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Full Length Research Paper

Response of sunflower hybrids to management practices under irrigated arid-environment

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Two field experiments were established at Research Farm, Bahauddin Zakariya University, (BZU) Multan, Pakistan, during the spring season of 2009 to study the interactive effect of sunflower (*Helianthus annuus* L.) hybrids in terms of growth, fraction of intercepted radiation (F_i), intercepted photo-synthetically active radiation (PAR), yield components and oil contents to planting geometries and nitrogen rates. Experiment 1 comprised nine treatments having combinations of three hybrids (H_1 = 19012; H_2 = Hysun-33; H_3 = DK-4040) and three planting geometries (PG_1 = flat sowing; PG_2 = ridge sowing; PG_3 = bed sowing) while, experiment 2 comprised 16 treatments having combinations of four hybrids (H_1 = 00989; H_2 = 01087; H_3 = 00997; H_4 = 010226) and four nitrogen rates (N_0 = control; N_1 = 75; N_2 = 150 and N_3 = 225 kg ha^{-1}). The results revealed that, the ontogeny maximum plant height ranged from 32 to 216 cm and from 36 to 299 cm in experiments 1 and 2, respectively. The ontogeny maximum number of leaves plant^{-1} were 21, 32, 28, 21 and 14 in experiment 1 and 20, 33, 29, 20 and 9 in experiment 2, respectively on respective harvest dates. The ontogeny maximum head diameter was 17, 22 and 25 cm and 20, 21 and 29 cm on respective dates for experiments 1 and 2, respectively. The ontogeny F_i values for experiments 1 and 2, ranged from 0.11 to 0.99 and from 0.09 to 0.99, respectively. The cumulative intercepted PAR ranged from 492 to 812 MJ m^{-2} and from 627 to 897 MJ m^{-2} in experiments 1 and 2, respectively. The achene weight ranged from 69.7 to 127.5 g and from 65.4 to 93.4 g in experiments 1 and 2, respectively. The number of achenes head^{-1} ranged from 919 to 1868 and 925 to 1678 for experiments 1 and 2, respectively. The achene oil contents ranged from 38.1 to 43.1% and 34.5 to 47.6% for experiments 1 and 2, respectively. However, average oil contents value was 41% for both experiments. From the results, the use of higher nitrogen rates and ridge or bed sowing techniques are recommended for the management practices for the newly developed sunflower hybrids farmers.

Key words: Sunflower hybrids, planting geometries, nitrogen rates, intercepted PAR.

INTRODUCTION

The major oilseed crops of Pakistan include cotton (*Gossypium hersutum* L.), rape/mustard (*Brassica* spp.), sunflower (*Helianthus annuus* L.) and canola (*Brassica napus* L.), etc. The total edible oil consumption during 2008 to 2009 was 2.821 million (M) tons and local production stood at 0.684 M tons, which was 24% of the total availability in the country, while the remaining 76% was made available through imports. In 2009, sunflower was planted on 3.53 M ha with total seed production of 5.54 M tons and total oil production of 2.11 M tons (GOP, 2010).

It is mainly cultivated for oil and oil production plant^{-1} depends on yield components (number of achenes head^{-1}, weight achene^{-1} and oil concentration) and these are mainly controlled genetically (Sadras and Villalobos, 1994; Connor and Hall, 1997; Dosio et al., 2000), but highly affected by the environment and growing conditions (Cardinali et al., 1982; Steer et al., 1984; Hall et al., 1985; Andrade and Ferreiro, 1996; Bange et al., 1997a and b; Malik et al., 2001). However, productivity of sunflower in the country is very low and possible reasons for it are the non-adoption of new developed short stature hybrids with high fertilizer requirements. The farmers are applying inappropriate planting geometries and are applying low nitrogen rates. Therefore, sowing of newly

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developed hybrids, with appropriate planting geometries and higher nitrogen rates are considered as promising strategy in order to increase edible oil production for food security and reduce the import bills (Gimenez et al., 1994; Malik et al., 2001; Zahoor et al., 2010).

Crop growth and productivity can be discussed in terms of biomass produced per unit of intercepted radiation (Gallagher and Biscoe, 1978). Interception of photosynthtically active radiation (PAR) is regulated concurrently by the canopy size (LAI) and structure (leaf angle and orientation). Cumulative intercepted PAR is a function of green area and the efficiency with which green area intercepts PAR (Monteith, 1965; Monteith, 1977; Sinclair and Horie, 1989; Muchow and Sinclair, 1994). The radiation utilization efficiency of different field crops including sunflower under stress free conditions has been found to be fairly stable (Monteith, 1977; Gallagher and Biscoe, 1978; Kiniry et al., 1989; Hall et al., 1995), but may vary during the various growth stages (Gallagher and Biscoe, 1978; Ferraris and Charles-Edwards, 1986; Trapani et al., 1992; Steer et al., 1993; Hall et al., 1995; Zahoor et al., 2010). The planting geometries also affect fraction of intercepted radiation (F_i), intercepted PAR, its utilization efficiency (Tollenaar and Aguilera, 1992; Zahoor et al., 2010) and finally, yield and yield components (Malik et al., 2001). Nitrogen supply can affect plant growth and productivity by changing canopy size and structure thus, altering intercepted PAR and ultimately, its utilization efficiency (Novoa and Loomis, 1981; Sinclair, 1990; Muchow and Sinclair, 1994; Gimenez et al., 1994; Zahoor et al., 2010). Thus, exploring the potential of newly developed hybrids through the exploitation of available natural resources (with proper planting geometries and higher nitrogen supply, ultimately, resulting in higher growth, intercepted PAR and yield components) have been proposed as possible solutions for reducing the import bills and increasing the profits for the low income farmers of the irrigated arid and semiarid areas (Ahmad et al., 2008; Ahmad et al., 2009; Zahoor et al., 2010).

