insecticide chlorpyriphos 20 EC @ 2.5 l ha^{-1}was sprayed at bud formation and 50% flowering stages to control semi looper and head borer. Bird damage was prevented by erecting nylon net over the field ataheight of 2.5 metre. Observations on appearance of various phenological stages viz.star bud, ray floret opening, commencement of flowering, 50 per cent flowering, 100 per cent flowering, seed filling and physiological maturity were recorded by taking daily visual observations from each experimental unit.

Thermal indices viz. growing degree days and heat use efficiency were computed by using crop phenology and meteorological data obtained from School of Climate Change and Agricultural Meteorology, PAU, Ludhiana. Growing degree days (GDD) were determined by "Remainder index" method as per Nuttonson (1955) using a base temperature of 4.0°C as suggested by Villalobos *et al* (1996). GDD were accumulated from the date of sowing to date of attainment of particular phenophase. Heat use efficiency (HUE) for seed as well as total dry matter was computed by dividing the dry matter accumulation or seed yield with accumulated GDD and expressed as kg ha^{-1}°C^{-1} day hr. Correlation and regression studies were done using SAS 9.3.

RESULTS AND DISCUSSION

Crop phenology

Delayed sowing caused progressive decrease in number of days taken for attainment of different growth stages viz. star bud, ray floret opening, flower initiation, 50 per cent flowering, 100 per cent flowering, seed filling and physiological maturity and also resulted in reduction in the duration of flowering and seed filling (Table 1). Early sown crop had longest seed filling and reproductive phases. The more number of days taken for appearance of various pheno-

Table 2: Effect of sowing dates, intra row spacing and N dose on duration of different stages, accumulated growing degree days (AGDD) for attainment of various phenophases and heat use efficiency (HUE) of sunflower hybrid PSH 996 (Mean of two years ± SD)

Treatment	AGDD (˚C day hrs) to attain..............stage							HUE (kg ha^{-1} ˚C day^{-1})	
	Star bud	Ray floret	Flower initiation	50% flowering	100% flowering	Seed filling	Physiological maturity	Seed	Stalk
Sowing date									
Jan., 20	698.6±23.9	180.6±1.8	64.2±0.7	98.3±23.3	108.7±22.0	130.2±9.6	639.0±23.3	1.57± 0.09	1.06± 0.11
Feb., 10	744.1±35.1	203.5±7.4	68.1±1.5	75.0±17.7	110.5±27.0	139.6±6.8	556.9±57.6	1.41± 0.06	0.87± 0.04
March,2	736.5±31.8	221.4±4.1	81.5±5.5	81.7±8.8	117.2±26.4	138.4±12.3	518.7±68.9	1.31± 0.04	0.74± 0.05
Intra row spacing (cm)									
30 cm	730.7±29.6	200.9±1.8	72.2±6.1	82.8±1.3	112.6±37.3	140.3±5.7	573.4±35.4	1.35± 0.06	0.87± 0.06
24 cm	722.1±31.0	202.8±7.2	70.3±0.8	87.2±13.5	111.7±13.0	131.9±0.6	569.5±57.8	1.51± 0.07	0.91± 0.06
N doses (kg ha^{-1})									
0	717.9V3.5	234.7±9.5	84.1±12.2	89.3±1.0	114.6±34.4	143.4±9.1	461.8±72.3	1.01± 0.08	0.70± 0.12
45	713.8±35.3	199.5±1.3	72.0±9.5	91.1±14.2	105.5±32.0	136.2±8.3	580.2±29.1	1.34± 0.05	0.88± 0.07
60	731.1±47.2	196.4±12.7	65.3±9.1	88.7±4.3	109.2±15.5	130.7±0.1	613.9±55.6	1.62± 0.09	0.98± 0.04
75	748.8±35.2	176.9±13.2	63.6±2.3	70.9±11.0	119.4±18.7	134.0±13.5	630.3±29.5	1.74± 0.01	1.00± 0.03

phases in earlier sown crop as compared to later sown crop might be due to comparatively low temperature conditions prevailing during the corresponding growth stages of earlier sown crop. Similarly, high temperature and comparatively low relative humidity (%) during seed filling stage of later sown crop (March 2) forced the crop to attain maturity quickly. Ritche and Ne Smith (1991) reported that rate of plant development is temperature driven and all physiological or morphological developments occurring in plant are markedly influenced by temperature. Reduced growth period under late sowing has also been reported by Kingra*et al.,* (2007). Variation in intra row spacing did not cause variation in number of days to attain various pheno-phases except seed filling and physiological maturity stages. Application of nitrogen also had effect on phasic development of sunflower (Table 1). The control treatment (o kg N ha^{-1}) took lesser number of days to attain star bud stage. Application of each higher dose of nitrogen progressively enhanced number of days to reach star bud stage. However, to attain other pheonological stages viz. ray floret opening, flower initiation, 50% flowering, 100 per cent flowering and seed filling stage followed a reverse trend where control treatment took more number of days than N application treatments, which indicate that N fertilization tended to advance the crop development. However, the numbers of days to reach physiological maturity were higher in the treatment receiving 75 kg N ha^{-1} and it decreased consistently under lower doses of N fertilizer. The duration of seed filling also registered consistent increase due to application of successive higher N dose. Application of N prolonged the crop duration by delaying crop maturity as nitrogen induce vegetative and generative growth and prevent premature senescence, thereby potentially enhancing the metabolic processes of plant and lengthening its life cycle, which ultimately resulted in significant increase in seed filling duration.

