

**EFFECT OF PLANTING DENSITY AND FERTILIZER
RATE ON PERFORMANCE OF NEWLY DEVELOPED
SUNFLOWER HYBRIDS (*Helianthus annuus* L.)**

SNEHA, M. A.

**DEPARTMENT OF AGRONOMY
COLLEGE OF AGRICULTURE, RAICHUR
UNIVERSITY OF AGRICULTURAL SCIENCES
RAICHUR – 584 104**

OCTOBER, 2020

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RATE ON PERFORMANCE OF NEWLY DEVELOPED
SUNFLOWER HYBRIDS (*Helianthus annuus* L.)**

*Thesis submitted to the
University of Agricultural Sciences, Raichur
in partial fulfillment of the requirement for the
Degree of*

MASTER OF SCIENCE (AGRICULTURE)

in

AGRONOMY

By

SNEHA, M. A.

**DEPARTMENT OF AGRONOMY
COLLEGE OF AGRICULTURE, RAICHUR
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COLLEGE OF AGRICULTURE, RAICHUR
UNIVERSITY OF AGRICULTURAL SCIENCES
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CERTIFICATE

This is to certify that the thesis entitled “**EFFECT OF PLANTING DENSITY AND FERTILIZER RATE ON PERFORMANCE OF NEWLY DEVELOPED SUNFLOWER HYBRIDS (*Helianthus annuus* L.)**” submitted by **Miss. SNEHA M. A.**, in partial fulfillment of the requirements for the award of the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **AGRONOMY**, College of Agriculture, Raichur, University of Agricultural Sciences, Raichur, is a record of bonafide research work carried out by her during the period of her study in this University under my guidance and supervision and that no part of the thesis has been submitted for the award of any other degree, diploma, associate ship, fellowship or other similar titles.

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Affectionately Dedicated to

my Beloved Parents,

M. ANJANEYULU REDDY

LAKSHMI, M.

Sister, TRIVENI, Brother in law,

PRAVEEN

and

FARMING COMMUNITY

ACKNOWLEDGEMENT

“Gratitude is the memory of the heart”

“Commit to the lord whatever you do and your plan will succeed”. I start with the name of almighty, who is most beneficent and merciful. I am greatly thankful to God for giving me blessing and always illuminating me with the light of success.

*This is a memorable occasion provides me a unique opportunity to express my deep sense of gratitude to my respected Major Advisor **Dr. B. K. Desai**, Director of Research, UAS, Raichur for his most precious guidance, help, inspiration all throughout the degree period and also for preparation and submission of my research work as a whole. He is not only a teacher for me but also a motivator and guardian too. I cannot but consider myself as extremely fortunate for the opportunity to work under his scholastic esteem guidance.*

*At this fortunate occasion, I am wordless, thanks to my advisory committee members, **Dr. B. G. Koppalkar**, Head and Professor, Department of Agronomy, UAS, Raichur for his constant help, valuable suggestions during the investigation and valuable counsel during the period of study. **Dr. M. R. Umesh**, Assistant Professor, Department of Agronomy, UAS, Raichur for his relentless support, kindness, patience and guidance throughout the course of this research, preparation and critical evaluation of the thesis. His level of guidance, lively encouragement, constructive criticism and generous assistance at every stage of my research work, is beyond measure and **Dr. P. H. Kuchanur**, Professor and Head, Genetics and Plant Breeding AC, Beemarayanagudi for his guidance and help rendered to me all through my research work.*

*It gives me immense pleasure to express my profound indebtedness and heartfelt thanks to **Dr. A. S. Halepyati**, Professor, Department of Agronomy, College of Agriculture, Raichur and **Dr. Vishwanth, S.** Assistant Professor, Department of Agronomy, College of Agriculture, Raichur for their inspiration and constant encouragement throughout my study.*

*I am extremely thankful to **Dr. K. N. Kattimani**, Hon'ble Vice Chancellor, University of Agricultural Sciences, Raichur and **Dr. Satyanarayan Rao**, Dean (PGS), UAS, Raichur, **Dr. Chandaragi**, Dean (Agri.), College of Agriculture, Raichur for their inspiring guidance which enabled to bring out the best of my ability. I also acknowledge the help of **B. S. Golasangi**, Technical Officer, Directorate of PG Studies, UAS, Raichur*

in editing the thesis script to bring it in a more presentable form and also to Smt. **B. V. Nirmala**, Assistant registrar and all Dean (PGS) office staff for their technical support.

On my personal note, with deep respect and thanks from the depth of my heart, I bow my head to the feet of my parents **Sri. M. Anjaneyulu Reddy** and **Smt. M. Lakshmi Kantham**, my sister, **Triveni** and brother in law **Praveen** for their foresight, sacrifices, love and blessings always showed on me, their boundless love, needy inspiration, unshakable confidence with me without whose affection and moral support, I would not have come up to this stage.

I have been highly fortunate and lucky to express my heartfelt thanks to my nearest and dearest sisters and brothers, **Raghuveer, Pooja, Keerti, Srikanth, Rajashree, Shanta, Swathi, Theertu, Roopesh, Sangu, Lavanya, sahana** and many more for sound and fruitful advice, helping me in my research work and also a constant encouragement throughout my journey of PG programme.

I would also like to thank the field assistants **Mr. Venkatesh** and **Mr. Yusuf** for their service and help without which this research would have been incomplete. Also I would like to thank Akki Xerox for his untimely support and for bringing out my thesis in a good shape.

I always felt cheerful in presence and thoughts of my friends in whose company I never felt the burden of my studies. Their helping hand was evident at every stage of my tension, anxiety and achievement. I must begin with ever best friends like, **Aishu, Charishma, Soumya, Navya, Ashu, Chaitra, Pavi, Prema, Greeshu, Giru, Suma, Vani, Priyanka, Riyana, Raviteja and Mahesh**. My heartily thanks to my classmates, in whose company I started my journey and travelled till to reach the destination of my life with **Jairaj, Pavan, Nagraj, Rajesh, Chethan and Mallikarjun**. I am also thankful to my Seniors, **Ashna, Krupa, Siddagangamma, Ramarao, Raghavendra, Suma, Megha, Tapaswini, Tejaswini, Tinku, Sreena and juniors, Lakshmi, Renuka, Sanjeev, Husna, Karuna, Rashmi** and friends of UG and PG life for their kind support.

Lastly, I thank all the wonderful people around me who have directly and indirectly helped me and could not find separate mention.

.....Any omission in this brief Acknowledge doesn't mean lack of gratitude.

Raichur

October, 2020

(SNEHA M. A.)

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LIST OF ABBREVIATIONS

Abbreviation		Expansion
%	:	Per cent
cm	:	Centimeter
m	:	Meter
g	:	Gram
kg	:	Kilogram
cm ²	:	Square centimeter
m ²	:	Meter square
ha	:	Hectare
kg ha ⁻¹	:	Kilogram per hectare
Mg ha ⁻¹	:	Megagram per hectare
t ha ⁻¹	:	Tonne per hectare
m ha ⁻¹	:	Million per hectare
EC	:	Electrical Conductivity
dS m ⁻¹	:	Decisiemen per meter
B:C	:	Benefit Cost ratio
S.Em. $\pm$	:	Standard Error of mean
CD (P=0.05%)	:	Critical difference at 5 per cent level of probability
DAS	:	Days after sowing
<i>et al.</i> ,	:	And others
Head ⁻¹	:	Per head
F-test	:	Fishers test
<i>i.e.</i> ,	:	That is

Max	:	Maximum
Min	:	Minimum
NS	:	Non significant
mm	:	Millimeter
°C	:	Degree Celsius
P ₂ O ₅	:	Phosphorus pentaoxide
N	:	Nitrogen
K ₂ O	:	Potassium oxide
OC	:	Organic carbon
pH	:	Potential hydrogen
RF	:	Rainfall
Temp.	:	Temperature
RH	:	Relative humidity
Rs.	:	Rupees
<i>viz.</i> ,	:	Namely
RDF	:	Recommended dose of fertilizer
CGR	:	Crop growth rate
RGR	:	Relative growth rate
LAI	:	Leaf area index
LAD	:	Leaf area duration
NAR	:	Net assimilation rate

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INTRODUCTION

I. INTRODUCTION

Oilseeds play an important role in agricultural economy of India. India occupies a prominent place in global oilseed scenario with 19 % of area, 6-7 % of vegetable oil production, 9-10 % of the total edible oil consumption and 13.6 % of vegetable oil imports. In India, oilseeds account for nearly 3 % of the gross domestic product and 5.98 % of the value of all agricultural products. India currently imports about 50 % of total oil requirement at a huge cost of 56,000 crores (Paroda, 2013). With the ever increasing demographic pressure the gap between domestic needs and production of agricultural produce in general and edible oil in particular is widening at an alarming rate. Coupled with the dwindling resources and their increasing cost, there is an urgent necessity to improve the productivity by improving production and resource use efficiency of oilseed crops for realizing higher yield potential.

Sunflower (*Helianthus annuus* L.) is an important oilseed crop and is native to southern parts of USA and Mexico. Sunflower ranks fourth next to soybean, groundnut and rape seed in total production of oilseeds of the world. Seeds of sunflower contain high concentration of oil together with an appropriate proportion of unsaturated fatty acids with non-cholesterol and anti-cholesterol properties. It is cultivated for domestic and industrial purpose for its excellent quality and high oil content. The seeds contain 42-49 % of oil and the cake contains 25-35 % of protein.

India is the largest producer of oilseeds in the world. In India, sunflower is grown over an area of about 0.25 m ha with a production of 0.22 m t and a productivity of 886 kg ha⁻¹ (Anon., 2018). The cultivation of sunflower is largely confined to southern parts of the country comprising the states of Karnataka, Maharashtra, Tamil Nadu and Andhra Pradesh. These four states contribute about 90 per cent of total acreage and 78 per cent of total production. However, recently sunflower has moved to northern parts of the country where the productivity is high. Karnataka is the leading sunflower producing state in the country and contributes nearly 63 per cent of total area and 54 per cent of the total production in the country.

Sunflower holds great promise due to its short duration, high productivity, photo insensitivity, wider acclimatization, high content of poly unsaturated fatty acids and rich edible oil. Favorable fatty acid composition, colorless and odorless nature of sunflower oil makes it one of the best choices for blending with other edible oils but certain

production constraints reduce its production to a great extent. Improper availability of hybrid and high yielding seeds suited for different agro climatic areas, improper nutrient management, bird attack and major diseases and pests lead to poor growth and yield attributing characters, ultimately affecting seed yield.

The productivity of sunflower in India is low (886 kg ha⁻¹) as compared to other sunflower growing nations and one of the major reason for low productivity is due to its cultivation mainly under rainfed conditions with sub optimal crop stand, imbalanced nutrition and lack of soil moisture conservation techniques, thus leading to poor seed set and high per cent of chaffy seed, low oil content and yield.

To achieve highest yield potential of a sunflower hybrid, providing ideal or optimum geometry is through best planting density. Plant spacing effects are highly pronounced in sunflower because there is no possibility of covering gaps between plants by branching or tillering. Thus, an optimum plant stand helps in harnessing the renewable resources in efficient manner towards achieving high crop yields. Planting geometry determines the distribution pattern of plants in a field. It affects evaporation, water use efficiency of the crop and weed intensity/competition. Proper spacing of plants in a particular area makes plant canopy more effective in intercepting the radiant energy and shading effect on weeds (Saleem *et al.*, 2008). Under dry land conditions, response to the applied fertilizers varies with the available soil moisture. Hence, efficient soil moisture conservation is the key for successful crop production under this situation.

Sunflower is a heavy feeder crop due to its higher potential of seed and oil yield and a tonne of crop removes as much as 63.3 kg N, 19.1 kg P₂O₅ and 126.2 kg K₂O (Aruna and Mohammad, 2011). Inadequate or imbalance use of fertilizer has been one of the critical constraints in sunflower production. Application of fertilizers having nutrients like nitrogen, phosphorous and potash can increase sunflower growth and yield substantially (Reddy *et al.*, 2007). Nitrogen, phosphorous and potash (NPK) ratio is an important indicator in crop production that identifies nutrient balance. Intensive agriculture with fertilizer use highly skewed towards nitrogen, has deprived the soil of other essential nutrients, especially P and K. Application of nitrogenous, phosphatic and potashic fertilizer at sub optimal level adversely affects the growth and yield. Hence, balanced fertilizer application is important for high crop yield and consequently more oil yield. Fertilizer application represents an important measure to correct nutrient

deficiencies and to replace elements removed in the products harvested, and has been shown to be particularly effective with respect to yield formation.

The exploitation of new genotypes of sunflower has opened up new horizons in production. However, development and identification of local specific production technology is of prime importance in relevance to enhancing hybrids productivity. Higher productivity of sunflower can be achieved with the identification of high yielding genotypes as well as suitable agronomic practices like maintenance of suitable optimum plant density and use of optimum fertilizer rate. All India Coordinated Research Project on Sunflower, University of Agricultural Sciences, Raichur has developed new sunflower hybrids suitable for agro-climatic zone 2 and 3 of Karnataka. Keeping in view the above facts, the present investigation is planned with following objectives to evaluate the performance of new sunflower hybrids under varied planting density and fertilizer levels.

Objectives of Investigation

- 1) Assess the effect of planting density and fertilizer rate on canopy development and yield of sunflower hybrids.
- 2) Estimation of seed quality, nutrient uptake and use efficiency under different planting density and fertilizer rates for new sunflower hybrids.
- 3) To work out the economics of different hybrids as influenced by different plant densities and nutrient management for sunflower production.

REVIEW OF LITERATURE

II. REVIEW OF LITERATURE

A field investigation was carried out on performance evaluation of different sunflower hybrids under various row spacing and fertilizer levels during *kharif*, 2019 at Main Agriculture Research Station, Raichur. The review pertaining to performance of different sunflower hybrids is presented under the following headings.

2.1 Sunflower hybrids

2.1.1 Growth and yield potential of hybrids

2.2 Sunflower hybrids and planting density

2.2.1 Sunflower growth and plant density

2.2.2 Yield, yield attributes and plant density

2.2.3 Seed quality and plant density

2.2.4 Nutrient content and uptake in different plant density

2.2.5 Economics and plant density

2.3 Effect of rate of fertilizer application

2.3.1 Effect on growth and growth attributes

2.3.2 Yield, yield attributes and fertilizer application

2.3.3 Quality parameters and fertilizer application

2.3.4 Nutrient uptake and fertilizer application

2.3.5 Economics

2.4 Interaction effect of species, plant density and fertilizer rate

2.1 Sunflower hybrids

The performance of sunflower hybrids depends on the agro-climatic conditions, genetic potential of the hybrid and cropping practices. The literature available on the performance of different plant genotypes on the growth, yield and quality is reviewed and presented below.

2.1.1 Growth and yield potential of hybrids

Ahmad *et al.* (2001) evaluated the yield potential and oil quality of two sunflower hybrids. Results indicated that C-206 has produced higher seed yield (3.40 t ha^{-1}) and oil concentration (42.84 %) than SF-100 during autumn season.

Reddy *et al.* (2002a) reported that sunflower hybrid KBSH-44 significantly produced higher yield and related growth attributes like plant height, leaf area, leaf area index, stem diameter and dry matter accumulation as compared to KBSH-1.

Reddy *et al.* (2002b) conducted an experiment to study the effect of fertilizer, gypsum and boron on dry matter accumulation, yield and nutrient content of Sunflower hybrids at Bangalore. Results indicated that increased dry matter accumulation in leaf ($18.37 \text{ g plant}^{-1}$), stalk ($49.04 \text{ g plant}^{-1}$) and head ($0.33 \text{ g plant}^{-1}$) was observed with KBSH-44 as compared to KBSH-1.

Sabale (2003) conducted field experiment to study the performance of sunflower cultivars (MSFH-1, MSFH-8, SS-56 and Morden) in *rabi* season. It was observed that greater 1000 seed weight (35.19 g), seed yield ($18.52 \text{ g plant}^{-1}$) and dry matter ($123.4 \text{ g plant}^{-1}$) was recorded in MSFH-8.

Pal (2004) carried out an field experiment at Pantnagar to evaluate sunflower cultivars for nutrient uptake and seed quality in spring season. Results indicated that the greater head diameter was noticed in No-3301 (21.23 cm) followed by MSFH-8 (21.13 cm) whereas, 1000 seed weight was found greatest in MSFH-8 followed by MSFH-999, MSFH-51 and No-6460.

Ekin *et al.* (2005) carried out a research to evaluate seed yield, oil yield and yield properties of some sunflower cultivars (NSH-1, NSH-712, NSH-43, NSH-111, TR-6149 and 64A52). Results concluded that TR-6149 had highest seed yield (3.96 and 2.38 ha^{-1} , respectively) and oil content (49.83 % and 50.20 %, respectively) in both years.

Bakht *et al.* (2006) studied the performance of various hybrids of sunflower in Peshawar valley and reported that DKS-4040 had highest number of seeds per head (1685), 100 seed weight (8.76 g) and seed yield (3389 kg ha^{-1}) as compared to G-101, Hysun-38, Mehran-11, SF-187, DKS-4040, Hysun-33, FH-106, FH-315, Bemisal-205 and Parsun-2.

Hakim *et al.* (2007) conducted experiment to study effect of sulphur and season on performance of sunflower hybrids. The study concluded that SAL-105 has produced the highest seed yield during spring and autumn season over Mehran-II, G-101 and Parsun-II.

Ceyhan *et al.* (2008) evaluated the response of sunflower genotypes (AS-615, S-288, Coban and TR-4098) to boron application. Results indicated that Coban has produced greater head diameter (14.8 cm), test weight (50.38 g) and boron concentration (80.72 mg kg⁻¹) as compared to other genotypes.

Pourdad and Beg (2008) compared sunflower hybrids and reported that NSH-213 has recorded the highest seed yield (2908 kg ha⁻¹) and head diameter (13 cm), whereas, VNIMK has recorded highest seed weight (46.6 g).

Parameswarappa and Lamani (2010) carried out a field trial to evaluate sunflower hybrids in late *kharif* and found that MSFH-51 recorded highest seed yield (2338 kg ha⁻¹) followed by MSFH-17 (2292 kg ha⁻¹), RSFH-213 (2280 kg ha⁻¹) and KBSH-1 (2217 kg ha⁻¹).

Alahdadi *et al.* (2011) evaluated the quantitative traits of sunflower hybrids viz., Azargol, Alstar, Hysun 33 and Hysun 25. Results indicated that Alstar hybrid has produced the highest seeds per head (771), 1000 grain weight (42.62 g), head diameter (13.30 cm), harvest index (32 %) and seed yield (1914 kg ha⁻¹). While, hybrid Azargol produced the greatest oil content (44.99 %) which was on par with Alstar (43.78 %).

Kaleem *et al.* (2011) evaluated sunflower hybrids viz., Alisson-RM, Parasio-24, MG-2 and S-278 for agronomic characters. They reported that hybrid MG-2 has recorded more number of seeds head⁻¹ (1182.5), biological yield (13980 kg ha⁻¹), seed yield (4360 kg ha⁻¹) and oil content (48.85 %) than other varieties grown during *kharif* season.

Kaya and Kolsarici (2011) evaluated the seed yield and oil content of sunflower viz., Sanbro, Tarsan-1018 and Ozdemirbey. Results indicated that Tarsan-1018 hybrid has produced significantly greater seed yield (3280 kg ha⁻¹) and oil content (54 %). While, hybrid Sanbro produced the lowest seed yield (3055 kg ha⁻¹) and oil content of 44.3 %.