It was therefore the objective of this study to evaluate the interactive effects of hybrids, planting geometries and nitrogen rates on the ontogeny growth, fraction of intercepted radiation, intercepted PAR, yield components and oil quality of sunflower under irrigated arid environmental conditions.

MATERIALS AND METHODS

Experimental site and agro-meteorological conditions

Two field experiments were conducted at the experimental farm, Bahauddin Zakariya University (BZU), Multan, Pakistan, (Latitude, 30.15°N; longitude, 71.30°E; 126.6 m from sea level) during the spring season of 2009. Standard meteorological data were obtained from the Central Cotton Research Institute (CCRI), Multan. Figure 1 summarizes the daily weather data for the experimental site during the spring sunflower season. The daily maximum and minimum air temperatures during the season ranged from 19.5 to 44.0°C and 11.0 to 28.0°C, respectively. The daily sunshine hours and total precipitation received for same period was 11.3 h and 21.5 mm, respectively. The soil analysis prior to sowing is presented in Table 1.

Experimental design and treatments

The experiments were laid out in a randomized complete block design (RCBD) with factorial arrangements and were replicated thrice. Experiment 1, comprised nine treatments having combinations of three hybrids and three planting geometries ($T_1 = H_1PG_1$ = 19012 × flat sowing; $T_2 = H_1PG_2$ = 19012 × ridge sowing; $T_3 = H_1PG_3$ = 19012 × bed sowing; $T_4 = H_2PG_1$ = Hysun-33 × flat sowing; $T_5 = H_2PG_2$ = Hyson-33 × ridge sowing; $T_6 = H_2PG_3$ = Hysun-33 × bed sowing; $T_7 = H_3PG_1$ = DK-4040 × flat sowing; $T_8 = H_3PG_2$ = DK-4040 × ridge sowing and $T_9 = H_3PG_3$ = DK-4040 × bed sowing) while, experiment 2 comprised 16 treatments having combinations of four hybrids and four nitrogen rates ($T_1 = H_1N_0$ = 00989 × 0 kg ha^{-1}; $T_2 = H_1N_1$ = 00989 × 75 kg ha^{-1}; $T_3 = H_1N_2$ = 00989 × 150 kg ha^{-1}; $T_4 = H_1N_3$ = 00989 × 225 kg ha^{-1}; $T_5 = H_2N_0$ = 01087 × 0 kg ha^{-1}; $T_6 = H_2N_1$ = 01087 × 75 kg ha^{-1}; $T_7 = H_2N_2$ = 01087 × 150 kg ha^{-1}; $T_8 = H_2N_3$ = 01087 × 225 kg ha^{-1}; $T_9 = H_3N_0$ = 00997 × 0 kg ha^{-1}; $T_{10} = H_3N_1$ = 00997 × 75 kg ha^{-1}; $T_{11} = H_3N_2$ = 00997 × 150 kg ha^{-1}; $T_{12} = H_3N_3$ = 00997 × 225 kg ha^{-1}; $T_{13} = H_4N_0$ = 010226 × 0 kg ha^{-1}; $T_{14} = H_4N_1$ = 010226 × 75 kg ha^{-1}; $T_{15} = H_4N_2$ = 010226 × 150 kg ha^{-1} and $T_{16} = H_4N_3$ = 010226 × 225 kg ha^{-1}). The sowing date for both experiments were 17th February, while final harvesting dates were 1st June and 20th May, 2009 for experiments 1 and 2, respectively.

Sampling procedures

A sample of 10 g of leaf lamina was taken from each treatment and leaf area was measured on an area meter. A total of six and five harvests were made to record the measurements in experiments 1 and 2, respectively. Leaf area index (LAI) was calculated as suggested by Watson (1947).

$$\text{Leaf area index}\ (\text{LAI}) = \frac{\text{Leaf area}}{\text{Land area}}$$

Intercepted photo-synthetically active radiation (PAR)

The fraction of intercepted radiation (Fi) was calculated from leaf area index using the exponential equation as suggested by Monteith and Elston (1983);

$$\text{Fraction of intercepted radiation}(\text{F}_\text{i}) = 1 - \exp(-k \times LAI)$$

Where, k is extinction co-efficient for total solar radiation (Monteith, 1977). K value of 0.90 was used as suggested by Gimenez et al. (1994). PAR was assumed to equal half (50%) of the total incident radiation (Szcicz, 1974). Multiplying these totals by appropriate estimates of Fi and Si gave the amount of intercepted radiation (Sa):

$$\text{Intercepted radiation (Sa)} = F_i \times S_i$$

Where, Si is the incident PAR.