Growing degree days (GDD)

The late sown crop (March 2) accumulated more growing degree days (GDD) than earlier sown crop (January 20 and February 10) while the differences between February 10 and March 2 were very narrow up to flower initiation stage but as the crop stage progressed to 50 per cent and 100 per cent flowering, the differences between January 20 and February 10 were narrowed down and March 2 sown crop continued to accumulate more GDD than earlier sown crop (Table 2). Similarly at seed filling stage, progressive increase in accumulated GDD was observed due to delayed sowing. Contrary to this, earliest sown and late sown crop accumulated almost same number of GDD for attainment of physiological maturity. However, for attainment of all other phenophases, the later sown crop (March 2) accumulated 5-9.5 per cent more GDD than that of earliest sown crop indicating higher

Table 3: Correlation and regression coefficients between various parameters recorded/computed on the basis of mean data of two years

Variable	Correlation (r)	Regression (b)	Coefficient of determination (r^2)
AGDD at seed filling with seed yield	-0.73**	-5.919**	0.533
AGDD at maturity with seed yield	0.78**	4.44**	0.621
Seed filling duration with seed yield	0.96**	91.32**	0.920
GDD accumulated during seed filling duration with seed yield	0.995**	3.96**	0.913

** Significant at 1% level

AGDD by earliest sown crop during seed filling stage. As sunflower is a photo and thermo-insenstive crop, thus transition of crop from one pheno-phase to another seems to be largely governed by dry matter accumulation by the plant, which in turn is governed by prevailing temperature and nutritional status of the crop plant. The increase in number of GDD accumulation with delay in sowing for attaining a particular stage might be due to the high temperature during the growth period of late sown crop. Though the earlier sown crop took more number of days for attaining physiological maturity but accumulated almost equal number of heat units due to the fact that low temperature prevailed at all phenological stages in general and during early phases of crop growth in particular. Increase in number of GDD accumulation with delayed sowing has also been reported by Kingra *et al.,* (2007). Wider sown crop accumulated more number of GDD for attainment of all pheno-phases (Table 2). The less number of accumulated GDD under dense sowing can be ascribed to the reduction in duration of pheno-phases due to intra row competition, which might have caused stress to the crop for early completion of life cycle. It is further evident from the data in Table 2 that application of 75 kg N ha^{-1} registered the highest number of accumulated GDD for attainment of star bud and physiological maturity stages. However, for attainment of all other phenol-phases, the control (0 kg N ha^{-1}) treatment accumulated more number of heat units (Table 2). It is evident that well fertilized crop maintained higher crop growth rate and completed the particular pheno-phase earlier than poorly-fed crop. More number of heat units accumulated up to star bud and physiological maturity stages due to 75 kg N ha^{-1} are associated with the more number of days taken for attaining a particular pheno-phase as nitrogen is known to increase vegetative growth of crop leading to increased crop duration.

Heat use efficiency (HUE)

A perusal of data in Table 2 indicated the highest heat use efficiency for seed as well as stalk under January 20 and the least under March 2 sown crop (Table 2). Sowing the crop at closer spacing led to marginally higher heat use efficiency for stalk but differences were very meager in case of seed. Application of each higher dose of N resulted in apparent increment in heat use efficiency for stalk up to the highest level but differences in HUE for seed between 60 and 75 kg N ha^{-1} were quite narrow. Although wider differences in HUE for seed was observed between other N doses. Heat use efficiency is directly proportional to dry matter accumulation by the plant. So, higher dry matter accumulation due to higher crop growth rate under January 20 sown crop improved its heat use efficiency. Likewise, improvement in heat use efficiency due to higher levels of N may also be due to enhanced growth rate of crop, hence heat use efficiency.

Correlation and regression studies

Simple correlation (r), regression (b) and coefficient of determination (r^2) among various parameters of sunflower (Tables 3) revealed highly significant ($P < 0.01$) negative correlation of AGDD at seed filling stage with seed yield indicating the influence of temperature on seed yield of sunflower. Data further indicate that with each unit increase in AGDD at seed filling stage, seed yield decreased by 5.919 units. AGDD at seed filling stage accounted for more than 53 per cent variation in seed yield of sunflower. Likewise, AGDD at maturity accounted for 60 per cent and seed filling duration accounted for 92 per cent variation in seed yield of sunflower and were significantly ($P < 0.01$) positively correlated with seed yield. The accumulation of growing degree days during seed filling (seed filling to maturity) was found to be highly significantly ($P < 0.01$) positively correlated with seed yield showing an increase of 3.96 units of seed yield due to each unit increase in accumulation of growing degree days during seed filling. Similarly, seed filling duration hadhighly significant ($P<0.01$) positive correlation and regression with seed yield, indicating that with each unit increase in seed filling duration, seed yield increased by 91.3 units.

CONCLUSIONS

Thermal energy utilization of the crop was improved by early sowing with ample nitrogen supply and optimum plant population. Thus, it can be concluded that agronomic measures such as adjustment of sowing time, intra row spacing and nitrogen supply etc. can be effectively used for harnessing the freely available solar energy.

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