Polat *et al.* (2011) from Turkey reported that hybrid P64A52 has produced more seed yield (10.6 %) over open pollinated cultivar GK-70 while, it was reverse for oil

percentage. While GK-70 has produced greater oil content (432 g kg⁻¹) as compared to P64A52.

Khan *et al.* (2012) evaluated sunflower hybrids on yield performance and results indicated that Hysun-33 has proved to be the best with maximum achene yield (2279 kg ha⁻¹), oil content (41.24 %), maximum protein percentage (26.76 %) than DK4040, Sunbred-265.

Zaidi *et al.* (2012) evaluated agronomic characteristics of different spring planted sunflower hybrids and results indicated that hybrid S-278 and Hysun-33 showed greater plant height (184.50 and 132.2 cm), head diameter (16.7 and 16.0 cm), seeds per head (1222 and 1212), 1000 seed weight (39.74 and 36.58 g) and seed yield (6.4 and 5.14 t ha⁻¹), respectively compared to other hybrids.

Ali *et al.* (2013) evaluated the growth and yield performance of various sunflower hybrids (Hysun-33, Hysun-38, S-278, SF-187, Pioneer-64A93FH-314 and FH-337). It was observed that hybrid S-278 had highest number of seeds per head (1980), head diameter (28.00 cm), 1000- seed weight and seed yield (2735 kg ha⁻¹) than rest of the hybrids.

Khan *et al.* (2013) compared the yield performance of sunflower hybrids under various agro-ecological conditions and reported that hybrid hysun-33 recorded the greater oil content and seed yield in addition to highest head diameter with 38.14 %, 3495 kg ha⁻¹ and 17.83 cm, respectively.

Sarwar *et al.* (2013) evaluated performance of various sunflower hybrids for yield and its related attributes. Twelve sunflower hybrids were G-101, DK-4040, SF-187, S-278, Hysun-33, FH-37, Ausigold-61, Ausigold-62, FSS-50, NX00989, NX-00997 and XIYU-12. It was observed that Hysun-33 had showed greater plant height (148.47 cm) and seeds per head (682.7) than rest of the hybrids. However, seed yield (3891 kg ha⁻¹) and other related traits such as leaf area index (4.33), head diameter (18.62 cm) and 1000-seed weight (49.11 g) was recorded higher in SF-187 over Hysun-33 for most of the traits.

Sheoran *et al.* (2014) conducted a field experiment to assess the genotypic variability for sustainable crop production in sunflower. The results indicated that sunflower hybrid PSH 569 produced significantly higher seed weight (59.2 g) and seed yield (2.06 t ha⁻¹) over SH 3322 and PSFH 118 hybrids.

Papatheohari *et al.* (2016) evaluated the growth, grain and oil productivity of three sunflower hybrids viz., PR64E83, Oleko and PR63A90. The results indicated that hybrid PR63A90 produced higher grain number per head (1545.19), grain yield (9910 kg ha⁻¹) and oil yield (3020 kg ha⁻¹) over other hybrids.

Khan *et al.* (2018) studied the agronomic and qualitative evaluation of different local sunflower hybrids i.e., twelve sunflower hybrids with two checks viz., SMH 1006, SMH 0907, SMH 0932, SMH 1208, NKS-278, SMH 1001, SMH 0917, SMH 1401, Hysun-33, SMH 0927, SMH 0909 and SMH 1215. Results reported that oil content (37.68 %) was significantly higher in SMH 1401 hybrid while the seed yield (2414.7 kg ha⁻¹) was highest in SMH 3932.

Ashraf *et al.* (2019) studied the physiological, morphological and qualitative traits of sunflower hybrids. They reported that hybrid Hysun-33 recorded higher number of achenes (1983.7), 1000-seed weight (54.633 g), biological yield (16357 kg ha⁻¹) and harvest index (23.16) over other hybrids.

Rajguru *et al.* (2019) reported that sunflower genotype Phule Bhaskar (1807 kg ha⁻¹) registered significantly higher oil content (37.9 %), 100 seed weight (5.2 g), seed yield (18.07 q ha⁻¹) and low hull content (24.4 %) with early maturity (85 days) over the check Bhanu, SS-56, LSF-8, Morden, Phule Raviraj, GK-2002 and TNAUSUF-7 genotypes.

2.2 Sunflower hybrids and planting density

Planting density is an important management factor in sunflower as well as other crops. The optimum plant density to attain highest yield may vary with the genotype and geographical location. The literature available on the effect of different plant densities on the growth, yield and economics of sunflower has been reviewed and presented below.

2.2.1 Sunflower growth and plant density

Legha and Giri (1999) revealed the results from two consecutive years of experimentation and stated that sunflower planted at 50 cm × 20 cm recorded greater dry matter production over 75 cm × 30 cm.

Kumar and Mohammad (2001) studied the influence of planting geometry at Hyderabad and observed that the higher leaf area per plant increased with increase of

every 15 cm row width from 30 cm to 90 cm. Highest leaf area per plant (2093 cm²) was observed under 90 cm inter row spacing and 20 cm intra row spacing.

Nawaz *et al.* (2001) recorded taller plants (164.8 cm) with inter row spacing of 30 cm compared in 45 cm wider rows (159.0 cm). Whereas, dry weight (146.8 g) was significantly higher at 60 cm row spacing.

2.2.2 Yield, yield attributes and plant density

Diepenbrock *et al.* (2001) studied the response of yield and quality traits of sunflower to row spacing and the results showed that achene yield (3.61 Mg ha⁻¹), 1000 achene weight (46 g) and biomass (12.72 Mg ha⁻¹) were significantly higher in 100 cm row spacing as compared to 75 cm and 50 cm.

Nawaz *et al.* (2001) at Pakistan studied the effect of row spacing (30, 45 and 60 cm) on sunflower and recorded significantly higher 1000 achene weight (37.81 g), number of seeds per head (1229.1) and seed yield (2066 kg ha⁻¹) of sunflower sown at 60 cm inter row spacing over narrow spacings of 30 and 45 cm.

Nayak *et al.* (2001) reported that row spacing at 45 cm recorded significantly higher seed yield over 60 cm. The average seed yield with 45 cm row spacing was 12.7 q ha⁻¹ as against 6.30 q ha⁻¹ with 60 cm row spacing, the reduction in yield due to wider spacing being 49 %. However, yield did not vary due to intra row spacing of 30, 25 and 20 cm under inter row spacing of 45 cm.

Patel and Thakur (2003) studied the effect of crop geometry on growth, yield and oil content of sunflower under clay loam soil of Chhattisgarh. Results indicated that crop geometry of 60 cm × 20 cm recorded significantly higher number of filled seeds per head (590), 1000-seed weight (49 g), seed yield (1371 kg ha⁻¹) and oil yield (551 kg ha⁻¹) of sunflower as compared to 40 cm × 30 cm and 50 cm × 20 cm.

Singh *et al.* (2003) studied the effect of plant spacing on growth and yield of sunflower hybrids at BHU farm, Varanasi. The results showed that spacing of 40 cm × 15 cm registered 63.4, 50.9 and 20.0 % higher seed yield over 70 × 20 cm, 60 × 20 cm and 50 × 15 cm, respectively.

Killi (2004) observed that at higher plant population (71420 plants ha⁻¹) sunflower variety P-6482 recorded significantly higher seed yield (5222 kg ha⁻¹) and oil yield (2157 kg ha⁻¹) over other plant populations *i.e.*, 35710 plants ha⁻¹ and 2800 plants ha⁻¹.

Shrikant *et al.* (2004) observed that row spacing had significant influence on the head diameter of sunflower. They found that reduced spacing from 60 cm × 20 cm to 45 cm × 30 cm significantly decreased the head size. Whereas, head diameter was recorded maximum under 60 cm × 20 cm during both the years of experimentation.

Sree and Sridhar (2004) opined that sunflower hybrid APSH-11 produced significantly higher oil yield (326 kg ha⁻¹) and seed yield (969 kg ha⁻¹) at 100 per cent plant population (60 × 30 cm) over 75 per cent and 200 per cent of recommended plant population. However, it was on par with 125 per cent plant population (45 × 30 cm).

Olowe (2005) conducted experiments to evaluate the response of sunflower to different plant population densities under rainfed condition. Three open pollinated varieties (Record, Isaanka and Funtua) were planted at 60 cm × 15 cm, 60 cm × 30 cm, 60 cm × 45 cm. The results showed that head diameter (12.3 cm), weight of achenes head⁻¹ (38.2 g), number of achenes head⁻¹ (485), 1000 seed weight (69 g) and seed yield (3 t ha⁻¹) were significantly higher with 60 cm × 45 cm planting geometry.

Jahangir *et al.* (2006) evaluated the effect of plant spacing (20, 25 and 30 cm) on the growth and yield of sunflower. They observed that the highest sunflower yield was obtained under a plant spacing of 20 cm. Whereas, Al-Thabet (2006) showed that spacing of 25 cm between rows recorded higher head diameter, seed yield ha⁻¹, seed oil percentage and oil yield ha⁻¹.

Ali *et al.* (2007) conducted an experiment to evaluate the effect of varying planting pattern on growth, seed yield and oil content of sunflower. The planting patterns were 45 × 10 cm, 45 × 20 cm, 45 × 30 cm, 60 × 10 cm, 60 × 20 cm, 60 × 30 cm, 75 × 10 cm, 75 × 10 cm and 75 × 10 cm. Results indicated that the yield attributes like seeds per head (1298), 1000-seed weight (51.52 g) and seed yield (3.76 t ha⁻¹) were maximum with 60 × 20 cm.

Beg *et al.* (2007) studied the row and plant spacing effects on agronomic performance of sunflower in warm and semi-cold areas with row spacings of 50 and 75 cm and intra row spacing of 20, 25, 30 and 35 cm. The highest yield of 1072 kg ha⁻¹ was obtained from spacing of 50 × 20 cm followed by 75 × 20 cm (972 kg ha⁻¹) and 50 × 35 cm (962 kg ha⁻¹).

Yasin *et al.* (2011) conducted an experiment to study the growth and yield response of autumn planted hybrid sunflower to varying planting densities in sandy clay

loam soils of Pakistan. Plants spaced at 60 × 25 cm recorded greater seed yield (2318 kg ha⁻¹) as compared to 75 cm × 20 cm (2281 kg ha⁻¹).

Rauf *et al.* (2012) conducted an experiment on yield and oil content of sunflower as influenced by spacing and observed that row spacing of 75 cm recorded greater 1000-achene weight (47.2 g), achene yield (2.97 t ha⁻¹) and biological yield (10.02 t ha⁻¹) than 60 cm of row spacing.

Baghdadi *et al.* (2014) reported that the higher seed yield (2498 kg ha⁻¹) and harvest index (18.93 %) were obtained from the 75 cm × 20 cm spacing over 65 cm × 23 cm, 50 cm × 30 cm and 35 cm × 43 cm.

Khan and Akmal (2016) conducted an experiment to evaluate the effect of planting geometry on yield and yield contributing traits of sunflower hybrid Hysun-33. The planting geometries were 70 cm × 20 cm and 90 cm × 15.5 cm and it was observed that biomass yield (10961 kg ha⁻¹), grain yield (2815 kg ha⁻¹) and oil content (4.44 g kg⁻¹) were found significantly higher at 90 cm × 15.5 cm as compared to 70 cm × 20 cm.

2.2.3 Seed quality and plant density

Reddy and Reddy (2005) carried out an experiment and found that KBSH-1 sown at 45 cm × 25 cm recorded highest seed oil content of 42.62 %.

Ali *et al.* (2007) evaluated the effect of varying planting pattern on growth, seed yield and oil content of sunflower. The planting patterns were 45 cm × 10 cm, 45 cm × 20 cm, 45 cm × 30 cm, 60 cm × 10 cm, 60 cm × 20 cm, 60 cm × 30 cm, 75 cm × 10 cm, 75 cm × 20 cm and 75 cm × 30 cm and reported that the oil content (42.25 %) was maximum with 60 × 20 cm as compared to other treatments.

Kumar *et al.* (2011) studied the effect of row spacings (30, 45 and 60 cm) on growth, yield and quality of spring sunflower. The results revealed that oil content and oil yield were significantly higher at a spacing of 45 × 30 cm. Oil content was increased by 6.2 and 6.0 %, oil yield by 1.2 and 18.1 % over 30 × 30 cm spacing over rest of spacing combinations during 2004 and 2005, respectively.

2.2.4 Nutrient content and uptake in different plant density

Sen *et al.* (2002) studied the effect of planting density on yield attributes, yield and nutrient uptake of restorer lines of sunflower. The trial included four spacings of 40

cm × 15 cm, 50 cm × 15 cm, 60 cm × 20 cm and 70 cm × 20 cm. The results indicated that maximum N, P, K and Boron content of seed and stalk of the sunflower was with wider plant spacing of 70 × 20 cm due to higher individual biomass production.

2.2.5 Economics and plant density

Shrikant *et al.* (2004) studied the effect of higher fertility levels combined with farmyard manure and row spacing on seed yield, oil yield and economics of sunflower. Results indicated that higher net returns (12,358 ha⁻¹) from the sunflower crop was obtained at 45 cm × 30 cm over 60 cm × 20 cm spacing (10,719 ha⁻¹).

Kumar *et al.* (2012) reported that the maximum gross returns (Rs. 22704 and Rs. 22720 ha⁻¹), net returns (9802 and 9818 Rs. ha⁻¹) and benefit cost ratio (1.75 and 1.76) was obtained with medium spacing of 45 cm × 30 cm during 2004 and 2005 years, respectively as compared to closer spacing of 30 cm × 30 cm and wider spacing of 60 cm × 30 cm.

2.3 Effect of rate of fertilizer application

Balanced fertilization has been found to be essential for sunflower growth and yield. The literature available on the effect of different level of fertilizers on the growth, yield and quality parameters, nutrient uptake and economics of sunflower cultivation has been reviewed and presented below.

2.3.1 Effect on growth and growth attributes

Kumar *et al.* (1991) worked in slightly alkaline deep black cotton soil observed that plant height at maturity was significantly affected by different levels of N, P and K over control. Maximum plant height (139.7 cm) was recorded with the application of 150 % RDF which was statistically at par with 100 % RDF (136.4 cm) but significantly superior over 50 % RDF (117.3 cm) and control (104.9 cm).

Sarmah *et al.* (1992) reported that each higher level of fertilizer significantly increased the dry matter accumulation at all stages and significant response was obtained up to 80 kg N + 40 kg P₂O₅ ha⁻¹. Similar results on dry matter accumulation with N application were reported by Kumar and Reddy (1997) and Legha and Giri (1999).

Nawaz *et al.* (2003) conducted an experiment to determine N, P and K requirements of sunflower with four levels each of N (0, 60, 120 and 180 kg ha⁻¹), P₂O₅

(0, 30, 60 and 90 kg ha⁻¹) and K₂O (0, 60, 120 and 180 kg ha⁻¹). Plant height (1.653 m) and number of leaves (28.33) was significantly higher with the application of 120-90-60 NPK kg ha⁻¹.

Sabale (2003) studied the response of sunflower cultivars to fertilization in *rabi* season. Results indicated that the application of 90 kg N + 45 kg P₂O₅ recorded significantly taller plants (194.5 cm), number of leaves (26.5), leaf area (2.86 cm²) and dry matter per plant (124.28 g) which was on par with application of 60 kg N + 30 kg P₂O₅ ha⁻¹ and superior over other treatments.

Kadasiddappa *et al.* (2007) studied the effect of fertilizer on growth, yield and economics of sunflower and reported that plant height at maturity was significantly influenced by different levels of N, P and K over control and the maximum plant height (142 cm) was recorded with the application of 150:100:100 kg N, P₂O₅, K₂O ha⁻¹.

Pavani *et al.* (2012) conducted an experiment on response of sunflower to different levels of nitrogen (60, 90 and 120 kg N ha⁻¹) during *kharif* on sandy loam soils of Hyderabad. They observed significantly higher plant height, LAI and head diameter with the application of 120 kg N over corresponding lower dose of 60 and 90 kg N ha⁻¹.

Banerjee *et al.* (2014) conducted a field experiment to study the productivity and profitability of spring planted sunflower hybrid with nitrogen, phosphorus and potassium fertilizer. The treatments comprised of NPK doses viz., farmer's fertilizer practice (60:30:30 kg NPK ha⁻¹), 100 % RDF (80:40:40 kg NPK ha⁻¹), 125 % RDF, 125 % PK, 125 % NK and 125 % NP. Results showed that application of 125 % RDF recorded maximum plant height (104.7 and 127.7 cm), dry matter production (74.38 and 99.79 g plant⁻¹) and leaf area index (1.73 and 1.51) at 50 and 100 DAS, respectively but it was statistically on par with 100 % RDF.

2.3.2 Yield, yield attributes and fertilizer application

Jat and Giri (2000) reported that yield attributes, seed and oil yield of sunflower increased with successive graded N up to 100 % RDF.

Angelova (2001) found that application of N @ 120 kg ha⁻¹ recorded 5.8 per cent higher seed yield as compared to 60 kg N ha⁻¹. While, Farghly (2001) reported that seed yield of sunflower fertilized with 75 kg N ha⁻¹ registered 6.3 and 13.3 per cent increase over 60 and 45 kg N ha⁻¹, respectively.

Taha *et al.* (2001) worked on effect of irrigation and N on yield and yield attributing characters of sunflower. Results indicated that application of 90 kg N ha⁻¹ recorded significantly higher capitulum diameter (14.6 cm) which was significantly superior over 60 kg N ha⁻¹.

Ayyappan *et al.* (2002) observed that higher head diameter, 100-seed weight and seed yield with the application of 120 and 150 kg N ha⁻¹. While, N @ 120 kg ha⁻¹ obtained higher seed oil content, whereas, N at 150 kg ha⁻¹ recorded highest seed protein content. Thus, 120 kg N ha⁻¹ was optimum for higher sunflower yield as well as oil content.

Poonguzhalan *et al.* (2002) reported that application of 100 % RDF (37.5, 50 and 37.5 kg NPK ha⁻¹) on red sandy loam soils at Bangalore registered the higher seed yield (11.82 q ha⁻¹) and stalk yield (13.03 q ha⁻¹) as compared with 75 % and 50 % RDF in sunflower.

Reddy *et al.* (2002a) conducted a field experiment with sunflower hybrid KBSH-44 and KBSH-1 at Bangalore during *kharif* with different fertilizers. Results indicated that the seed and stalk yield increased with graded fertilizer levels. Application of 125 % RDF recorded significantly highest yield of 2102 kg ha⁻¹ and was on par with 125 % RDF + 500 kg gypsum ha⁻¹.

Reddy *et al.* (2003) studied the effect of nutrients and moisture conservation practices on growth and yield of sunflower. Results indicated that higher seed yield was obtained with the application of 35:50:35 kg N:P:K ha⁻¹ at Raichur during *rabi* season which was 53.5 % higher over farmer's practice (17.5:25:17.5 kg N:P:K ha⁻¹).

Thavaprakash *et al.* (2003) studied the effect of different N:P ratios on the seed yield and nutrient uptake of the sunflower. It was observed that N:P at 2:1.25 and 2:2 ratios resulted in 21 and 27 per cent increase in the seed yield of sunflower over N:P of <1.

Chitale *et al.* (2004) studied the effect of higher fertility levels on seed yield and economics of sunflower and reported that the application of 150 % RDF recorded higher head diameter (14.8 and 14.5 cm) and seed yield (1758 and 1740 kg ha⁻¹) during 2000 and 2001, respectively compared to 100 % RDF.