Statistical analysis

The data collected from both the experiments were analyzed statistically for the analysis of variance (ANOVA). The treatment means

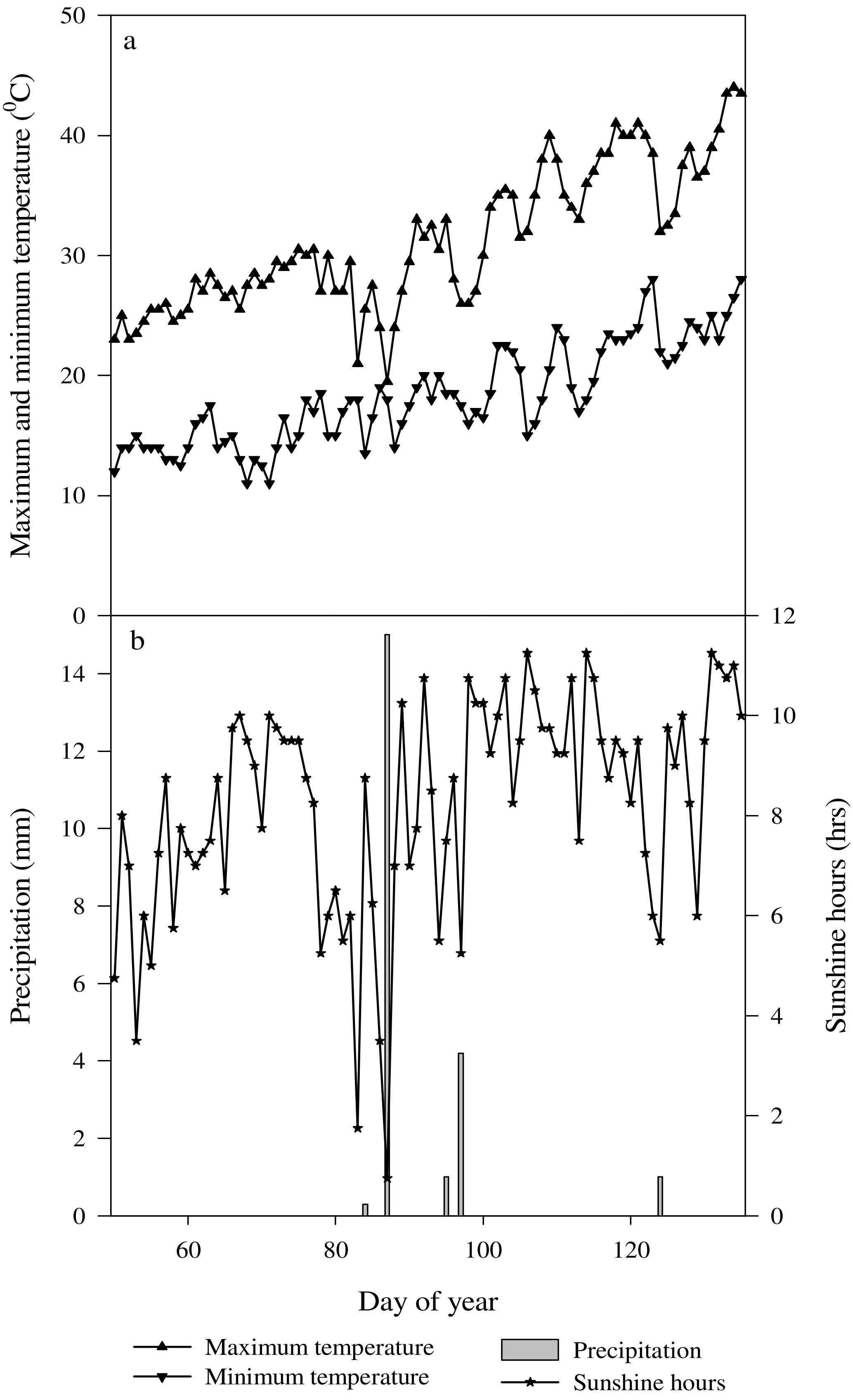

Figure 1. Daily maximum and minimum air temperatures; (a) precipitation and sunshine hours (b) during spring sunflower season 2009.

Table 1. Prior to sowing soil physio-chemical analysis of experimental site.

Characteristic	Value	Characteristic	Value
pH	8.01	Available K (ppm)	245
EC (ds m^{-1})	11.9	Sand (%)	28
Organic matter (%)	0.75	Silt (%)	54
Total nitrogen (%)	0.04	Clay (%)	18
Available P (ppm)	5.2	Total soluble salts (%)	0.28

were compared by employing least significant differences test. MSTATC computer software was used to carry out statistical analysis (Russel and Eisensmith, 1983).