Malik *et al.* (2004) studied the levels of N, P and K on yield and yield components of sunflower with three N levels (0, 110, and 130 kg ha⁻¹), four P levels (0, 70, 90 and 110 kg ha⁻¹) and four K levels (0, 70, 90 and 110 kg ha⁻¹). The results reported that increased levels of NPK increased sunflower yield and yield components but decreased the seed oil content. Although the highest seed yield was recorded when fertilized with 130-90-90 NPK kg ha⁻¹.

Jahangir *et al.* (2006) evaluated the response of nitrogen (80, 100 and 120 kg ha⁻¹) and phosphorus (45, 60 and 75 kg ha⁻¹) on growth and yield of sunflower. Maximum number of seeds per head (339.8), 100 seed weight (5.73 g), head diameter (13.2 cm) and seed yield (2.08 t ha⁻¹) was recorded with application of 120 kg N + 75 kg P₂O₅ ha⁻¹.

Reddy *et al.* (2007) evaluated the productivity of sunflower, as influenced by site specific integrated nutrient management in *Alfisols* and maximum seed yield (1297 kg ha⁻¹) and oil yield (424 kg ha⁻¹) was recorded with application of 50 % NPK + 50 % N through FYM which was comparable with the application of 100 % NPK.

Girme (2009) studied the effect of fertilizers on yield and quality of sunflower hybrids. Results indicated that the application of 125 % RDF recorded significantly higher seed yield (1644 kg ha⁻¹) than the 75 % and 100 % RDF.

Gudade *et al.* (2009) conducted an experiment at Akola to study the response of new sunflower varieties to fertilizer levels. It was observed that seed yield obtained with 150 % RDF (120:90:00 NPK kg ha⁻¹) was significantly higher than lower levels which offered a yield advantage of 28.07 and 15.36 % over 50 % and 100 % RDF, respectively.

Sarkar and Mallick (2009) studied the effect of N on sunflower and reported that application of 120 kg N ha⁻¹ increased growth parameters, yield attributes and seed yield by 20 % over 60 kg N ha⁻¹.

Siddiqui *et al.* (2009) studied the effect of N, P and K on sunflower and reported that all yield attributes increased as the dose of fertilizers increased. Largest head diameter, higher number of seeds head⁻¹, higher seed yield (1738.0 kg ha⁻¹) were recorded by application of 90:45:45 kg NPK ha⁻¹ as compared to 60:30:30 kg NPK ha⁻¹.

Muraliathanari *et al.* (2009) studied the effect of sunflower nutrient management practices viz., No manure control (NM₁), 100 % RDF (40:20:20 NPK kg ha⁻¹) through inorganic (NM₂), 75 % of RDF through organic + 25 % through inorganic (NM₃), 50 %

of RDF through organic + 50 % through inorganic (NM₄) and 25 % of RDF through organic + 75 % through inorganic (NM₅) were assigned to subplot. It was observed that the application of 100 % RDF through inorganic fertilizer recorded higher head diameter (14.22 cm), higher number of seeds head⁻¹ (542), 100 seed weight (5.97 g) and higher shelling percentage (87.3 %).

Yadav *et al.* (2009) studied the effect of nutrient levels on productivity and profitability of sunflower. The results revealed that nutrient management with 125 % RDF (75:40:41.5 kg NPK ha⁻¹) recorded significantly higher seed yield (1.76 t ha⁻¹), stalk yield (6.56 t ha⁻¹), N, P and K uptake, net income and B:C ratio over the other treatments.

Pavani *et al.* (2012) conducted an experiment on response of sunflower to different levels of nitrogen (60, 90 and 120 kg N ha⁻¹) on sandy loam soils of Hyderabad and they observed that application of 120 kg N ha⁻¹ recorded significantly higher number of filled seeds head⁻¹ (783), seed yield (2108 kg ha⁻¹) and harvest index (34.1 %) over 60 and 90 kg N ha⁻¹.

Suryavanshi *et al.* (2012) studied the effect of yield and economics of sunflower hybrids and varieties as influenced by different fertilizer levels at Latur during rainy season of 2008, 2009 and 2010. Pooled results indicated that 150 % RDF (90:45:45 kg NPK ha⁻¹) recorded significantly higher seed yield over 100 %, 50 % RDF and control.

Olowe *et al.* (2013) revealed that application of nitrogen at 60 and 90 kg N ha⁻¹ significantly increased head weight, head diameter, achene weight per head, number of achene per head and seed yield (1956.0 kg ha⁻¹) as compared to the control, but these growth and yield characters were not affected significantly by P application.

Ullasa *et al.* (2013) evaluated the best management practices for higher yields in sunflower at GKVK, Bengaluru. The results revealed that application of 133 % RDF (120: 120: 80 kg N, P₂O₅, K₂O ha⁻¹) recorded higher seed yield (2478 kg ha⁻¹), head diameter (17.3 cm), test weight (5.95 g) which was statistically at par with 100 % RDF (90: 90: 60 kg N, P₂O₅, K₂O ha⁻¹).

Ali *et al.* (2014) studied the effect of different levels of N and P fertilization on yield and nutrient content of irrigated hybrid sunflower. It was observed that application of N @ 80 kg ha⁻¹ and P @ 100 kg ha⁻¹ resulted in an increased seed yield.

Waqas *et al.* (2017) studied the effect of fertilizers on growth, yield and quality of hybrid sunflower. Results indicated that higher seed yield (2955.5 kg ha⁻¹), biological yield (12857 kg ha⁻¹), 1000-seed weight (64.9 g), head diameter (31.1 cm), plant height (157.7 cm) were recorded with application of 50:90:60 kg NPK ha⁻¹.

Chantal *et al.* (2018) studied the effect of different nitrogen fertilizer levels on sunflower growth and yield attributes. The results reported that application of NPK at the rate of 100-50-30 kg NPK ha⁻¹ significantly improved and enhanced sunflower head diameter (54.87 cm) and grain yield (2886.1 kg ha⁻¹).

2.3.3 Nutrient uptake and fertilizer application

Thavaprakash and Malligawad (2002) studied the effect of NP levels and ratios on yield and economics of sunflower. It was reported that application of N:P at 2:2 ratio resulted in greater uptake of N (186.27 kg ha⁻¹), P (27.78 kg ha⁻¹) and K (126.68 kg ha⁻¹) by sunflower.

Reddy *et al.* (2007) evaluated the productivity and nutrient uptake of sunflower as influenced by site specific integrated nutrient management in *Alfisols*. It was revealed that the greater uptake of NPK @ 52.9, 15.0 and 51.0 kg ha⁻¹, respectively by application of 100 % NPK, which was comparable with the application of 50 % N rest of N equivalent to FYM.

Gudade *et al.* (2009) evaluated the response of new sunflower varieties to fertilizer levels and found significant increase in total uptake of N, P and K by application of fertilizer at 150 % RDF (120:90:00 kg NPK ha⁻¹). The magnitude of increase in uptake of N, P and K were 42.93, 30.74 and 21.72 % by application of 150 % RDF over 100 % RDF.

Jogdand (2010) studied the effect of different levels of fertilizer doses on growth, uptake and yield of sunflower. It was revealed that the application of 100 % RDF (60:30:30 kg NPK ha⁻¹) significantly improved uptake of nutrients at all the stages of sunflower.

Zubillaga *et al.* (2010) evaluated the effect of varying levels of P and N as well as the interaction of P × N on the nutrient uptake and yield of sunflower. It was observed that the higher yield and N uptake was recorded by application of 92:12 kg NP ha⁻¹.

Dev (2012) studied the effect of nutrient and hybrids on growth and yield of sunflower and reported that application of 100 % RDF + B + S resulted in higher nutrient uptake of N and P over 75 % RDF. While, highest K uptake was noticed in 150 % NPK.

2.3.4 Quality parameters of sunflower hybrids and fertilizer application

Parameswari *et al.* (2012) reported that significantly maximum seed, stalk yield, harvest index and oil yield were observed with the application of 120 kg N ha⁻¹ and lowest in 60 kg N ha⁻¹. Whereas, highest oil content was recorded by 60 kg N ha⁻¹ (40.3 %) and lowest in 120 kg N ha⁻¹ (38.0 %).

Malihe *et al.* (2013) studied the effect of different doses of N and K on yield and yield components of sunflower. The results showed that the application of 225 kg N ha⁻¹ and 150 kg K₂O ha⁻¹ recorded significantly higher biological yield, seed yield and oil content.

Ullah and Akmal (2018) studied the response of sunflower to nitrogen and phosphorus and reported that application of 120 kg ha⁻¹ nitrogen and 90 kg ha⁻¹ phosphorus recorded highest oil content and protein content than 80 kg ha⁻¹ nitrogen, 60 kg ha⁻¹ phosphorus and 40 kg ha⁻¹ nitrogen and 30 kg ha⁻¹ phosphorus.

2.3.5 Economics

Prasad *et al.* (1999) recorded maximum net returns with the application of 40 kg N ha⁻¹. Further, increased level of 60 kg N ha⁻¹ reduced net returns significantly in the first year while during second year it was at par with 40 kg N ha⁻¹.

Rehman (2002) has worked out optimum N, P and K fertilizers for greater economic returns of sunflower and reported that application of fertilizers of 110:70:00 kg NPK ha⁻¹ seemed to be appropriate level for getting maximum yield and quality of sunflower. While, Thavaprakash and Malligawad (2002) stated that application of 120:120:60 kg NPK ha⁻¹ was found to enhance yield and economics. Malik *et al.* (2004) opined that application of 110-70 kg N and P was found to be sufficient to get higher yield and net returns.

Dev (2012) reported that application of 150 % NPK has resulted greater gross returns, net returns and cost-benefit ratio over 75 %.

2.4 Interaction effect of species, plant density and fertilizer rate

Tenebe *et al.* (1996) studied the interaction effect of N and plant population on the growth and yield of sunflower. Results indicated that seed yield was greatest by application of 100 kg N ha⁻¹ at 80,000 plants ha⁻¹. El-Karamity and El-Sergy (1997) at Egypt, evaluated the response of sunflower genotypes (Hysn, G.101 and Pioneer 6480) grown at 50, 60 and 70 cm row spacing. The results showed that significant increase in plant height, head diameter, weight of seeds per head, 100-seed weight, seed and oil yield. While, seed oil percentage was significantly increased with increased row spacing up to 60 cm gave the highest seed and oil yield fed⁻¹ followed by 70 cm apart.

Ahmad *et al.* (2001) evaluated sunflower hybrids (SF-100 and C-206) to potassium application in spring and autumn seasons. Hybrid SF-100 has produced significantly higher seed yield ha⁻¹ over C-206 during spring while in autumn SF-100 has produced significantly lower seed yield than C-206.

Pal (2002) evaluated sunflower hybrids MSFH-8 and variety Morden at different plant densities. Results revealed that both MSFH-8 and Morden recorded highest seed yield at 83,000 plants ha⁻¹ and lowest at 44,000 plants ha⁻¹. However, MSFH-8 (42.1 %) gave higher seed yield at all plant densities than Morden.

Allam *et al.* (2003) evaluated the response of sunflower hybrids (Vidoc and Euroflora) to planting densities (55,533, 83,300 and 166,600 plants ha⁻¹). The results indicated that the highest seed yield (3.64 t ha⁻¹) was produced by Vidoc. In addition, the results also revealed that the increased plant density increased the seed yield (4.47 t ha⁻¹) and oil yield. In contrast, the stem diameter, head diameter, 100-seed weight and seed yield per plant were decreased by increased plant density.

Mojiri and Arzani (2003) studied the effect of nitrogen rate and plant density on yield and yield components of sunflower with levels of nitrogen (0, 75, 150, and 225 kg ha⁻¹) and plant densities (65000, 75000, 85000 and 95000 plants ha⁻¹). Higher grain and oil yield were obtained with application of 150 kg N ha⁻¹ at plant density of 85000 plants ha⁻¹.

Poonia (2003) revealed that tested hybrid recorded highest leaf area index (2.11) at 60 cm × 30 cm. Whereas, dry matter, crop growth rate and net assimilation rate were

highest at 45 cm × 30 cm. Jahangir *et al.* (2006) also opined that 20 cm plant spacing was found optimum along with 120:75 kg N P₂O₅ ha⁻¹ produced larger head diameter (14.5 cm) and seed yield (2.55 t ha⁻¹).

Greater seed yield (3023 kg ha⁻¹) and highest net returns (Rs.19743) was realized at 120:90:60 kg NPK ha⁻¹ for FH-314 hybrid (Iqbal *et al.*, 2008). In another study, Ishfaq *et al.* (2009) reported that hybrid Hysun-33 at 75 cm row spacing produced significantly higher head diameter, number of achenes and 1000 achene weight as compared to SF-187 at 45 cm and 60 cm row spacing.

Abdel-Motagally and Osman (2010) sunflower hybrid Sakha-53 with application of 142:114 kg N and K ha⁻¹ produced significantly higher plant height, stem diameter, 100-seed weight, seed yield per plant, seed and oil yield.

Bakht *et al.* (2010) reported that maximum seed yield (2813 kg ha⁻¹) was recorded by Parsun-1 with application of 150:100:100 kg NPK ha⁻¹. It also recorded higher leaf area index (LAI), crop growth rate (CGR) and dry matter accumulation (DMA).

Sunflower sown at 60 cm × 30 cm along with the application of 125 % RDF (100:62.5:37.5 kg N:P₂O₅: K₂O ha⁻¹) was found to be the best package of agro-techniques for *rainfed* sunflower for realizing higher productivity and economic returns (Joythi *et al.*, 2011). Whereas, Khakwani *et al.* (2014) also reported taller plants (162.88 cm), higher seed yield (4645.8 kg ha⁻¹), biomass production (19736 kg ha⁻¹) and the benefit-cost ratio (3.9) was obtained by application of 150:120:100 kg NPK ha⁻¹ and planting density of 11.11 plants m⁻².

For sunflower hybrid S-278 plant spacing 60 cm × 20 cm with 125 kg N was found optimum to realize higher yield (Ali *et al.*, 2012). Nasim *et al.* (2012) reported that application of 180 kg N ha⁻¹ for Hysun-38 gave significantly higher grain yield and maximum dry matter production.

Ibrahim (2012) revealed that the hybrid (Record) gave the highest values for leaf area (0.56 cm²), head diameter (33.9 cm), 1000 seed weight (80.82 g), seed oil percentage (45.9 %) and total oil production (1.23 t ha⁻¹) at the lowest plant density of 45000 plants ha⁻¹, whereas, it gave the highest values for total dry matter production (16.3 t ha⁻¹), seed yield (3.6 t ha⁻¹) and total oil yield (1.23 t ha⁻¹) at 75000 plants ha⁻¹.

For hybrid Hysun-33 plant spacing of 75 cm x 20 cm and application of 150-105 N-P kg ha⁻¹ recorded higher seed yield, number of seeds head⁻¹, 1000-achene weight, biological yield and harvest index under irrigated condition (Yasin *et al.*, 2013). In another study Awais *et al.* (2015) reported that application of 150 kg N ha⁻¹ with 83,333 plants ha⁻¹ for same hybrid recorded higher seed yield.

Nasim *et al.* (2016) estimated the correlation between yield and growth parameters of sunflower hybrids. It was concluded that among the sunflower hybrids, Hysun-33 excelled in productivity and seed oil content with the application of 180 kg N ha⁻¹.

Ravichandran and Srinivasan (2017) observed that the yield parameters viz., head diameter (32.2 cm), seeds per head (1499), head weight (24.6 g), seed volume weight (42.1 g) and seed yield (2041 kg ha⁻¹) were significantly higher under 60 cm × 30 cm spacing along with 100 % RDF.

MATERIAL AND METHODS

III. MATERIAL AND METHODS

A field experiment on “**Effect of planting density and fertilizer rate on performance of newly developed sunflower hybrids (*Helianthus annuus* L.)**” was conducted during *kharif*, 2019 at Main Agricultural Research Station, UAS, Raichur. The details of the experimental material used and methods adopted in the present investigation are elucidated in this chapter under appropriate heads.

3.1 Location of the experimental site

The present investigation was carried out at Plot number 18 of Main Agricultural Research Station, UAS, Raichur during *kharif*, 2019. Raichur is situated in North Eastern Dry Zone (Zone-2) of Karnataka at 16° 15' N latitude and 77 ° 20' E longitude with an altitude of 389 meters above mean sea level.

3.2 Climatic conditions

The mean monthly meteorological data for the crop period from July to November, 2019 and the average for the past 87 years recorded at the meteorological observatory located at one kilometer distance from experimental site is presented in Table 1 and shown in Fig. 1.

3.3 Soil characteristics

The soil of the experimental site was clay in texture. Representative soil samples from the experimental site were collected to a depth of 30 cm before sowing of the crop. The samples were air-dried, powdered and allowed to pass through 2 mm sieve and were analyzed for physico-chemical properties. The values obtained along with the method of determination are presented in Table 2. The soil was clay in texture with a pH of 7.60, electrical conductivity of 0.23 dS m⁻¹ and bulk density of 1.30 Mg m⁻³. The soil was medium in organic carbon status (0.62 %), low in available nitrogen (200.48 kg ha⁻¹), medium in phosphorus (21.42 kg ha⁻¹) and potassium (232.56 kg ha⁻¹).

3.4 Experimental details

The details of the experiment are given below

Table 1. Mean monthly meteorological data for the year 2019 and mean of the last 87 years (1932-2018) at Main Agricultural Research Station, Raichur

Month	Rainfall (mm)		Temperature (°C)				Relative Humidity (%)		
			Maximum		Minimum				
	1932-2018	2019	1932-2018	2019	1932-2018	2019	1932-2018	2019	
								RH I	RH II
January	3.77	10.00	30.87	29.95	19.56	16.32	62.19	69.54	41.00
February	0.77	0.00	33.60	33.89	21.68	20.35	60.09	62.78	42.00
March	26.69	0.00	36.62	38.14	22.60	23.90	64.88	53.80	23.00
April	48.67	13.50	38.86	40.75	23.99	26.23	60.95	50.00	19.00
May	49.23	10.40	39.60	41.38	24.78	27.56	63.97	52.83	19.00
June	63.18	67.00	36.44	37.30	24.01	25.20	71.04	75.10	37.80
July	90.69	79.60	34.44	34.60	22.73	22.70	75.08	81.80	47.30
August	170.42	46.00	33.36	32.80	22.02	23.70	77.08	83.80	48.80
September	193.63	312.20	33.99	31.70	20.77	23.10	80.00	89.10	59.10
October	72.60	130.40	32.28	30.60	20.42	22.80	74.96	91.30	64.00
November	11.48	0.00	31.40	31.10	18.98	20.80	67.99	85.90	50.20
December	3.86	0.00	30.57	29.90	18.62	19.00	68.11	83.20	47.00
Total	734.99	669.1	-	-	-	-	-	-	-

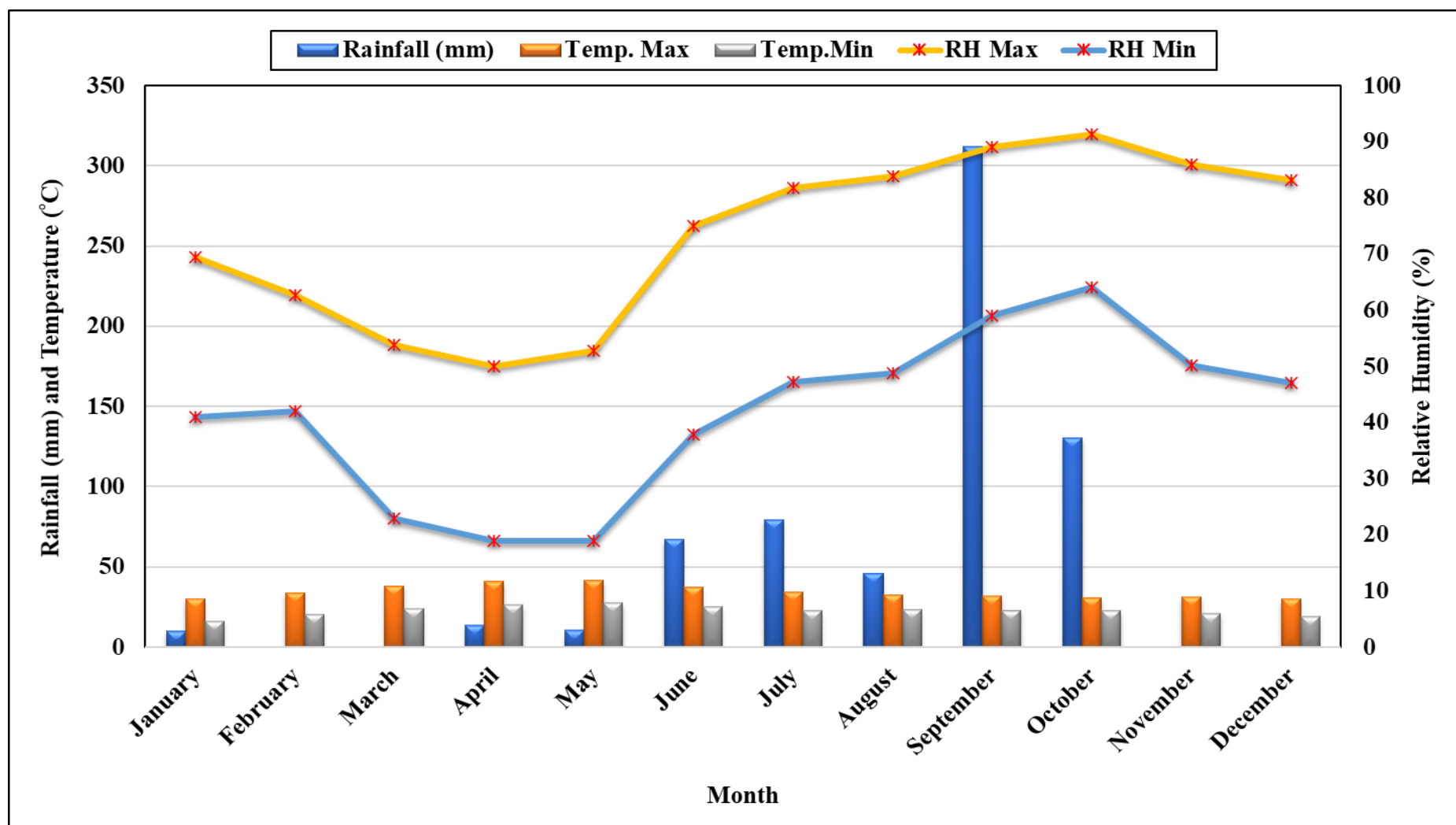


Fig. 1. Mean monthly meteorological data for the experimental year 2019 at Main Agricultural Research Station, Raichur

Table 2. Physical and chemical properties of the soil in experimental site

Properties	Values	Method
I. Physical properties		
1. Particle size analysis		
Sand (%)	24.40	International pipette method (Piper, 1966)
Silt (%)	25.00	
Clay (%)	50.60	
2. Bulk density (Mg m ⁻³)	1.30	Core sampler method (Dastane, 1967)
3. Soil texture	Clay	
II. Chemical properties		
Soil pH	7.60	pH meter (Piper, 1966)
Electrical Conductivity (dS m ⁻¹)	0.23	Conductivity bridge (Piper, 1966)
Organic carbon (%)	0.62	Walkely and Black’s wet oxidation method (Jackson, 1973)
Available nitrogen (kg ha ⁻¹)	200.48	Alkaline permanganate method (Subbiah and Asija, 1956)
Available phosphorus (kg ha ⁻¹)	21.42	Olsen’s method (Jackson, 1973)
Available potassium (kg ha ⁻¹)	232.56	Flame Photometry method (Jackson, 1973)

3.4.1 Treatment details

Main plots: Hybrids (H)

H₁: RSFH 12-700

H₂: RSFH 12-705

H₃: RSFH 1887

Sub plots: Spacings (S)

S₁: 60 cm × 30 cm

S₂: 75 cm × 30 cm

Sub-sub plots: Fertilizer levels (F)

F₁: 100 % RDF

F₂: 125 % RDF

F₃: 150 % RDF

RDF: Recommended Dose of Fertilizer (90:90:60 kg NPK ha⁻¹)

3.4.2 Design and layout

The treatment combinations were laid out in split-split plot design with three replications. The plan of layout is shown in Fig. 2.

3.4.3 Plot size

Gross plot : 7.2 m × 3.9 m = 28.08 m²

Net plot : 6.0 m × 2.7 m = 16.20 m²

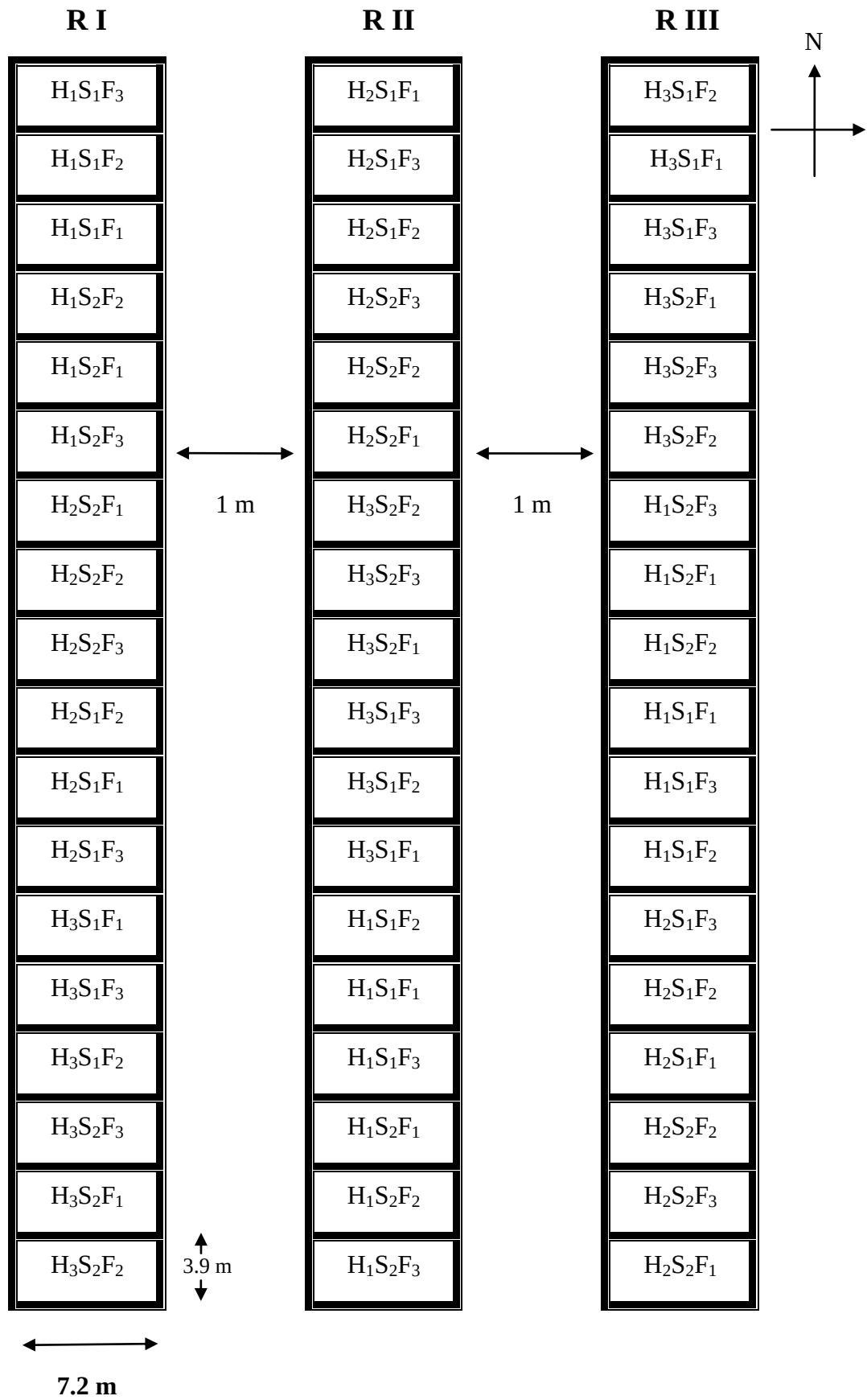


Fig. 2. Plan of layout of the experiment



Plate 1. General view of experimental site

3.5 Agronomic practices

The land was ploughed with tractor after harvest of the previous crop and harrowed twice to crush the clods. Stubbles and weeds were removed from the experimental area and the soil was brought to fine tilth. Before sowing, the plots were laid out as per the plan and small bunds were formed around each plot. Each plot was levelled in order to avoid stagnation of water within the plot.

Certified seeds were used for sowing. The crop was sown on 27th August, 2019. Two seeds per hill were hand dibbled at 30 cm distance between two hills in a row. To ensure uniform stand and to maintain required plant population, gap filling was done at 13 days after sowing (DAS). Single plant per hill was retained after thinning. Hand weeding was done at 20 and 40 days after sowing to avoid crop weed competition. Two intercultivations were taken up with the help of blade hoe at 30 DAS. Plant protection measures were followed with lamda cyhalothrin @ 1 ml per liter of water for the control of insect pest of crop. For the management of Alternaria leaf spot spraying of hexaconazole @ 1 ml/l of water was applied. Suitable measures were taken to avoid bird damage to crop. The crop was harvested at physiological maturity when the outer bracts of the flower heads turned to brown, back of the heads turned to lemon yellow and when the seeds were easily detachable. The heads were harvested first from the border rows followed by net plots. The heads were sun dried and then threshed manually to separate the seeds. The threshed produce was winnowed and seed yield from each plot was recorded after drying. The stalks after cutting to the ground level were left in the field for drying until they attained a constant weight and later the dry weights were recorded.

3.6 Growth observations recorded

Biometric observations on the morpho-physiological parameters at different stages were taken on five representative randomly tagged plants in each plot and the mean values were presented. These observations were made at 30, 60 DAS and at maturity. The destructive samples included five plants taken from each plot for recording dry matter of leaves, stem and head separately.

Plant height (cm) was measured using a linear meter scale from base of the plant to the apex of the terminal bud or head of the tagged plants at 30, 60 and at maturity. The

number of functional green leaves were counted and recorded from the tagged plants at 30, 60 and at maturity.

The leaf area was worked out by disc method on dry weight basis at 30, 60 DAS and at maturity as per the procedure suggested by Vivekanandan *et al.* (1972). The average leaf area was expressed in cm² plant⁻¹.

$$LA = \frac{W_a \times A}{W_d}$$

Where,

LA = Leaf area (cm² plant⁻¹)

W_a = Oven dry weight of all leaves (inclusive of 10 discs weight)

W_d = Oven dry weight of 10 discs in g

A = Area of the 10 discs (cm²)

Leaf area index

Leaf area index (LAI) was worked out by dividing the leaf area per plant by land area occupied by the plant.

$$LAI = \frac{A}{P}$$

Where,

A = Leaf area plant⁻¹ (cm²)

P = Land area occupied by the plant⁻¹ (cm²)

Relative chlorophyll content (SPAD readings)

The relative chlorophyll readings were taken on five plants on 10 leaves at 30, 60 and at maturity using SPAD and the average values were presented. The instrument measures transmission of red light at 650 nm at which chlorophyll absorbs light, and transmission of infrared light at 940 nm, at which no absorption occurs. Before the measurement, instrument is calibrated - transmission is measured with no leaf inside. Thus, when a leaf is clamped by the meter, a certain portion of red light is absorbed and

the meter can calculate a relative value (in SPAD, from Soil Plant Analysis Development, unit), showing how green the leaf is. Basically, SPAD value correlates with actual chlorophyll content in the leaf.

Normalized differential vegetation index (NDVI)

It was estimated by using hand held green seeker model 505 (NTech industries Inc.). The NDVI values of each treatment was estimated. NDVI stands for Normalized Difference Vegetation index and it is the “sensor” value displayed on the optical sensor. This indicates photosynthetically active radiation (PAR) absorbed by plant and also indicating healthiness of plant. NDVI values computed by the following formula.

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

Where, NIR and Red represent reflectance in the near infrared and red bands, respectively.

Dry matter accumulation was recorded at 30, 60 and at maturity from the destructive samples. Five plants from each plot were cut from the base at each interval and separated into leaf, stem and head. They were shade dried and later oven dried at 65°C to constant weight. Dry weight of leaf, stem and head was recorded separately and expressed in g plant⁻¹.

Physiological parameters like crop growth rate (CGR), relative growth rate (RGR), leaf area duration (LAD) and net assimilation rate (NAR) were calculated at 30, 60 DAS and at harvest based on dry weights and leaf area values.

Crop growth rate (CGR)

Crop growth rate (CGR) is defined as the rate of dry matter production per unit land area per unit time. It was worked out by using the formula

$$\text{Crop growth rate (g m}^{-2} \text{ day}^{-1}) = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{1}{P}$$

Where, W_1 and W_2 are whole plant dry weights in grams at times t_1 and t_2 , respectively in days and P is the ground area (m²) and expressed in g m⁻² day⁻¹.

Relative growth rate (RGR)

The relative growth rate of a plant at time instant (t) is defined as the increase of plant material per unit material initially present per unit of time and is mathematically expressed (Hunt, 1978) as shown below.

$$\text{Relative growth rate (g g}^{-1} \text{ day}^{-1}) = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$$

Where, W_1 and W_2 are the dry weights in grams at times t_1 and t_2 respectively in days.

Net assimilation rate (NAR)

Since leaf surface is the primary photosynthetic organ, the productive efficiency expressed on leaf area basis provides accurate measure of growth. It is defined as net increase in plant dry weight (photosynthesis minus respiration) per unit of assimilation surface per unit time. The net assimilation rate (NAR) was calculated using the following formula (Redford, 1967).

$$\text{Net assimilation rate (g m}^{-2} \text{ day}^{-1}) = \frac{(W_2 - W_1) (\log_e A_2 - \log_e A_1)}{(t_2 - t_1)(A_2 - A_1)}$$

Where, W_1 and W_2 are the dry weights in grams at times t_1 and t_2 , respectively in days and A_1 and A_2 are total leaf areas of plant at times t_1 and t_2 .

Leaf area duration (LAD)

Leaf area duration (LAD) indicates the magnitude and persistence of leaf area during crop growth period. LAD based on leaf area of individual plants from successive harvest was calculated as per the formula given below.

$$\text{Leaf area duration (days)} = \frac{(LAI_2 + LAI_1) \times (t_2 - t_1)}{2}$$

Where, LAI_1 and LAI_2 are leaf area index at times t_1 and t_2 , respectively.

3.7 Yield attributes

Five tagged plants from the net plot area were used for recording growth parameters and were harvested separately at physiological maturity and were used for recording various yield components.

Head diameter (cm) from the five tagged plants was measured with the help of thread which was placed on scale and the reading was noted. Seed filling percentage workout by formula.

$$\text{Seed filling percent (\%)} = \frac{\text{Number of filled seeds per head}}{\text{Total number of seeds per head}} \times 100$$

One hundred seeds (g) were taken randomly from the produce of each net plot area and the weights were recorded to compute 100 seed weight. The sun-dried heads from the net plot area were threshed. Seeds were cleaned and seed weight per plot was recorded and expressed as kg ha⁻¹.

The stalks (after removing heads) from each plot area was sun dried completely for a week and the weight was recorded and expressed in kg ha⁻¹.

Harvest index was recorded as the ratio of economic yield to biological yield (Singh and Stoskoff, 1971).

$$\text{HI (\%)} = \frac{\text{Economic yield (kg ha}^{-1}\text{)}}{\text{Biological yield (kg ha}^{-1}\text{)}} \times 100$$

3.8 Quality parameters

The sampled seeds of each treatment was used for determination of oil content (%) by using NMR (Nuclear Magnetic Resonance) spectrometer available at MARS, Raichur. For each estimation 12 g (40 ml) seed was used.

The oil yield (kg ha⁻¹) was worked out by multiplying oil content with the seed yield kg ha⁻¹.

3.9 Soil chemical analysis

The soil samples collected from experimental site from 0-15 and 15-30 cm depth after harvest of sunflower crop and composite sample was dried under shade, gently powdered to pass through a 2 mm sieve and soil samples were subjected to chemical analysis as per the standard procedures. The available nitrogen was determined by Alkaline Permanganate method (Subbiah and Asija, 1956). Available phosphorus was determined by Olsen method (Olsen *et al.*, 1954) and available potassium was determined by Flame Photometer (Jackson, 1973).

3.10 Plant chemical analysis

Plant samples used for studying dry matter production were used for estimating nitrogen, phosphorus and potassium content in whole plant. The plant samples were dried at 60 ± 5 °C in a hot air oven and powdered using a grinder fitted with stainless steel blades and preserved in polythene bags for further analysis (Jackson, 1973).

Plant nitrogen content

Nitrogen in the plant sample was determined by Kjeldahl's method as described by Jackson (1973). Powdered samples were digested with concentrated sulphuric acid in the presence of digestion mixture (K_2SO_4 : $CuSO_4 \cdot 5H_2O$:Se powder in the ratio 100:20:1). The nitrogen content in the aliquot of digested sample was determined by distillation under alkaline medium. The liberated ammonia was trapped in boric acid mixed indicator and was titrated against standard acid. The per cent nitrogen was calculated using the following formula.

$$\text{Nitrogen (\%)} = \frac{\text{TV (ml)} \times N. H_2SO_4 \times \text{Volume of plant digest} \times 0.014}{\text{Aliquot taken} \times \text{Weight of plant sample (g)} \times 100} \times 100$$

Plant phosphorus content

A known quantity of powdered plant sample (0.5 g) was digested with microdigester. Further, digestion was done with 10 ml of di-acid mixture (HNO_3 : $HClO_4$, 10:4) until white residue was developed. Then, the residue was dissolved in 6 N HCl and volume was made up to 50 ml. Blank was prepared in the same way without plant material.

Phosphorus was estimated by vanadomolybdate method (Jackson, 1973). 0.5 g of dried stover sample was pre-digested with 5 ml of concentrated nitric acid. It was further digested with 10 ml di-acid mixture (concentrated nitric acid and perchloric acid at 10: 4 proportions). The digested material was then made up to 100 ml with distilled water. From this 5 ml of aliquot was taken in a 50 ml volumetric flask along with 10 ml vanadomolybdic acid reagent and the volume was made up to 50 ml with distilled water. Yellow colour developed was measured at 490 nm against a reagent blank. The concentration of phosphorus in the sample was obtained by comparing with phosphorus standard curve and per cent phosphorus was calculated using following formula.

$$\text{Phosphorus (\%)} = \frac{\text{Graph ppm} \times \text{Volume of digest} \times \text{Volume made}}{10^6 \times \text{Aliquot taken} \times \text{Weight of plant sample}} \times 100$$

Plant potassium content

The potassium concentration in the digested plant material was determined by flame photometric method (Jackson, 1973). One ml of an aliquot of di-acid digest was transferred to 50 ml volumetric flask and volume was made up with distilled water. Flame photometer was calibrated using 50 and 100 ppm potassium standards. Diluted solution of plant digest was fed to flame photometer and reading was recorded. The potassium content in the sample was determined using flame photometer and was calculated as follows:

$$\text{Potassium (\%)} = \frac{\text{Graph ppm} \times \text{Dilution factor} \times \text{Volume of digest}}{10^6 \times \text{Weight of plant sample}} \times 100$$

Plant NPK uptake

The nutrient uptake by plant was calculated by using the following formula,

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{[\text{Nutrient concentration (\%)} \times \text{Biomass (kg ha}^{-1}\text{)}]}{100}$$

3.11 Economic returns

The price of the inputs and the produce prevailed during the experimental period was considered for working out the cost of cultivation and gross income. Gross return (Rs. ha⁻¹) was obtained from the income realized from the sale of seed and stalk of sunflower based on current market rate. Net return was obtained by subtraction of total cost of production from the gross returns. The summary table of cost of cultivation is presented in Appendix. Net returns (Rs. ha⁻¹) = Gross returns (Rs. ha⁻¹) - Cost of cultivation (Rs. ha⁻¹).