RESULTS

Ontogeny plant height

The plant height increased gradually from 25th March to 30th April (36 to 72 DAS). There was a smaller increase in the height up to 5th May (77 DAS) and then, was fairly stable until final harvest (102 DAS) in experiments 1 (Figure 2a) while, in experiment 2 (Figure 3a) plant height values increased gradually from 20th March to 19th April (31 to 61 DAS), and then, there were smaller increases up to final harvest on 20th May (92 DAS). For experiment 1, the maximum plant height ranged from 32 to 216 cm on the 25th March (36 DAS) and 30th May (102 DAS), respectively (Figure 2a). The maximum plant height for hybrids was observed for bed sown crop, while, the minimum values for the parameter were recorded in flat sown crop (Figure 2a). In the case of experiment 2, the maximum plant height ranged from 36 to 299 cm on 20th March (31 DAS) and 20th May (92 DAS), respectively (Figure 3a). The plant height increased gradually with the increase of nitrogen rates. The greater plant height was recorded in the case of higher nitrogen rates (150 and 225 kg ha^{-1}), as compared to the control (0) or lower (75 kg ha^{-1}) nitrogen rate (Figure 3a).

Ontogeny number of leaves plant^{-1}

The interactive effects of treatments on the number of leaves plant^{-1} are shown in Figures 2b and 3b for experiments 1 and 2, respectively. The number of leaves plant^{-1} increased progressively from 25th March to 10th April (36 to 52 DAS) and decreased gradually from 10th April to 30th May (52 to 102 DAS) in experiment 1 (Figure 2b) while, in experiment 2 (Figure 3b), number of leaves plant^{-1} increased progressively from 20th March to 4th April (31 to 46 DAS) and then, decreased gradually from 4th April to 20th May (46 to 92 DAS). The number of leaves plant^{-1} were 21, 32, 28, 21 and 14 on 25th March, 10th April, 30th April, 5th May and 30th May, respectively from 36 to 102 DAS in experiment 1. The respective values for experiment 2 were 20, 33, 29, 20 and 9 on 20th March, 4th April, 19th April, 5th May and 20th May, respectively from 31 to 92 DAS.

Ontogeny head diameter

The head diameter increased gradually from 30th April to 15th May (71 to 86 DAS) in experiment 1 (Figure 2c) and from 19th April to 5th May (61 to 77 DAS) in experiment 2 (Figure 3c). The head diameter was 17, 22 and 25 cm on 30th April, 5th May and 30th May, respectively from 72 to 102 DAS in experiment 1. The respective values for experiment 2 were 20, 21 and 29 on 19th April, 5th May and 20th May, respectively from 60 to 92 DAS. Overall, the head diameter ranged from 9 to 23 cm during the whole growing season of spring sunflower in experiment 1. Although, the peak values for head diameter were found at the final harvest dates on 30th May (102 DAS) and 20th May (92 DAS) in experiments 1 and 2, respectively.

Ontogeny fraction of intercepted radiation

The F_i increased linearly from 31 DAS (in both experiments) and reached a maximum on 60 DAS in experiment 1 and 63 DAS in experiment 2. Thereafter, F_i declined till final harvest (102 DAS and 92 DAS in experiments 1 and 2, respectively). For experiment 1, the F_i was higher for hybrids at ridge or bed sown crops, while, the minimum values for the parameter was recorded at flat sown crop (Figure 4a). The F_i values for experiment 1 ranged from 0.11 to 0.99 (Figure 4a). In experiment 2 for hybrids, higher values for F_i were observed at higher nitrogen rates (150 and 225 kg ha^{-1}), while the minimum values for the parameter were recorded for the control (0) or lower (75 kg ha^{-1}) nitrogen rate (Figure 4a and b). Overall, increasing nitrogen rates significantly increased F_i when compared with the control (N_0) or lower rate of nitrogen (75 kg ha^{-1}). The F_i values for experiment 2 ranged from 0.09 to 0.99 (Figure 4b).