Benefit-cost ratio was obtained from the ratio between gross returns and cost of cultivation.

$$\text{Benefit cost ratio} = \frac{\text{Gross returns (Rs. ha}^{-1}\text{)}}{\text{Cost of cultivation (Rs. ha}^{-1}\text{)}}$$

3.12 Statistical analysis

The data recorded on various parameters during the course of investigation was statistically analyzed duly following the analysis of variance technique for split plot design as suggested by Panse and Sukhatme (1978). The statistical significance was tested with F test at 0.05 level of probability and wherever the F value was found significant, critical difference (CD) was worked out to test the significance.

Correlation

The correlation studies was made between seed yield and yield parameters. The values of correlation coefficient (r) was calculated and tested for their significance at five per cent as per the procedure outlined by Snedekar and Cocoharan (1967).

RESULTS AND DISCUSSION

IV. RESULTS AND DISCUSSION

The present investigation on effect of planting density and fertilizer rate on performance of newly developed sunflower hybrids (*Helianthus annuus* L.) was conducted at Main Agricultural Research Station, UAS, Raichur, Karnataka during *kharif* 2019. The results obtained through this investigation are presented and discussed in this chapter with reference to the effect of hybrids, plant spacing and fertilizer rate on growth, yield, nutrient uptake and their economics. An attempt has been made to support the findings with probable reasons and relevant literature.

4.1 Weather and crop

Weather is the basic and key factor responsible for the plant growth apart from management. Thus, change in weather parameters directly affect the crop growth, development and expected yield. The year to year yield fluctuation was primarily consequence of complex weather conditions that exists in an agroclimatic situation other than soil fertility status. In this context, the weather conditions prevailed during the experimental era would certainly have a direct effect on the potentiality of any crop in general and on sunflower in particular in the experiment.

During *kharif* 2019 the average rainfall received during the crop growth period from August to November was 122.0 mm. In addition cloudy weather prevailed during September led to slight infestation of *Alternaria* disease and *Spodoptera* pest in sunflower. The total precipitation recorded was not adequate for better growth and development. Therefore, soil moisture condition was maintained by providing irrigations at dry spells.

4.2 Growth parameters of sunflower

4.2.1 Plant height (cm)

The data pertaining to effect of spacing and fertilizer rates of sunflower hybrids on plant height recorded at 30, 60 DAS and at maturity are presented in Table 3 and depicted in Fig. 3. The plant height was found to progressively increase at all the stages of crop growth until maturity. The rate of increase in plant height was higher during initial stage of crop growth up to 60 days. Thereafter, the rate of increase was slow up to maturity.

The significant differences in plant height were observed among hybrids at all the crop growth stages. Hybrid, RSFH-12-700 recorded significantly taller plants at 30 (30.7

cm), 60 DAS (175.9 cm) and at maturity (181.8 cm) as compared to RSFH-12-705 (29.5, 169.9 and 172.4 cm, respectively) and RSFH 1887 (28.2, 159.4 and 164.3 cm, respectively). The significant differences in plant height among different sunflower hybrids were found due to genotypic character and their genetic makeup. Similar findings were also recorded by Sarwar *et al.* (2013) and Khan *et al.* (2018).

Plant height was significantly influenced by varied plant spacings at 60 DAS and at maturity. It showed increased trend in narrow plant spacing. The narrow row spacing of 60 cm recorded taller plants at 60 DAS (171.6 cm) and at maturity (175.6 cm) as compared to wider row spacing at 75 cm (165.1 and 170.0 cm). Ali *et al.* (2007) reported that greater plant height in narrow spaced plots might be due to increased competition among the sunflower plants for light. Similar results were reported by Basha (2000) and Bassal (2003). Allam *et al.* (2003) opined that wider spacing in sunflower increases the crop canopy ability to receive the radiation due to more light penetration than denser plants. Increased light intensity disturbed the level of auxin in plants that finally decreased plant height in wider spacing.

The average plant height was significantly influenced by rate of fertilizer application at 30, 60 DAS and at maturity. Application of 150 per cent RDF has recorded taller plants at 30 (30.1 cm), 60 DAS (173.7 cm) and at maturity (178.6 cm) by over 100 per cent RDF (28.8, 160.3 and 163.6 cm, respectively) but on par with application of 125 per cent RDF (29.6, 171.2 and 176.2 cm, respectively). Plant height was improved with the higher level of fertilizer application. Ali *et al.* (2014) reported that sufficient application of fertilizer significantly influenced plant height of sunflower by improving vegetative growth, root growth and better absorption of nutrients. Adequate supply of fertilizer helped the plants to grow taller compared to others as stated by Kadasiddapa *et al.* (2007) and Pavani *et al.* (2012).

Combination of hybrids, row spacing and fertilizer rate had no significant effect on sunflower plant height throughout the crop season.

4.2.2 Number of leaves per plant

Data on number of leaves per plant of sunflower hybrids was significantly influenced by row spacing and fertilizer rate at different crop growth stages (Table 4 and Fig. 4). It was evident that, number of leaves per plant increased with the advancement up to 60 DAS and thereafter declined upto maturity.

Table 3. Effect of spacing and fertilizer levels on plant height (cm) of sunflower hybrids at different growth stages

Treatment	H ₁ : RSFH-12-700		H ₂ : RSFH-12-705		H ₃ : RSFH 1887		
	S ₁	S ₂	S ₁	S ₂	S ₁	S ₂	Mean
30 DAS							
F ₁ :100%RDF	30.8	29.3	29.0	28.4	27.9	27.2	28.8
F ₂ :125%RDF	30.9	30.5	29.8	29.5	28.5	28.3	29.6
F ₃ :150%RDF	31.3	31.5	30.4	29.9	28.8	28.6	30.1
Mean	31.0	30.4	29.7	29.2	28.4	28.0	29.5
Mean of H	30.7		29.5		28.2		
Mean of S	29.7 (S ₁)		29.3 (S ₂)				
	H	S	F	H × S	H × F	S × F	H × S × F
S.Em. ±	0.4	0.3	0.3	0.5	0.6	0.5	0.8
C.D. @ 5%	1.5	NS	0.9	NS	NS	NS	NS
60 DAS							
F ₁ :100%RDF	175.4	165.5	163.0	154.4	154.1	149.5	160.3
F ₂ :125%RDF	180.4	173.8	177.2	171.3	165.6	159.0	171.2
F ₃ :150%RDF	183.5	177.1	179.2	174.3	166.4	161.5	173.7
Mean	179.7	172.1	173.1	166.7	162.0	156.7	168.4
Mean of H	175.9		169.9		159.4		
Mean of S	171.6 (S ₁)		165.1 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	2.8	1.8	2.3	3.2	4.1	3.3	5.8
C.D. @ 5%	10.8	6.5	6.9	NS	NS	NS	NS
At maturity							
F ₁ :100%RDF	174.7	172.0	162.3	158.0	162.2	152.3	163.6
F ₂ :125%RDF	186.3	184.5	178.5	175.6	171.7	160.8	176.2
F ₃ :150%RDF	187.9	185.1	181.4	178.6	175.3	163.3	178.6
Mean	182.9	180.5	174.1	170.7	169.7	158.8	172.8
Mean of H	181.8		172.4		164.3		
Mean of S	175.6 (S ₁)		170.0 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	2.3	1.6	2.1	2.7	3.6	2.9	5.1
C.D. @ 5%	9.1	5.5	6.1	NS	NS	NS	NS

S₁: 60 cm × 30 cm; S₂: 75 cm × 30 cm

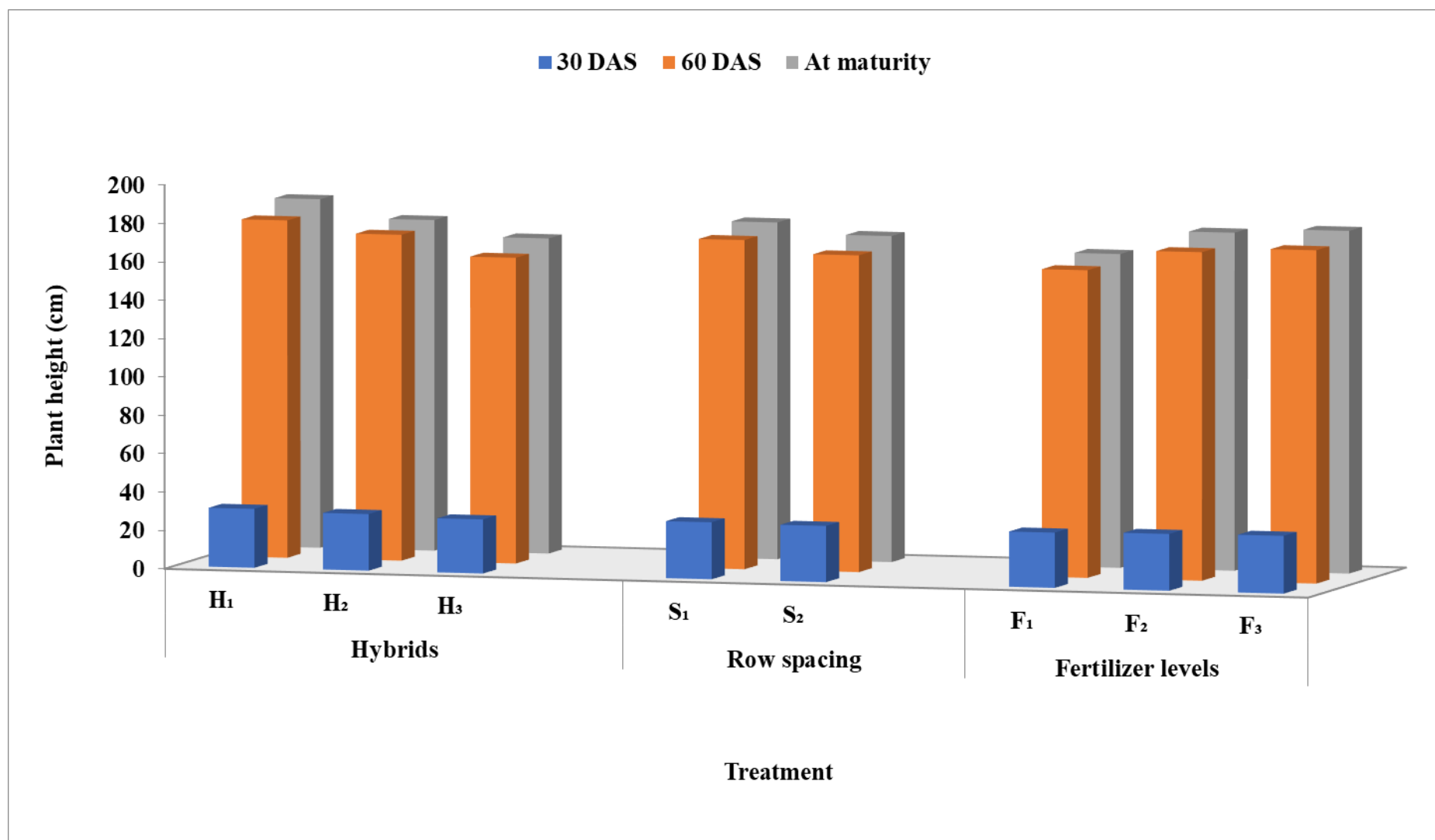


Fig. 3. Plant height (cm) of sunflower hybrids as influenced by spacing and fertilizer levels at different growth stages

At 30 DAS, there were no significant differences among hybrids for number of leaves per plant. While, at 60 DAS, RSFH-12-700 (22.4) recorded greater number of leaves per plant and at maturity (18.1) as compared to RSFH-12-705 (20.7 and 16.8, respectively) and RSFH 1887 (19.5 and 16.3, respectively) at respective growth stages. Increased number of leaves might be due to the genetic potential of the hybrid. Bakht *et al.* (2006) observed significant differences in number of leaves among different sunflower hybrids.

The data indicated that number of leaves per plant at different crop growth stages was not significantly influenced by row spacings.

Different rates of fertilizer application significantly influenced number of leaves per plant at all the growth stages. The crop fertilized with 150 per cent RDF recorded significantly higher number of leaves at 30, 60 DAS and at maturity (12.5, 22.0 and 17.6, respectively) as compared to rest of the fertilizer rates. However, the treatments which received 150 and 125 per cent RDF (12.4, 21.4 and 17.3, respectively) were on par with each other at all the growth stages and superior over 100 per cent RDF (11.5, 19.2 and 16.3, respectively). It implies that application of graded fertilizers increased the number of leaves in sunflower. Banerjee *et al.* (2014) reported that sufficient fertilizer application enhances stem height of sunflower plants. Thereby, longer stem possess more number of nodes, which in turn results in more number of leaves. More number of leaves per plant may be due to enhanced plant height and vegetative growth. The results are in conformity with findings of Nawaz *et al.* (2003) and Pavani *et al.* (2012).

All the interaction effects among sunflower hybrids, spacing and levels of fertilizer did not reach to the levels of significance in case of number of leaves per plant at all the crop growth stages.

4.2.3 Leaf area per plant (cm²)

Data on leaf area per plant was significantly influenced by the various hybrids and fertilizer rate (Table 5 and Fig. 5). Data revealed that leaf area per plant increased with growth advancement in age of the crop up to 60 DAS, thereafter, it decreased towards the maturity of the crop.

Table 4. Effect of spacing and fertilizer levels on number of leaves plant⁻¹ of sunflower hybrids at different growth stages

Treatment	H ₁ : RSFH-12-700		H ₂ : RSFH-12-705		H ₃ : RSFH 1887		
	S ₁	S ₂	S ₁	S ₂	S ₁	S ₂	Mean
30 DAS							
F ₁ :100%RDF	12.0	12.0	11.3	11.0	11.3	11.3	11.5
F ₂ :125%RDF	13.0	13.0	12.3	12.3	12.0	11.6	12.4
F ₃ :150%RDF	13.6	13.3	12.6	12.6	11.0	11.6	12.5
Mean	12.8	12.7	12.1	11.9	11.4	11.5	12.1
Mean of H	12.8		12.1		11.5		
Mean of S	12.1 (S ₁)		12.1 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.4	0.2	0.2	0.4	0.3	0.3	0.5
C.D. @ 5%	NS	NS	0.6	NS	NS	NS	NS
60 DAS							
F ₁ :100%RDF	20.6	20.3	18.6	18.3	19.0	18.0	19.2
F ₂ :125%RDF	23.3	22.6	21.6	21.3	20.3	19.3	21.4
F ₃ :150%RDF	24.0	23.6	22.3	21.6	21.0	19.6	22.0
Mean	22.6	22.1	20.8	20.4	20.1	18.9	20.8
Mean of H	22.4		20.7		19.5		
Mean of S	21.2 (S ₁)		20.5 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.4	0.3	0.2	0.5	0.4	0.3	0.6
C.D. @ 5%	1.4	NS	0.7	NS	NS	NS	NS
At maturity							
F ₁ :100%RDF	16.9	16.7	15.9	16.0	16.0	15.8	16.3
F ₂ :125%RDF	18.6	18.3	17.2	17.0	16.4	16.3	17.3
F ₃ :150%RDF	19.2	18.7	17.3	17.2	16.8	16.4	17.6
Mean	18.2	17.9	16.8	16.7	16.4	16.2	17.1
Mean of H	18.1		16.8		16.3		
Mean of S	17.2 (S ₁)		16.9 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.3	0.2	0.2	0.4	0.4	0.3	0.5
C.D. @ 5%	1.3	NS	0.7	NS	NS	NS	NS

S₁: 60 cm × 30 cm; S₂: 75 cm × 30 cm

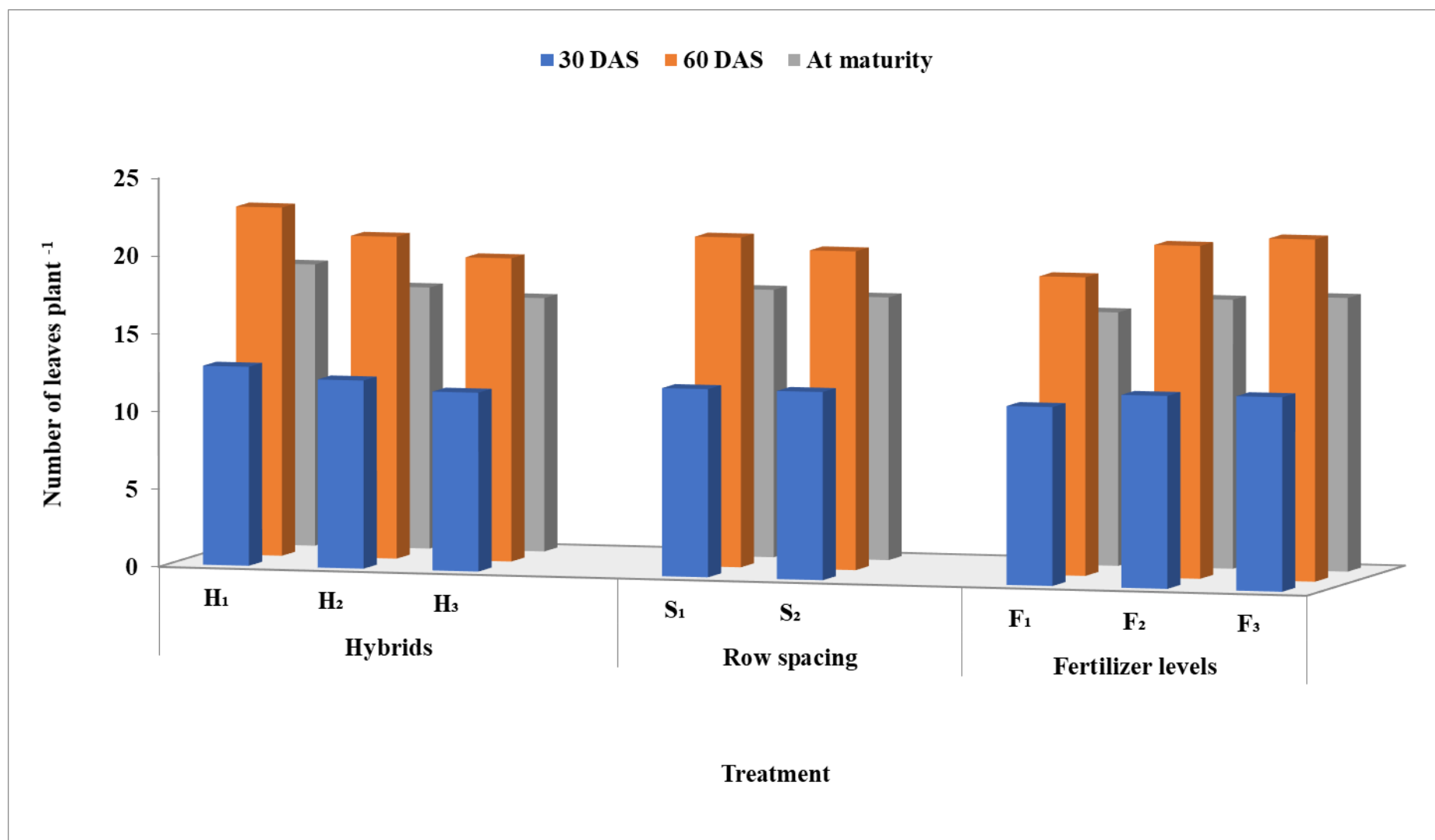


Fig. 4. Number of leaves plant^{-1} of sunflower hybrids as influenced by spacing and fertilizer levels at different growth stages



H₁: RSFH-12-700



H₂: RSFH-12-705



H₃: RSFH 1887

Plate 2. Different sunflower hybrids tested in the experiment

Table 5. Effect of spacing and fertilizer levels on leaf area (cm²) plant⁻¹ of sunflower hybrids at different growth stages

Treatment	H ₁ :RSFH-12-700		H ₂ :RSFH-12-705		H ₃ :RSFH 1887		
	S ₁	S ₂	S ₁	S ₂	S ₁	S ₂	Mean
30 DAS							
F ₁ :100%RDF	946	960	785	845	641	849	838
F ₂ :125%RDF	1210	1286	1101	1182	871	897	1091
F ₃ :150%RDF	1429	1449	1119	1189	878	1019	1181
Mean	1195	1231	1001	1072	796	921	1036
Mean of H	1213		1037		859		
Mean of S	998 (S ₁)		1075 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	28	24	46	42	80	65	113
C.D. @ 5%	109	NS	134	NS	NS	NS	NS
60 DAS							
F ₁ :100%RDF	3539	3561	2848	2845	2794	2896	3080
F ₂ :125%RDF	4141	4204	3855	3869	2913	3213	3699
F ₃ :150%RDF	4296	4385	3904	3981	3177	3553	3883
Mean	3992	4050	3535	3565	2961	3220	3554
Mean of H	4021		3550		3091		
Mean of S	3496 (S ₁)		3612 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	77	37	76	64	132	108	187
C.D. @ 5%	300	NS	223	NS	NS	NS	NS
At maturity							
F ₁ :100%RDF	2583	2735	2114	2126	2059	2133	2292
F ₂ :125%RDF	3176	3315	3053	3059	2364	2379	2891
F ₃ :150%RDF	3330	3577	3104	3148	2374	2929	3077
Mean	3029	3209	2757	2777	2265	2480	2753
Mean of H	3119		2768		2373		
Mean of S	2684 (S ₁)		2822 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	87	52	64	90	110	90	156
C.D. @ 5%	338	NS	186	NS	NS	NS	NS

S₁: 60 cm × 30 cm; S₂: 75 cm × 30 cm

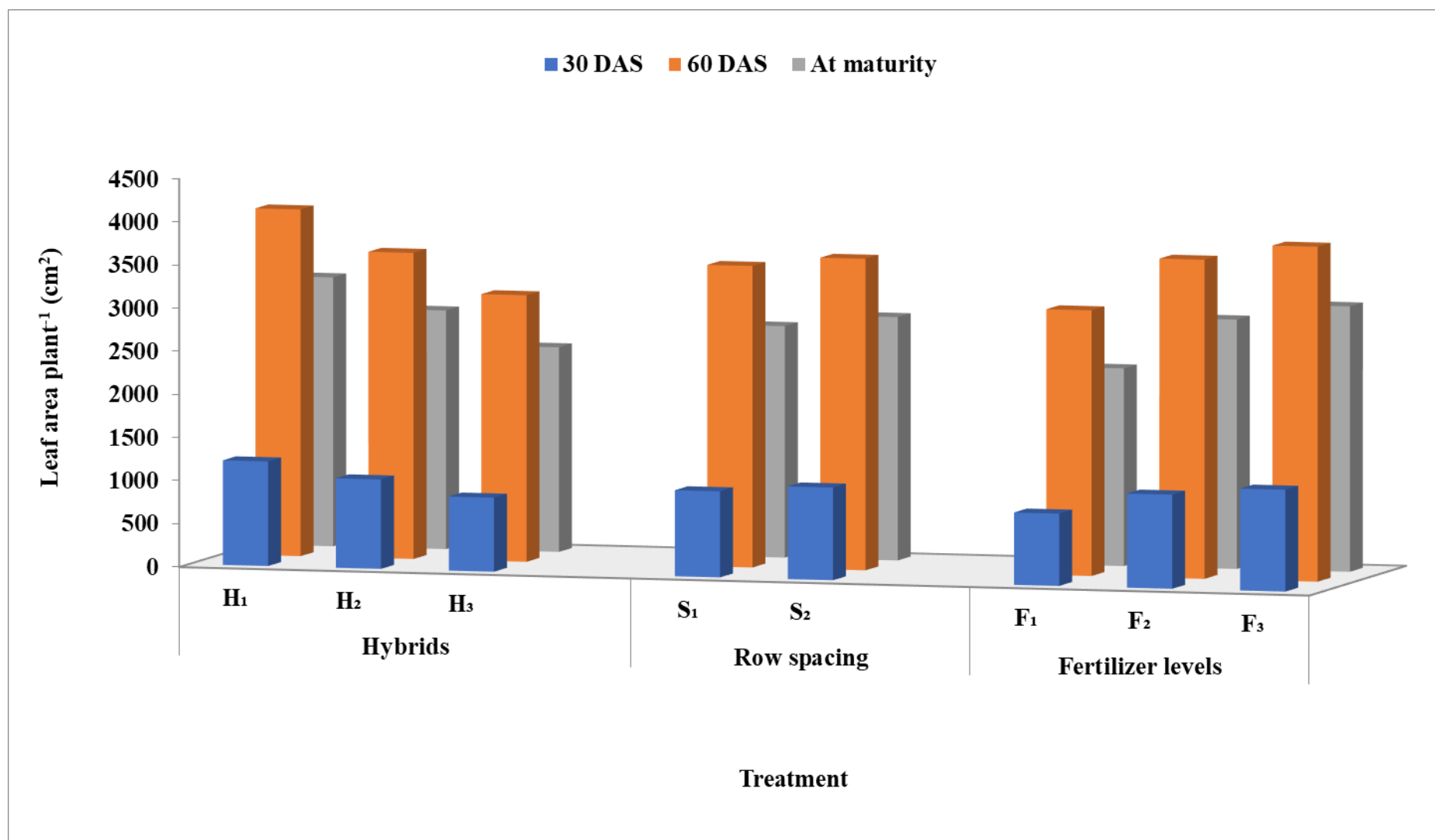


Fig. 5. Leaf area plant⁻¹ (cm²) of sunflower hybrids as influenced by spacing and fertilizer levels at different growth stages

The data at 30, 60 DAS and at maturity indicated that sunflower hybrid RSFH-12-700 recorded significantly higher leaf area per plant (1213, 4021 and 3119 cm², respectively) as compared to RSFH-12-705 (1037, 3550 and 2768 cm², respectively) and RSFH 1887 (859, 3091 and 2373 cm², respectively). Differences in leaf area might be due to the genetic potential among various hybrids. Similar results were reported by Shankerrao (1986) and Lodh (1988).

The data indicated that leaf area per plant at different crop growth stages was not significantly influenced by row spacings.

Effect of fertilizer rate had significant effect on leaf area per plant at different growth stages (Table 5). Application of 150 per cent RDF (1181, 3883 and 3077 cm², respectively) recorded significantly greater leaf area per plant at 30, 60 DAS and at maturity, respectively than that of 100 per cent RDF (838, 3080 and 2292 cm², respectively) and was on par with 125 per cent RDF (1091, 3699 and 2891 cm², respectively). The increased leaf area might be due to higher application of N, P and K which encouraged production of more carbohydrates by influencing cell division and its enlargement. These findings on changes in leaf area of sunflower by fertilizer rate were given by Sharma (1994).

The leaf area per plant was not significantly influenced by combination of row spacings, hybrids and fertilizer rate at all the stages of crop growth.

4.2.4 Leaf area index

The data on leaf area index (LAI) revealed that LAI was significantly influenced by hybrids, spacing and fertilizer levels (Table 6 and Fig. 6). It was lowest up to 30 days and peaked at 60 DAS and thereafter slightly decreased towards maturity. It was significantly influenced by different sunflower hybrids at 30, 60 DAS and at maturity. Greater LAI was recorded in RSFH-12-700 (0.61, 2.01 and 1.56) followed by RSFH-12-705 (0.52, 1.77 and 1.38) and the lowest with RSFH 1887 (0.43, 1.54 and 1.18) at 30, 60 DAS and at maturity, respectively. The higher number of leaves in RSFH-12-700 was reflected in the LAI. Among sunflower hybrids, varied LAI was observed due to differential genetic makeup of hybrids as supported by Ali *et al.* (2000) and Sarwar *et al.* (2013).

Table 6. Effect of spacing and fertilizer levels on leaf area index plant⁻¹ of sunflower hybrids at different growth stages

Treatment	H ₁ :RSFH-12-700		H ₂ :RSFH-12-705		H ₃ :RSFH 1887		
	S ₁	S ₂	S ₁	S ₂	S ₁	S ₂	Mean
30 DAS							
F ₁ :100%RDF	0.52	0.42	0.43	0.37	0.35	0.37	0.41
F ₂ :125%RDF	0.67	0.57	0.61	0.52	0.48	0.39	0.54
F ₃ :150%RDF	0.79	0.64	0.62	0.53	0.49	0.45	0.59
Mean	0.66	0.54	0.55	0.47	0.44	0.40	0.51
Mean of H	0.61		0.52		0.43		
Mean of S	0.55 (S ₁)		0.48 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.01	0.01	0.02	0.02	0.04	0.03	0.05
C.D. @ 5%	0.06	0.05	0.07	NS	NS	NS	NS
60 DAS							
F ₁ :100%RDF	1.96	1.58	1.58	1.26	1.55	1.28	1.54
F ₂ :125%RDF	2.30	1.87	1.72	1.72	1.62	1.43	1.84
F ₃ :150%RDF	2.38	1.95	1.77	1.76	1.76	1.58	1.93
Mean	2.21	1.8	1.69	1.58	1.64	1.43	1.77
Mean of H	2.01		1.77		1.54		
Mean of S	1.94 (S ₁)		1.60 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.04	0.02	0.03	0.04	0.06	0.05	0.09
C.D. @ 5%	0.16	0.08	0.11	NS	NS	NS	NS
At maturity							
F ₁ :100%RDF	1.43	1.21	1.17	0.95	1.14	0.95	1.14
F ₂ :125%RDF	1.76	1.47	1.69	1.36	1.31	1.06	1.44
F ₃ :150%RDF	1.85	1.59	1.72	1.39	1.32	1.30	1.53
Mean	1.68	1.42	1.53	1.23	1.26	1.10	1.37
Mean of H	1.56		1.38		1.18		
Mean of S	1.50 (S ₁)		1.25 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.04	0.03	0.03	0.05	0.05	0.04	0.08
C.D. @ 5%	0.17	0.10	0.09	NS	NS	NS	NS

S₁: 60 cm × 30 cm; S₂: 75 cm × 30 cm

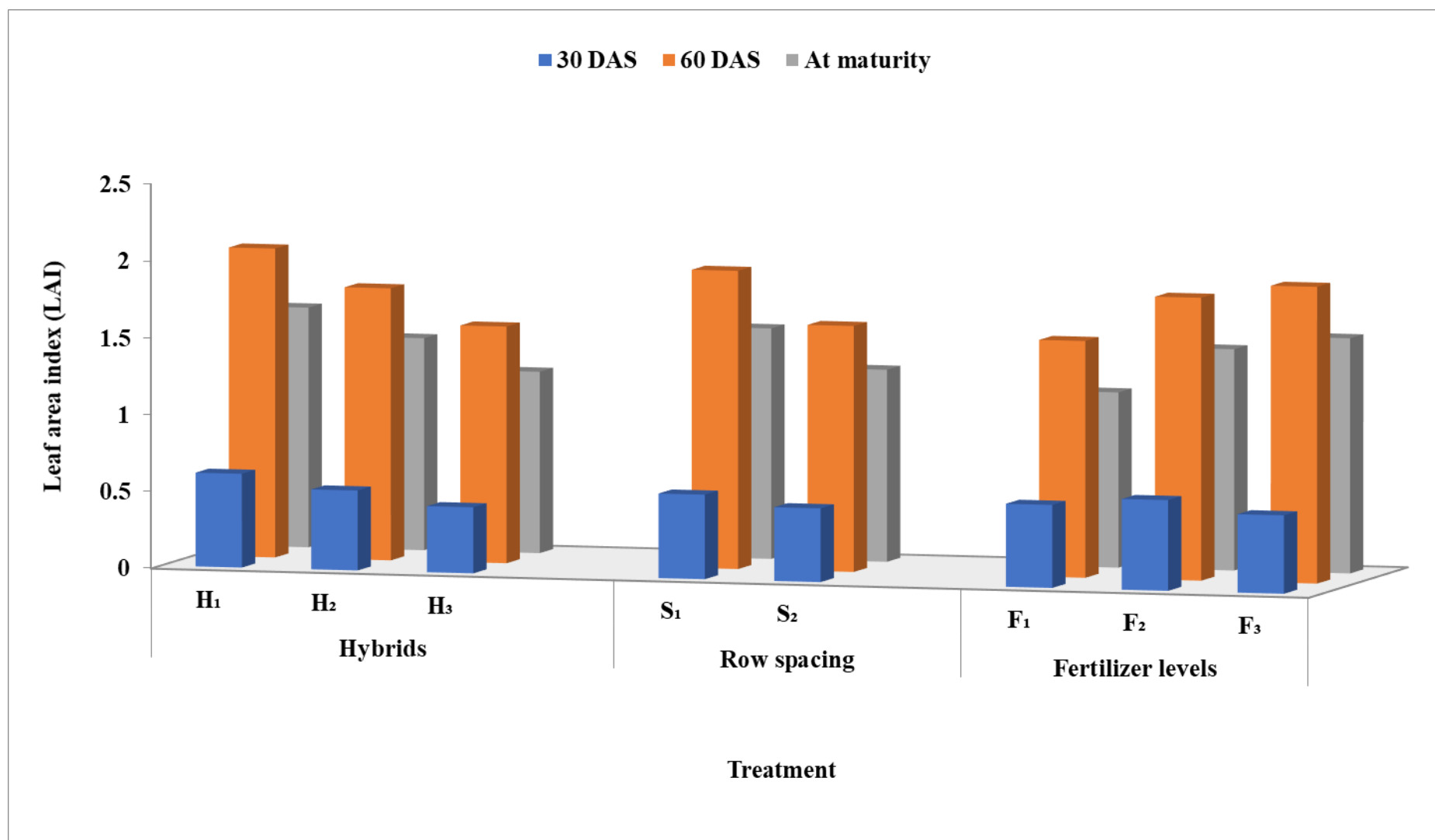


Fig. 6. Leaf area index (LAI) of sunflower hybrids as influenced by spacing and fertilizer levels at different growth stages



S_1 : 60 cm x 30 cm



S_2 : 75 cm x 30 cm

Plate 3. Plant stand of sunflower hybrids grown at different spacings at 30 DAS

It was significantly influenced by varied plant spacings at 30, 60 DAS and at maturity. It was increased in narrow row spacing. The row spacing at 60 cm (0.55, 1.94 and 1.50, respectively) recorded greater LAI as compared to 75 cm (0.48, 1.60 and 1.25, respectively) at 30, 60 DAS and at maturity. Ishfaq *et al.* (2009) indicated that reduced ground area per plant with higher plant population in lower plant spacing caused more LAI in sunflower. The same observation was also made by Aguilar-Garcia *et al.* (2005) and Khan and Akmal (2016).

Leaf area index was significantly differed at 30, 60 DAS and at maturity by rates of fertilizer. Application of 150 per cent RDF (0.59, 1.93 and 1.53) recorded the higher magnitude of LAI over 100 per cent RDF and was on par with 125 per cent (0.54, 1.84 and 1.44) at 30 DAS, 60 DAS and at maturity, respectively. The lowest LAI was obtained in 100 per cent RDF (0.41, 1.54 and 1.14) at 30, 60 DAS and at harvest, respectively. Maximum LAI values were observed under 150 per cent RDF could be due to sufficient supply of N that produced larger leaves and more number of leaves per plant that has resulted enhanced photosynthetic surface area. Waqas *et al.* (2017) reported that the greater leaf expansion in sunflower hybrid could be attributed to high rate of cell division and cell enlargement. Thavaprakash and Malligawad (2002) reported that N:P ratio of more than 1.0 resulted in higher LAI due to the increased leaf area per plant which was influenced by the higher leaf dry matter per plant.

Combined effect of sunflower row spacing, rate of fertilizer application and hybrids had no significant effect on LAI at various growth stages.

4.2.5 Total dry matter production (TDMP) (g plant⁻¹)

The data on TDMP (g plant⁻¹) at various growth stages revealed that TDMP was significantly influenced by fertilizer levels and hybrids (Table 7 and Fig. 7). The TDMP per plant increased continuously from emergence to maturity. The greater TDMP per plant was recorded at maturity. The rate of increase of dry matter was faster between 30 to 60 DAS and thereafter the increase was slow up to maturity.