Intercepted photo-synthetically active radiation

The intercepted PAR ranged from 492 to 812 MJ m^{-2} for

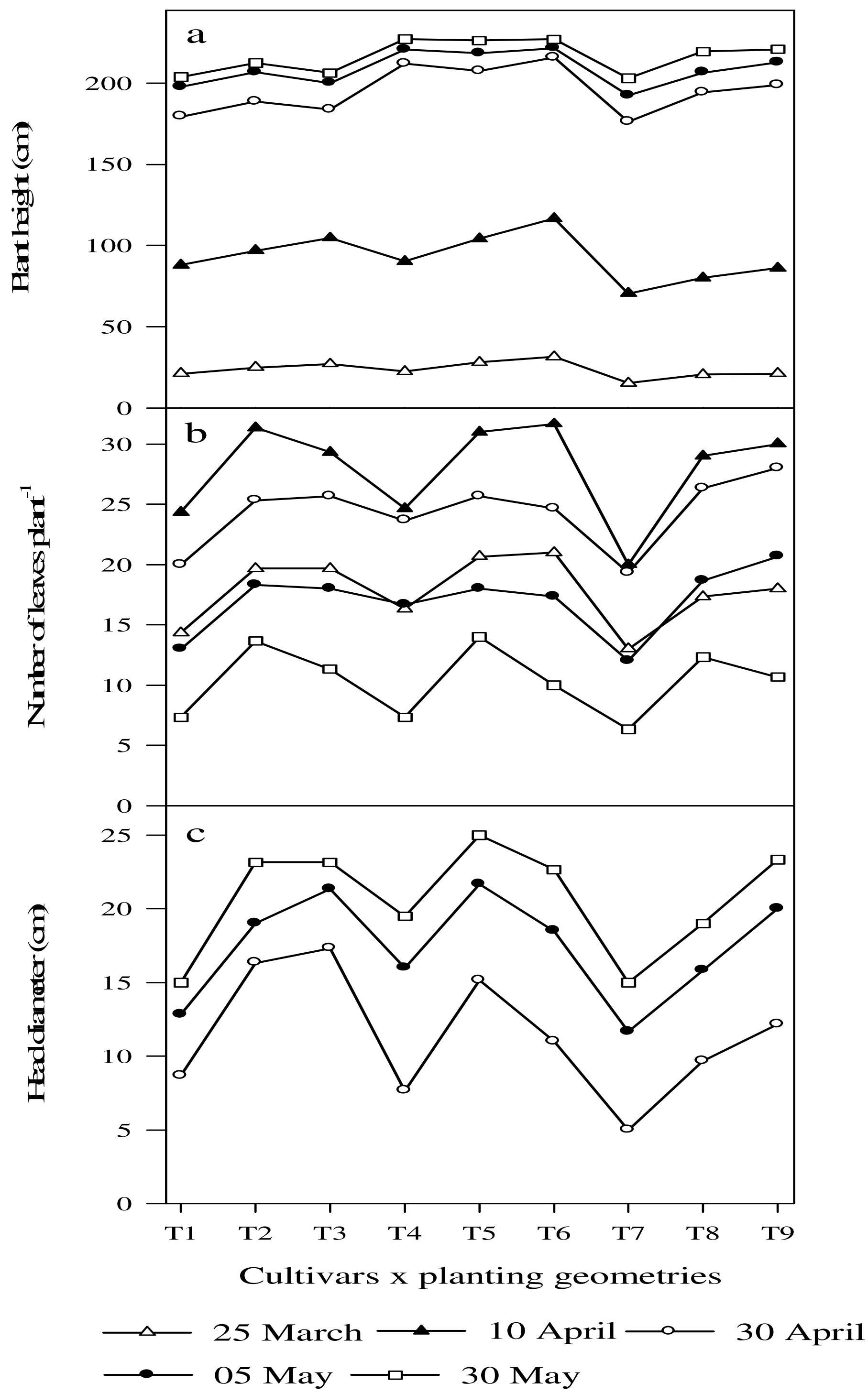

Figure 2. Ontogeny plant height.(a) number of leaves plant^{-1} (b) and head diameter (c) as affected by sunflower hybrids and planting geometries.

experiment 1 (Table 2). The highest intercepted PAR values were recorded for the treatment having combination of hybrid DK-4040 and bed crop, while the minimum values for the parameter was recorded in the treatment having combination of hybrid H_1 (19012) and flat sown crop (Table 2) and in experiment 2 intercepted PAR ranged from 627 to 897 MJ m^{-2} (Table 3). The higher intercepted PAR values were recorded for higher nitrogen rates (150 or 225 kg ha^{-1}), while the minimum values for the parameter were recorded in the control (0) or lower