At all the crop growth stages, the significant TDMP differences were observed among the hybrids. The maximum TDMP at 30, 60 DAS and at maturity was found in RSFH-12-700 (5.7, 113.7 and 145.9 g, respectively) which was significantly superior over RSFH-12-705 (5.2, 100.3 and 133.8 g, respectively) and RSFH 1887 (4.9, 90.4 and

Table 7. Effect of spacing and fertilizer levels on total dry matter accumulation (g plant⁻¹) of sunflower hybrids at different growth stages

Treatment	H ₁ :RSFH-12-700		H ₂ :RSFH-12-705		H ₃ :RSFH 1887		
	S ₁	S ₂	S ₁	S ₂	S ₁	S ₂	Mean
30 DAS							
F ₁ :100%RDF	5.1	5.2	4.4	4.5	4.4	4.7	4.7
F ₂ :125%RDF	5.9	5.9	5.4	5.6	4.8	5.1	5.4
F ₃ :150%RDF	6.2	6.2	5.6	5.7	5.0	5.3	5.7
Mean	5.7	5.7	5.1	5.3	4.7	5.0	5.3
Mean of H	5.7		5.2		4.9		
Mean of S	5.2 (S ₁)		5.3 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.1	0.1	0.1	0.1	0.2	0.2	0.3
C.D. @ 5%	0.2	NS	0.3	NS	NS	NS	NS
60 DAS							
F ₁ :100%RDF	96.9	97.6	72.4	75.1	69.9	85.3	82.9
F ₂ :125%RDF	117.0	120.6	109.7	111.9	93.7	96.4	108.2
F ₃ :150%RDF	123.1	127.3	116.4	116.4	94.0	102.9	113.4
Mean	112.3	115.2	99.5	101.1	85.8	94.8	101.5
Mean of H	113.7		100.3		90.4		
Mean of S	99.3 (S ₁)		103.7 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	1.5	1.7	2.2	3.0	3.8	3.1	5.4
C.D. @ 5%	6.0	NS	6.5	NS	NS	NS	NS
At maturity							
F ₁ :100%RDF	119.7	121.8	103.7	105.5	102.1	108.4	110.2
F ₂ :125%RDF	155.3	157.1	143.2	146.1	114.9	118.4	139.2
F ₃ :150%RDF	158.0	163.9	151.8	152.5	116.8	134.2	146.2
Mean	144.3	147.6	132.9	134.7	111.3	120.3	131.8
Mean of H	145.9		133.8		115.8		
Mean of S	129.5 (S ₁)		134.2 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	2.2	1.8	3.1	3.1	5.4	4.4	7.6
C.D. @ 5%	8.5	NS	9.1	NS	NS	NS	NS

S₁: 60 cm × 30 cm; S₂: 75 cm × 30 cm

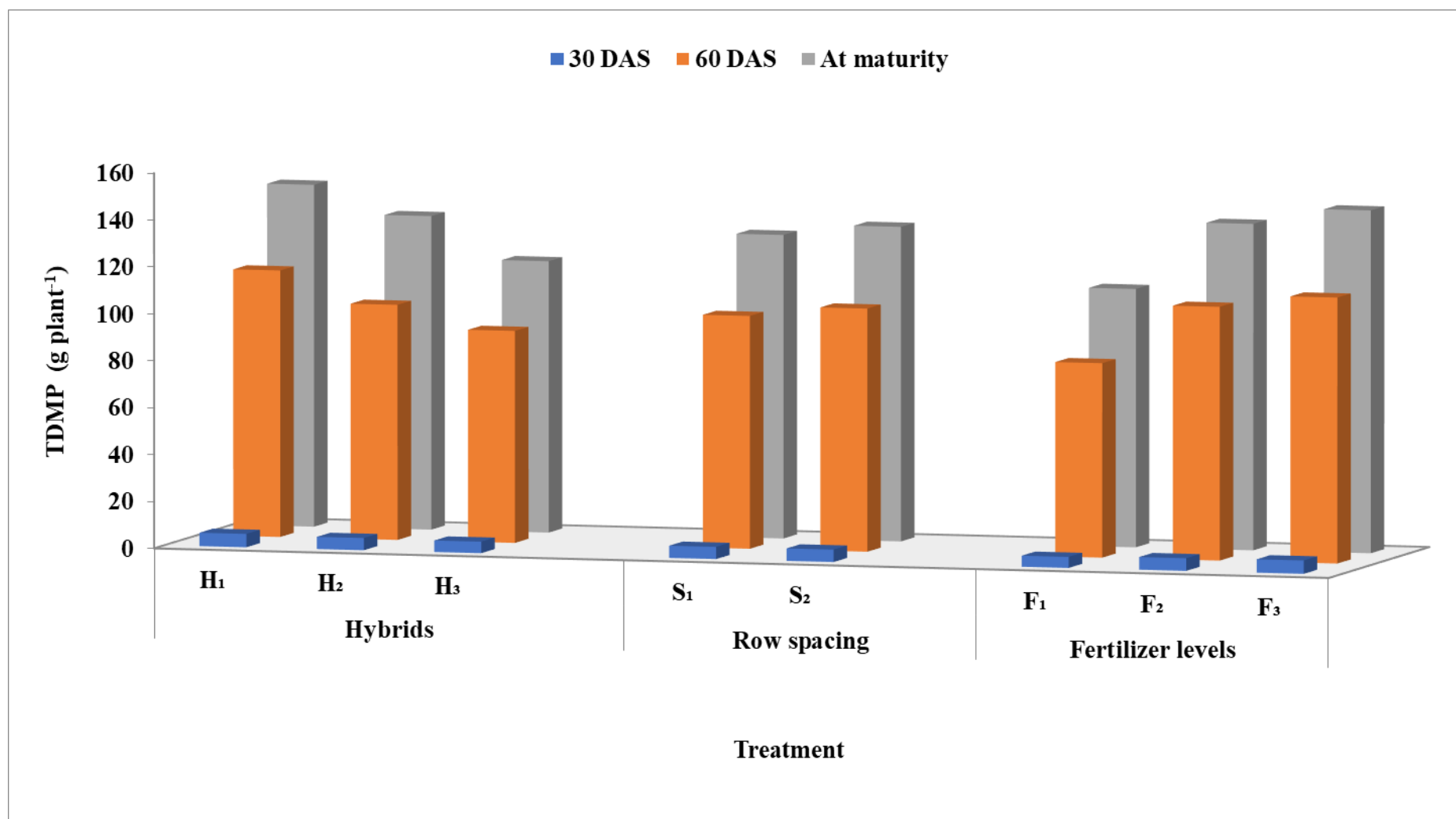


Fig. 7. Total dry matter production (g plant^{-1}) of sunflower hybrids as influenced by spacing and fertilizer levels at different growth stages

115.8 g, respectively). Inherently, hybrid RSFH-12-700 produced more vegetative growth in terms of larger leaves, resulting in larger leaf area per plant and ultimately more photo-assimilates resulting in higher dry matter per plant. Differences in TDM of different hybrids was due to different growth habits, crop growth duration, moisture availability *etc.*, Kaleem *et al.* (2011) opined that differences among hybrids could be due to genetic potential of the sunflower hybrids. Ibrahim (2012) stated that the hybrid superiority might be due to its ability to make better use of available resources compared with other hybrids to give higher dry matter production.

The total dry matter per plant was not significantly influenced by row spacing at all the crop growth stages. The TDMP was significantly influenced by rate of fertilizer application. Application of 150 per cent RDF (5.7, 113.4 and 146.2 g) has recorded significantly greater TDMP over 100 per cent RDF (4.7, 82.9 and 110.2 g) and found to be on par with the application of 125 per cent RDF (5.4, 108.2 and 139.2 g) at 30, 60 DAS and at maturity, respectively. The rise in TDMP with increased rates of fertilizer was attributed to better crop growth rate, which resulted in maximum photosynthates and LAI. Yadav *et al.* (2009) further opined that improved growth attributes under graded NPK might have helped in better nutrient uptake by the sunflower crop which in turn resulted in assimilation of photosynthates towards sink as well as higher dry matter accumulation. The study also corroborates with the work done by Dordas and Sioulas (2009) on safflower, Murthy *et al.* (2011) and Nasim *et al.* (2011) on sunflower.

The interaction effect of hybrids, row spacing and rate of fertilizer application had no significant effect on TDMP per plant at all the growth stages of crop.

4.2.6 Dry matter accumulation in leaf (g plant^{-1})

The data pertaining to dry matter accumulation in leaf at various growth stages was significantly influenced by fertilizer levels and hybrids (Table 8). The dry matter accumulation in leaf increased with the advancement of the crop age up to 60 DAS and subsequently declined due to leaf senescence towards maturity.

Sunflower hybrids did not show significant difference with respect to dry matter accumulation in leaf at 30 DAS and 60 DAS. However, at maturity, RSFH-12-700 (26.86 g) recorded maximum dry matter in leaf and was on par with RSFH-12-705 (24.72 g) and lowest dry matter in leaf was observed in RSFH 1887 (20.72 g). This was due to greater

Table 8. Dry matter accumulation in leaf (g plant⁻¹) of sunflower hybrids as influenced by spacing and fertilizer levels at different growth stages

Treatment	H ₁ :RSFH-12-700		H ₂ :RSFH-12-705		H ₃ :RSFH 1887		
	S ₁	S ₂	S ₁	S ₂	S ₁	S ₂	Mean
30 DAS							
F ₁ :100%RDF	3.78	3.78	3.53	3.61	3.40	3.62	3.62
F ₂ :125%RDF	4.30	4.31	4.03	4.07	3.75	3.75	4.03
F ₃ :150%RDF	4.64	4.71	4.07	4.11	3.75	3.86	4.19
Mean	4.24	4.27	3.87	3.93	3.63	3.74	3.95
Mean of H	4.25		3.90		3.69		
Mean of S	3.91 (S ₁)		3.98 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.12	0.06	0.07	0.11	0.13	0.11	0.18
C.D. @ 5%	NS	NS	0.22	NS	NS	NS	NS
60 DAS							
F ₁ :100%RDF	31.00	30.76	25.15	26.21	23.45	25.32	26.94
F ₂ :125%RDF	34.10	35.27	33.15	33.21	25.98	28.15	31.64
F ₃ :150%RDF	34.90	34.90	33.83	33.90	26.83	31.26	32.61
Mean	33.33	33.64	30.71	31.11	25.42	28.24	30.40
Mean of H	33.45		30.91		26.83		
Mean of S	29.79 (S ₁)		31.00 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	1.28	0.57	0.50	0.98	0.87	0.71	1.24
C.D. @ 5%	NS	NS	1.47	NS	2.05	NS	NS
At maturity							
F ₁ :100%RDF	23.13	24.57	19.73	19.87	18.27	20.03	20.93
F ₂ :125%RDF	27.53	28.37	26.90	26.93	20.20	20.70	25.10
F ₃ :150%RDF	28.40	29.17	27.40	27.47	20.40	24.73	26.26
Mean	26.35	27.37	24.68	24.75	19.62	21.82	24.10
Mean of H	26.86		24.72		20.72		
Mean of S	23.55 (S ₁)		24.65 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.71	0.40	0.55	0.69	0.95	0.77	1.34
C.D. @ 5%	2.79	NS	1.60	NS	NS	NS	NS

S₁: 60 cm × 30 cm; S₂: 75 cm × 30 cm

leaf area, LAI and number of leaves in hybrid RSFH-12-700. At all the growth stages spacing had no significant effect on leaf dry matter (g plant^{-1}).

Dry matter accumulation in leaf was significantly influenced by rates of fertilizer application at all the crop growth stages. Application of 150 per cent RDF (4.19, 32.61 and 26.26 g) recorded significantly greater leaf dry matter over 100 per cent RDF (3.62, 26.94 and 20.93 g) but was on par with application of 125 per cent RDF (4.03, 31.64 and 25.10 g) at 30, 60 DAS and at maturity, respectively. Greater dry matter accumulation in leaf was observed at higher levels of fertilizers over lower rates. It was attributed to the improved growth parameters such as number of leaves, LAI and photosynthates accumulated in sunflower. These findings are in conformity with those of Sarkar and Mallick (2009).

At all the crop growth stages, the interaction effect of row spacing, fertilizer levels and hybrids on dry matter accumulation in leaf was found to be not significant.

4.2.7 Dry matter accumulation in stem (g plant^{-1})

The data pertaining to dry matter accumulation in stem at various growth stages was significantly influenced by hybrids and fertilizer levels (Table 9). Dry matter accumulation in stem was increased with the progress of crop age.

At all the crop growth stages, the significant differences among the hybrids were observed in dry matter accumulation in stem. The greater stem dry matter was recorded in RSFH-12-700 (1.59, 66.57 and 72.59 g) over rest of the hybrids at 30, 60 DAS and at maturity, respectively.

At all the crop growth stages, row spacing had no significant effect on stem dry matter accumulation. However, dry matter accumulation in stem was significantly influenced by different levels of fertilizers at all the crop growth stages. At 30, 60 DAS and at maturity, greater stem dry matter accumulation was observed with the application of 150 per cent RDF (1.55, 64.11 and 73.22 g, respectively) over 100 per cent RDF (1.17, 46.53 and 50.00 g, respectively) but was comparable with 125 per cent RDF (1.48, 60.80 and 67.91 g, respectively). Due to better cell multiplication and elongation under sufficient nutrient availability, higher dry matter accumulation in stem was observed with 150 per cent RDF. These findings are in conformity with those of Sarkar and Mallick (2009) and Pavani *et al.* (2012).

Table 9. Dry matter accumulation in stem (g plant⁻¹) of sunflower hybrids as influenced by spacing and fertilizer levels at different growth stages

Treatment	H ₁ :RSFH-12-700		H ₂ :RSFH-12-705		H ₃ :RSFH 1887		
	S ₁	S ₂	S ₁	S ₂	S ₁	S ₂	Mean
30 DAS							
F ₁ :100%RDF	1.41	1.42	0.95	1.01	0.93	1.27	1.17
F ₂ :125%RDF	1.64	1.64	1.46	1.46	1.28	1.38	1.48
F ₃ :150%RDF	1.66	1.75	1.52	1.55	1.36	1.46	1.55
Mean	1.57	1.60	1.31	1.34	1.19	1.37	1.40
Mean of H	1.59		1.33		1.28		
Mean of S	1.36 (S ₁)		1.44 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.04	0.03	0.03	0.05	0.06	0.05	0.08
C.D. @ 5%	0.16	NS	0.10	NS	NS	NS	NS
60 DAS							
F ₁ :100%RDF	55.13	56.60	38.83	39.83	38.17	50.63	46.53
F ₂ :125%RDF	62.57	73.20	59.00	61.30	54.20	54.50	60.80
F ₃ :150%RDF	71.20	80.73	61.74	61.77	52.33	56.90	64.11
Mean	62.97	70.18	53.19	54.3	48.23	54.01	57.15
Mean of H	66.57		53.74		51.12		
Mean of S	54.80 (S ₁)		59.50 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	2.43	2.34	2.04	4.05	3.53	2.88	5.00
C.D. @ 5%	9.50	NS	5.96	NS	NS	NS	NS
At maturity							
F ₁ :100%RDF	56.83	57.83	44.83	45.27	44.60	50.67	50.00
F ₂ :125%RDF	78.03	78.17	70.87	72.03	51.70	56.67	67.91
F ₃ :150%RDF	81.63	83.07	75.60	76.17	54.87	68.00	73.22
Mean	72.16	73.02	63.76	64.49	50.39	58.45	63.71
Mean of H	72.59		64.13		54.42		
Mean of S	62.11 (S ₁)		65.32 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	2.06	1.98	2.24	3.44	3.89	3.17	5.50
C.D. @ 5%	8.06	NS	6.55	NS	NS	NS	NS

S₁: 60 cm × 30 cm; S₂: 75 cm × 30 cm

Combination of hybrids, row spacing and fertilizer rates had no significant effect on dry matter accumulation in stem throughout the crop season.

4.2.8 Dry matter accumulation in capitulum (g plant⁻¹)

Dry matter accumulated in sunflower capitulum at various growth stages was significantly influenced by hybrids and fertilizer levels (Table 10). It is evident from the data that there was considerable increase in dry matter accumulation in capitulum from 60 DAS to maturity in all the treatment combinations.

Among sunflower hybrids, RSFH-12-700 (10.23 and 47.15 g, respectively) accumulated significantly higher dry matter in capitulum at 60 DAS and at harvest as compared to RSFH-12-705 (8.66 and 43.83 g, respectively) and RSFH 1887 (7.78 and 41.24 g, respectively). Dry matter accumulation in head was maximum in RSFH-12-700 due to the higher head diameter and 1000 seed weight.

From the data, it could be observed that the dry matter accumulation in capitulum both at 60 DAS and at harvest did not differ significantly by row spacing.

The dry matter accumulation in capitulum was significantly influenced by rates of fertilizer. Application of 150 per cent RDF (10.00 and 47.00 g, respectively) recorded significantly greater dry matter in capitulum over 100 per cent RDF (7.62 and 40.13 g, respectively) and 125 per cent RDF at 60 DAS (9.13 g) and at maturity (45.10 g) but was found to be on par with the application of 125 per cent RDF. The higher percentage of dry matter accumulation in sunflower head might be due to increased photosynthetic capacity during head development and increased translocation of photosynthates from source to sink under adequate availability of nutrients. It was also evident from the greater head diameter and seed weight under 150 per cent RDF than others.

All the interaction effects between hybrids, spacing and fertilizer levels on dry matter accumulation in capitulum was found to be non significant both at 60 DAS and at maturity.

4.2.9 Relative chlorophyll readings (SPAD)

The data pertaining to SPAD chlorophyll meter readings of sunflower at different growth stages was significantly influenced by hybrids and fertilizer levels (Table 11 and Fig. 8). The SPAD values increased from 30 DAS, reached peak at 60 DAS and thereafter decreased towards maturity.

Table 10. Dry matter accumulation in capitulum (g plant⁻¹) of sunflower hybrids as influenced by spacing and fertilizer levels at different growth stages

Treatment	H ₁ : RSFH-12-700		H ₂ : RSFH-12-705		H ₃ : RSFH 1887		
	S ₁	S ₂	S ₁	S ₂	S ₁	S ₂	Mean
60 DAS							
F ₁ :100%RDF	8.93	8.93	6.76	7.10	6.53	7.47	7.62
F ₂ :125%RDF	9.97	11.03	9.20	9.20	7.27	8.10	9.13
F ₃ :150%RDF	10.83	12.03	9.83	9.87	7.97	9.33	10.00
Mean	9.91	10.67	8.59	8.72	7.26	8.30	8.91
Mean of H	10.23		8.66		7.78		
Mean of S	8.59 (S ₁)		9.23 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.19	0.19	0.18	0.33	0.33	0.27	0.46
C.D. @ 5%	0.75	NS	0.55	NS	NS	NS	NS
At maturity							
F ₁ :100%RDF	43.43	43.69	34.83	41.16	38.06	39.60	40.13
F ₂ :125%RDF	46.16	50.36	45.36	46.16	42.63	39.93	45.10
F ₃ :150%RDF	47.63	51.63	47.26	48.23	42.03	45.20	47.00
Mean	45.74	48.56	42.48	45.18	40.91	41.57	44.08
Mean of H	47.15		43.83		41.24		
Mean of S	43.04 (S ₁)		45.10 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.93	0.68	0.78	1.17	1.35	1.10	1.91
C.D. @ 5%	3.65	NS	2.27	NS	NS	NS	NS

S₁: 60 cm × 30 cm; S₂: 75 cm × 30 cm

The relative chlorophyll meter readings at different stages of crop growth were significantly influenced in different sunflower hybrids. At 30, 60 DAS and at maturity, RSFH-12-700 (32.2, 69.2 and 32.9, respectively) produced higher relative chlorophyll readings as compared to RSFH-12-705 (30.9, 67.4 and 31.6, respectively) and RSFH 1887 (29.9, 66.2 and 30.6, respectively). The effect of row spacing on chlorophyll readings was found to be non significant.

Rates of fertilizer application significantly influenced the relative chlorophyll readings at all the growth stages. The crop fertilized with 150 per cent RDF (32.0, 68.7 and 32.7, respectively) recorded significantly greater chlorophyll readings at 30, 60 DAS and at maturity and was superior over 100 per cent RDF (29.6, 66.1 and 30.4, respectively) but on par with the application of 125 per cent RDF (31.5, 68.1 and 32.2, respectively). The higher SPAD readings obtained under graded rates of fertilizer would probably be evident from LAD values and relatively higher plant N content due to higher leaf photosynthetic area coupled with persistence of the leaf area for relatively longer period. These results are in similar line with those of Pavani *et al.* (2012). Ullah and Akmal (2018) reported that sufficient nutrients availability for sunflower growth resulted in the highest green chlorophyll in plant parts which led to higher SPAD meter readings.

Chlorophyll meter readings were not significantly influenced by combination of row spacings and fertilizer rates at all the crop growth stages.

4.2.10 Normalized difference vegetation index (NDVI) readings

The data pertaining to NDVI at different crop growth stages was influenced by hybrids and fertilizer levels (Table 12). At all the crop growth stages, the significant differences in NDVI readings were observed among hybrids. Maximum NDVI readings were observed in RSFH-12-700 (0.74, 0.75 and 0.34) as compared to RSFH-12-705 (0.71, 0.71 and 0.30) and RSFH 1887 (0.68, 0.70 and 0.25) at 30, 60 DAS and at maturity, respectively. Whereas, NDVI readings were not significantly influenced by row spacing.