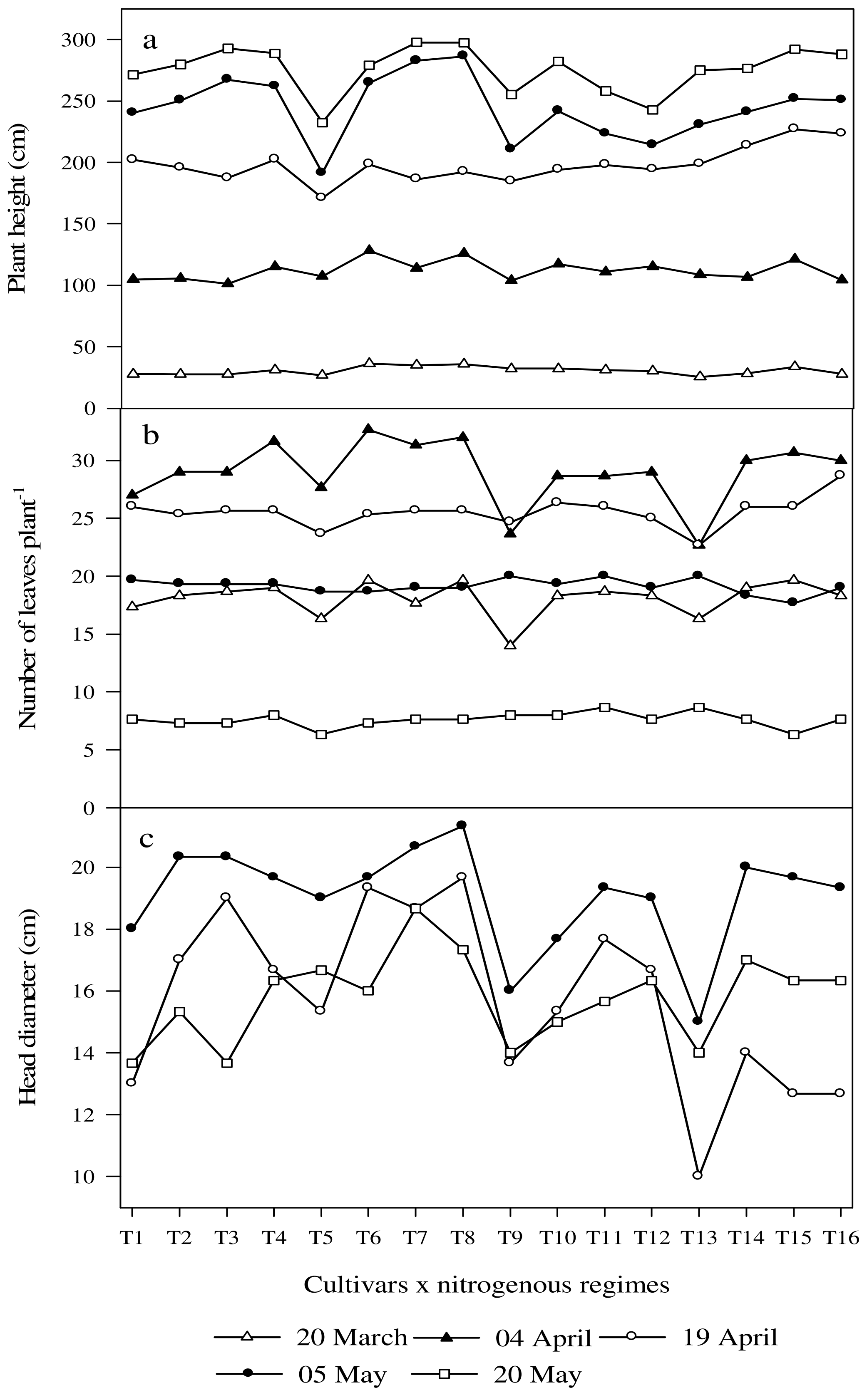

Figure 3. Ontogeny plant height (a), number of leaves plant^{-1} (b) and head diameter (c) as affected by sunflower hybrids and nitrogen rates.

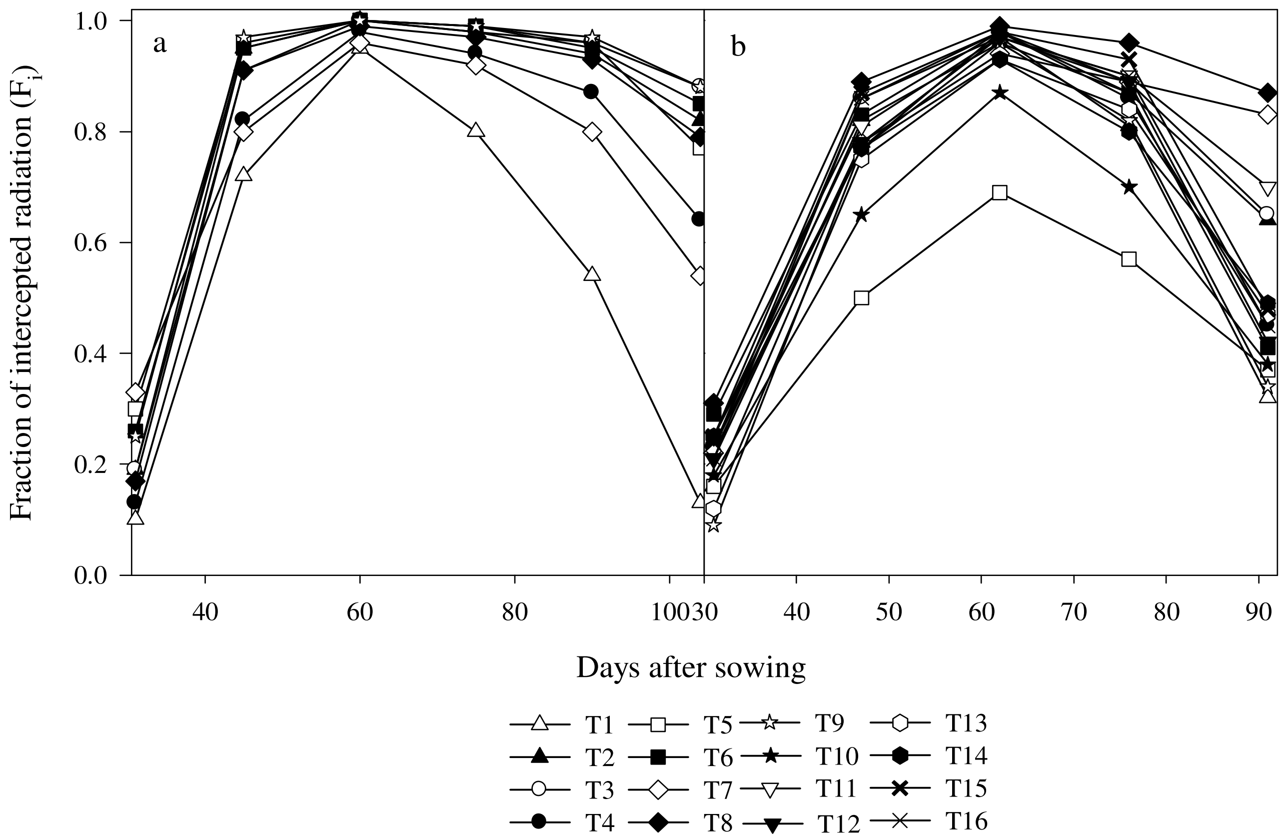

Figure 4. Ontogeny fraction of intercepted radiation as affected by sunflower hybrids and planting geometries; (a) sunflower hybrids and nitrogen rates (b).

Table 2. Intercepted PAR, achene weight, number of achenes head^{-1} and achene oil contents as affected by sunflower hybrids and planting geometries.

Treatment	Intercepted PAR (MJ m^{-2})	Achene weight (g)	Number of achenes head^{-1}	Achene oil content (%)
$T_1 = H_1PG_1$	492.5c	69.7c	919.0c	38.6b
$T_2 = H_1PG_2$	779.0a	109.3a	1661.3c	40.6a
$T_3 = H_1PG_3$	787.4a	106.7a	1636.0c	43.1a
$T_4 = H_2PG_1$	696.0b	104.3b	1383.0b	41.1a
$T_5 = H_2PG_2$	797.5a	127.5a	1867.7c	41.1a
$T_6 = H_2PG_3$	798.9a	112.0a	1490.7b	38.1b
$T_7 = H_3PG_1$	682.4b	83.0bc	935.0c	40.3b
$T_8 = H_3PG_2$	762.1a	103.1b	1378.7b	41.1a
$T_9 = H_3PG_3$	812.1a	110.7a	1401.0b	41.0a
LSD 5%	62.03	21.52	322.2	2.63

Treatments are presented in the materials and methods section.

nitrogen (75 kg ha^{-1}) rate (Table 3).

Achene weight

The achene weight ranged from 69.7 to 127.5 g for experiment 1 (Table 2). The highest achene weight values were recorded for bed or ridge sown crop, while, the minimum values for the parameter was recorded in case of flat sown crop (Table 2). In experiment 2, achene weight ranged from 65 to 93 g (Table 3). The highest achene weight values were recorded for higher nitrogen

Table 3. Intercepted PAR, achene weight, number of achenes head^{-1} and achene oil contents as affected by sunflower hybrids and nitrogen rates.

Treatment	Intercepted PAR (MJ m^{-2})	Achene weight (g)	Number of achenes head^{-1}	Achene oil content (%)
$T_1 = H_1N_0$	734.5g	81.7b	1082.0b	41.04b
$T_2 = H_1N_1$	816.6c	93.4a	1437.7a	41.68b
$T_3 = H_1N_2$	810.6c	79.7b	1434.0a	41.52b
$T_4 = H_1N_3$	778.3e	81.0b	1340.7a	37.62b
$T_5 = H_2N_0$	627.4i	82.9b	964.3b	47.60a
$T_6 = H_2N_1$	788.3d	81.9b	1569.3a	41.98a
$T_7 = H_2N_2$	842.2b	78.1c	1440.3a	42.95a
$T_8 = H_2N_3$	897.2a	84.8b	1597.3a	41.91a
$T_9 = H_3N_0$	727.7g	65.4c	925.0b	35.90b
$T_{10} = H_3N_1$	697.9h	89.6b	1236.3b	41.90a
$T_{11} = H_3N_2$	833.6b	84.3b	1598.3a	33.51c
$T_{12} = H_3N_3$	773.2e	84.2b	1183.7b	42.09a
$T_{13} = H_4N_0$	753.1f	78.8c	1379.7a	44.56a
$T_{14} = H_4N_1$	768.6e	82.3b	1578.0a	41.00b
$T_{15} = H_4N_2$	810.0c	92.0b	1674.3a	41.73a
$T_{16} = H_4N_3$	791.8d	76.1b	1678.0a	42.12a
LSD 5%	10.39	10.77	420.9	5.88

Treatments are presented in the materials and methods section.

rates (150 or 225 kg ha^{-1}), while the minimum values for the parameter were recorded in the control (0) or lower nitrogen rate (75 kg ha^{-1}) (Table 3).

Number of achenes head^{-1}

The number of achenes head^{-1} ranged from 919 to 1868 for experiment 1 (Table 2). The highest number of achenes head^{-1} values were recorded for bed or ridge sown crops, while, the minimum values for the parameter were recorded in flat sown crop (Table 2). In experiment 2, the number of achenes head^{-1} ranged from 925 to 1678 (Table 3). The highest number of achenes head^{-1} values were recorded for higher nitrogen rates (150 or 225 kg ha^{-1}), while, the minimum values for the parameter were recorded in the control (0) or lower nitrogen rate (75 kg ha^{-1}) (Table 3).

Achenes oil contents

The achene oil contents ranged from 38.1 to 43.1% for experiment 1 (Table 2). The achene oil contents values were statistically non-significant. In experiment 2, achene oil contents ranged from 33.5 to 47.6% (Table 3). However, average oil contents value was 41% for both experiments (Tables 2 and 3).

DISCUSSION

The superiority of bed or ridge sowing for growth (ontogeny plant height, number of leaves plant^{-1} and head diameter), incident radiation (F_i and intercepted PAR) and yield components (achene weight, number of achenes head^{-1}) might be due to the fact that in these planting geometries, there may be more efficient utilization of the input resources, that is, nutrients, water, space and light when compared with flat sown crop. Furthermore, there was more lodging in the case of flat sown crop due to less support when compared with other planting geometries (Table 2). Plant height is a function of both genetic constitution and the environmental conditions under which it is grown. The greater plant height indicated maximum chances for radiation interception, its utilization efficiency and consequently higher photosynthetic rate (Al-Thabet, 2006). Leaves are the food manufacturing factories of the plant and the greater number of leaves ensured the better crop yield due to higher photosynthetic capacity by increasing LAI and resultantly higher F_i, intercepted PAR and its utilization efficiency. It is obvious that there was substantial increase of number of leaves plant^{-1} from the start of the growth of sunflower until 10th April, that had a peak line for the said parameter and after that, there was a sharp decline with minimum number of leaves plant^{-1} at final harvest date on 30th May and 20th May in experiments 1 and 2, respectively (Figures 2 and 3). The decrease in number of leaves plant^{-1} occurred due to senescence of leaves that was preceded in older leaves and they dropped down. The hybrids sown by ridge and bed planting geometries produced higher number of leaves plant^{-1}, probably due to better root and shoot growth, uniform plant spacing and maximum availability of water, nutrients and support when compared with flat sown crop. Plants grown at low nitrogen availability show a reduction both in number and size of leaves (Trewavas, 1985; Gimenez et al., 1994; Palmer et al., 1996). In this study, low availability of nitrogen reduced the vegetative growth of sunflower crop. Similarly, the reduced head size in the case of flat sown crop was probably due to more intra-plant competition for nutrients, moisture, light and air, thus, producing heads having smaller diameter (Figures 2 and 3). The results obtained in this study confirm the findings of many scientists (Esechie et al., 1996; Legha and Giri, 1999; Vahedi et al., 2010). Gimenez et al. (1994) and Gardner et al. (1994) concluded that, for any given canopy size (LAI), canopy structure (leaf angle and orientation) determine the fraction of intercepted radiation (Fi), interception of PAR and its utilization efficiency with which that PAR drives photosynthetic gain in terms of productivity. The reproductive growth of the sunflower hybrids started 60 DAS, so, before the switching of vegetative phase into reproductive one, the F_i reached its maximum value, after that, the partitioning of assimilates into reproductive organs and leaf senescence resulted in the decrease of the parameter (Figures 2 and 3). The significantly better performance of sunflower hybrids at higher nitrogen rates was probably due to higher availability of nitrogen and thus, ultimately higher nitrogen use efficiency (NUE). Differences in F_i, intercepted PAR and its utilization efficiency might be a possible cause of difference in growth of hybrids at various planting geometries and nitrogen rates. The differences in F_i, interception of PAR and its utilizetion efficiency resulted from the production of fewer, smaller leaves at the lower nitrogen rates than the higher nitrogen rates (Figure 4a,b). Ontogeny F_i was small during early developmental phase when compared with the rapid growth phase (Zahoor et al., 2010). Average F_i for all harvest dates followed a curvilinear relationship with time (Figure 4a,b). The mean F_i values were smaller during early harvests, then fairly stable and finally, there was a sharp decline. This kind of trend (curvilinear) was also reported by many scientists for sunflower crop (Steer et al., 1993; Hall et al., 1995). In this study, both experiments 1 and 2 showed curvilinear F_i over time course for the reproductive period (Figure 4a.b). This indicates a better description of changes in ontogeny F_i, at least during reproductive phase affected by interactive impact of hybrids, planting geometries and nitrogen rates.

Conclusion

The results revealed that for newly developed sunflower hybrids, the ridge or bed sowing are the appropriate planting geometries when compared with the traditional flat sowing. Similarly, the nitrogen rates (150 or 225 kg ha^{-1}) are recommended to achieve food security in edible oil under arid irrigated environmental conditions.

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