Effect of fertilizer rate on NDVI readings was found significant at all crop growth stages. At 30, 60 DAS and at maturity, the higher NDVI readings were observed with application of 150 per cent RDF (0.74, 0.74 and 0.30, respectively). It was on par with the application of 125 per cent RDF (0.73, 0.73 and 0.30, respectively) and found significantly superior over 100 per cent RDF (0.66, 0.71 and 0.27, respectively). Patil *et*

Table 11. Relative chlorophyll readings (SPAD) of sunflower hybrids as influenced by spacing and fertilizer levels at different growth stages

Treatment	H ₁ : RSFH-12-700		H ₂ : RSFH-12-705		H ₃ : RSFH 1887		
	S ₁	S ₂	S ₁	S ₂	S ₁	S ₂	Mean
30 DAS							
F ₁ : 100% RDF	30.7	30.8	28.6	29.5	28.5	29.8	29.6
F ₂ : 125% RDF	32.2	32.9	31.4	31.9	29.8	30.4	31.5
F ₃ : 150% RDF	33.1	33.6	32.1	32.1	30.2	31.1	32.0
Mean	32.0	32.4	30.7	31.2	29.5	30.4	30.0
Mean of H	32.2		30.9		29.9		
Mean of S	30.7 (S ₁)		31.3 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.4	0.3	0.4	0.5	0.7	0.5	0.9
C.D. @ 5%	1.6	NS	1.1	NS	NS	NS	NS
60 DAS							
F ₁ : 100% RDF	67.7	67.9	65.0	65.3	64.8	65.6	66.1
F ₂ : 125% RDF	69.6	69.8	68.2	68.5	66.0	66.6	68.1
F ₃ : 150% RDF	70.1	70.3	68.7	68.7	66.3	68.0	68.7
Mean	69.1	69.3	67.3	67.5	65.7	66.7	67.6
Mean of H	69.2		67.4		66.2		
Mean of S	67.4 (S ₁)		67.9 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.6	0.6	0.7	1.1	1.3	1.0	1.8
C.D. @ 5%	2.2	NS	2.2	NS	NS	NS	NS
At maturity							
F ₁ : 100% RDF	31.4	31.5	29.7	30.1	29.3	30.2	30.4
F ₂ : 125% RDF	33.1	33.6	32.2	32.3	30.4	31.2	32.2
F ₃ : 150% RDF	33.9	34.3	32.6	32.7	30.9	31.7	32.7
Mean	32.8	33.1	31.5	31.7	30.2	31.0	31.8
Mean of H	32.9		31.6		30.6		
Mean of S	31.5 (S ₁)		31.9 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.2	0.5	0.4	0.8	0.7	0.6	1.0
C.D. @ 5%	0.9	NS	1.2	NS	NS	NS	NS

S₁: 60 cm × 30 cm; S₂: 75 cm × 30 cm

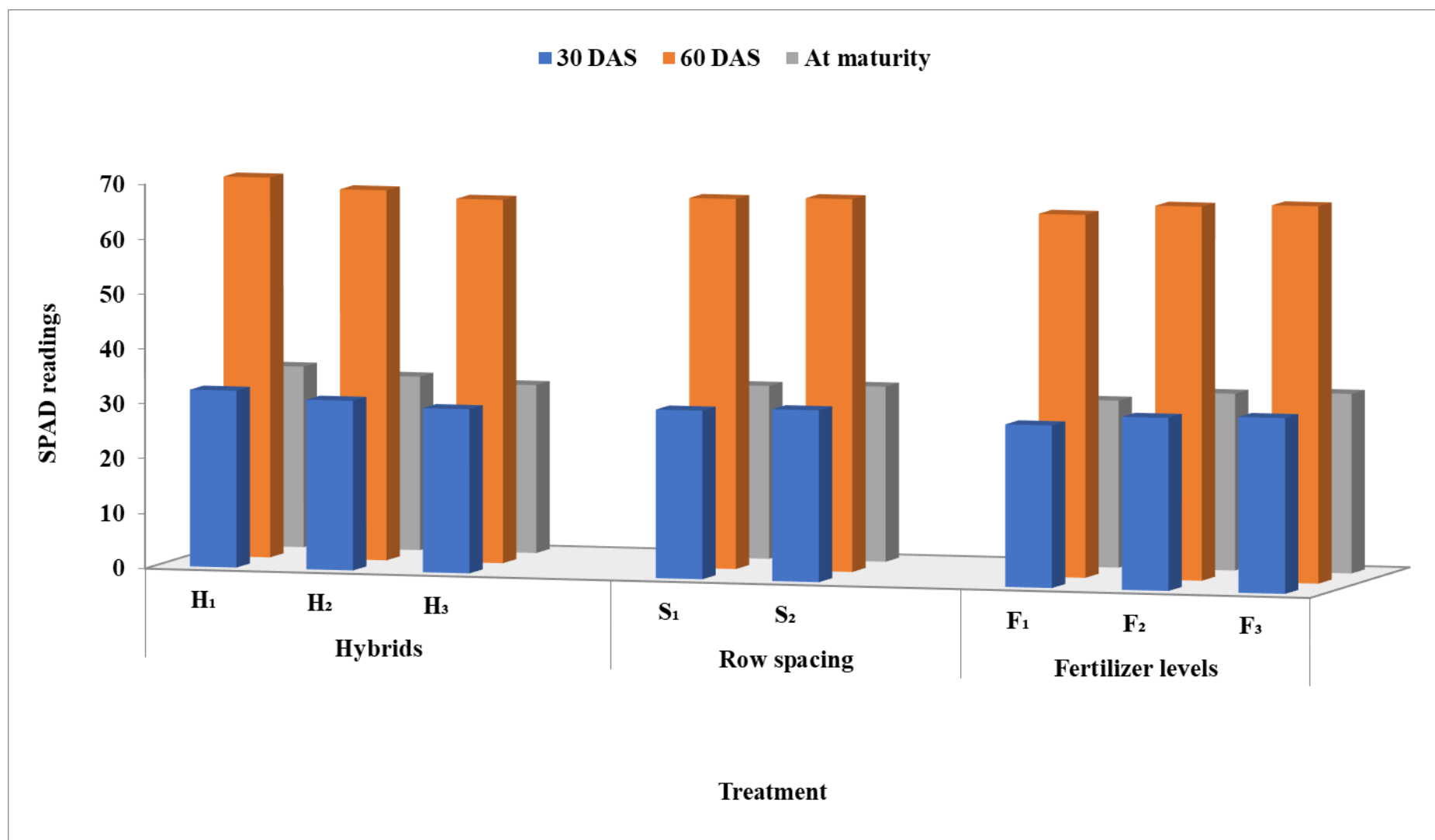


Fig. 8. SPAD readings of sunflower hybrids as influenced by spacing and fertilizer levels at different growth stages

Table 12. Green seeker readings (NDVI) of sunflower hybrids as influenced by spacing and fertilizer levels at different growth stages

Treatment	H ₁ : RSFH-12-700		H ₂ : RSFH-12-705		H ₃ : RSFH 1887		Mean
	S ₁	S ₂	S ₁	S ₂	S ₁	S ₂	
30 DAS							
F ₁ : 100% RDF	0.70	0.71	0.64	0.65	0.63	0.65	0.66
F ₂ : 125% RDF	0.76	0.76	0.73	0.74	0.69	0.71	0.73
F ₃ : 150% RDF	0.76	0.76	0.74	0.75	0.71	0.71	0.74
Mean	0.74	0.74	0.70	0.71	0.68	0.69	0.71
Mean of H	0.74		0.71		0.68		
Mean of S	0.70 (S ₁)		0.72 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.01	0.01	0.01	0.01	0.02	0.01	0.02
C.D. @ 5%	0.03	NS	0.02	NS	NS	NS	NS
60 DAS							
F ₁ : 100%RDF	0.74	0.73	0.70	0.70	0.68	0.70	0.71
F ₂ : 125%RDF	0.76	0.76	0.71	0.72	0.70	0.71	0.73
F ₃ : 150% RDF	0.77	0.77	0.72	0.73	0.71	0.72	0.74
Mean	0.76	0.75	0.71	0.72	0.70	0.71	0.73
Mean of H	0.75		0.71		0.70		
Mean of S	0.72 (S ₁)		0.73 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.01	0.01	0.01	0.01	0.01	0.01	0.02
C.D. @ 5%	0.03	NS	0.02	NS	NS	NS	NS
At maturity							
F ₁ : 100% RDF	0.31	0.31	0.28	0.30	0.22	0.22	0.27
F ₂ : 125% RDF	0.35	0.35	0.29	0.30	0.26	0.26	0.30
F ₃ : 150% RDF	0.35	0.35	0.27	0.31	0.28	0.26	0.30
Mean	0.34	0.34	0.28	0.30	0.25	0.25	0.29
Mean of H	0.34		0.30		0.25		
Mean of S	0.29 (S ₁)		0.30 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C.D. @ 5%	0.04	NS	0.02	NS	NS	NS	NS

S₁: 60 cm × 30 cm; S₂: 75 cm × 30 cm

al. (2016) indicated that greater application of nitrogen synthesized more chlorophyll and greenness of leaf which led to the less reflectance of canopy in cotton *i.e.*, higher NDVI values. With increase in nitrogen fertilization, NDVI values increased significantly. Similar results were reported by Silva *et al.* (2012) on sunflower crop. The NDVI readings were not significantly affected between hybrids, spacings and fertilizer levels.

4.2.11 Leaf area duration (LAD) (Days)

The data pertaining to the LAD at 0 to 30 DAS, 31 to 60 DAS and 61 DAS to maturity was influenced by hybrids, spacing and fertilizer levels (Table 13 and Fig. 9). The LAD increased gradually with the advancement of crop age.

Results showed that the significant effect of hybrids on LAD, at 0 to 30 DAS, 31 to 60 DAS and 61 DAS to maturity. RSFH-12-700 (9.1, 39.2 and 53.5 days, respectively) significantly the higher LAD followed by RSFH-12-705 (7.7, 34.3 and 47.3 days, respectively). Lowest LAD was observed in RSFH 1887 (6.4, 29.4 and 40.8 days, respectively). However, the cultivars with highest LAI and whose leaf surfaces lasted longer time had maximum LAD as reported by Miralles *et al.* (1997) in sunflower.

Row spacing at 60 cm (8.3, 37.4 and 51.5 days) recorded maximum and significantly more LAD over 75 cm (7.2, 31.2 and 42.9 days) row spacing at 0 to 30 DAS, 31 to 60 DAS and 61 DAS to maturity, respectively. Thus, narrow row spacing of 60 cm recorded significantly higher LAD compared to wider spacing of 75 cm. These findings are in close agreement with those of Awais *et al.* (2013).

The different levels of fertilizers significantly influenced LAD throughout the growth stages. LAD increased significantly with subsequent increase in fertilizer levels. Significantly maximum LAD was recorded with the application of 150 per cent RDF (8.8, 37.8 and 52.0 days) than 100 per cent RDF (6.2, 29.3 and 40.3 days) and was on par with the application of 125 per cent RDF (8.1, 35.8 and 49.3 days) at 0 to 30 DAS, 31 to 60 DAS and 61 DAS to maturity, respectively. Enhanced photosynthesis with increased nitrogen flow had positive effect of nitrogen on LAD. These results are in line with the earlier findings reported by Awais *et al.* (2013). Gungula *et al.* (2003) indicated that increased nitrogen application increased the photosynthesis rate and leaf durability.

All the interactions were found non significant at 0 to 30 DAS, 31 to 60 DAS and 61 DAS to maturity except hybrid and fertilizer level interaction at maturity stage. LAD was maximum (63.5 days) with the application of 150 per cent RDF to hybrid RSFH-12-

Table 13. Leaf area duration (days) at different growth stages as influenced by spacing and fertilizer levels of sunflower hybrids

Treatment	H ₁ : RSFH-12-700		H ₂ : RSFH-12-705		H ₃ : RSFH 1887		Mean
	S ₁	S ₂	S ₁	S ₂	S ₁	S ₂	
0 –30 DAS							
F ₁ : 100% RDF	7.9	6.4	6.5	5.6	5.3	5.6	6.2
F ₂ : 125% RDF	10.1	8.6	9.2	7.9	7.2	5.9	8.1
F ₃ : 150% RDF	11.9	9.6	9.3	7.9	7.3	6.8	8.8
Mean	9.9	8.2	8.3	7.1	6.6	6.1	7.7
Mean of H	9.1		7.7		6.4		
Mean of S	8.3 (S ₁)		7.2 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.2	0.2	0.3	0.3	0.6	0.5	0.8
C.D. @ 5%	0.9	0.7	1.0	NS	NS	NS	NS
31- 60 DAS							
F ₁ : 100% RDF	37.4	30.1	30.3	24.6	28.6	24.9	29.3
F ₂ : 125% RDF	44.6	36.6	41.3	33.7	31.5	27.4	35.8
F ₃ : 150% RDF	47.7	38.9	41.8	34.5	33.8	30.5	37.8
Mean	43.2	35.2	37.8	30.9	31.3	27.6	34.3
Mean of H	39.2		34.3		29.4		
Mean of S	37.4 (S ₁)		31.2 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.8	0.5	0.7	0.8	1.2	1.0	1.7
C.D. @ 5%	3.1	1.7	2.0	NS	NS	NS	NS
61 DAS – maturity							
F ₁ : 100% RDF	51.3	41.9	41.3	33.1	40.4	33.5	40.3
F ₂ : 125% RDF	61.0	50.1	57.6	46.2	43.9	37.3	49.3
F ₃ : 150% RDF	63.5	53.1	58.4	47.5	46.3	43.2	52.0
Mean	1.0	0.5	0.7	0.8	1.0	1.8	47.2
Mean of H	53.5		47.3		40.8		
Mean of S	51.5 (S ₁)		42.9 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	1.0	0.5	0.7	0.8	1.3	1.0	1.8
C.D. @ 5%	3.9	1.7	2.1	NS	3.7	NS	NS

S₁: 60 cm × 30 cm; S₂: 75 cm × 30 cm

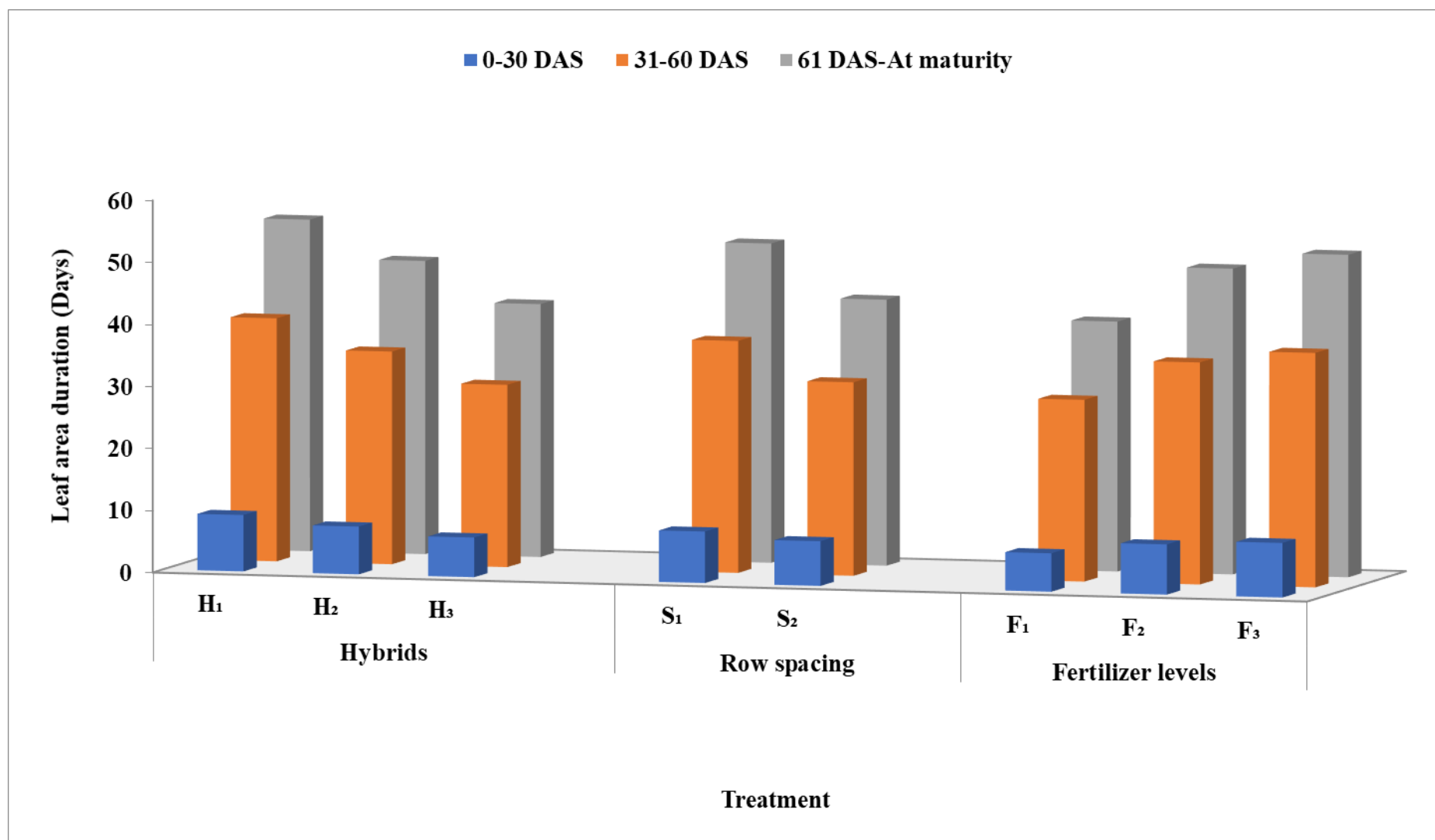


Fig. 9. Leaf area duration (days) of sunflower hybrids as influenced by spacing and fertilizer levels at different growth stage

700. It indicate newly developed hybrids responded to graded fertilizer rate over present recommendation.

4.2.12 Crop growth rate ($\text{g m}^{-2} \text{ day}^{-1}$)

Crop growth rate (CGR) was lower during the initial crop growth stage (30 DAS), it reached maximum at 60 DAS thereafter declined towards maturity. Sunflower hybrids affected the CGR significantly except at 61 DAS to maturity (Table 14). At 30 DAS ($0.96 \text{ g m}^{-2} \text{ day}^{-1}$) and 31-60 DAS ($17.15 \text{ g m}^{-2} \text{ day}^{-1}$) RSFH-12-700 recorded significantly higher CGR than RSFH-12-705 (0.87 and $15.80 \text{ g m}^{-2} \text{ day}^{-1}$, respectively) and RSFH 1887 (0.81 and $14.17 \text{ g m}^{-2} \text{ day}^{-1}$, respectively). Greater CGR in new hybrid was mainly due to increased leaf number, size and vegetative growth of plant.

Row spacing at 60 cm (0.97 and $17.18 \text{ g m}^{-2} \text{ day}^{-1}$) recorded significantly higher crop growth than wider spacing of 75 cm (0.79 and $14.23 \text{ g m}^{-2} \text{ day}^{-1}$) at 0-30 DAS and 31-60 DAS, respectively. Awais *et al.* (2013) opined that sunflower achieved more CGR with greater plant population due to higher interception of radiant light.

From the data, it was observed that there were significant differences among different fertilizer levels at 0 to 30 DAS and 31 to 60 DAS with respect to CGR. In general, there was a corresponding increase in CGR with increased fertilizer rate from 100 to 150 per cent RDF.

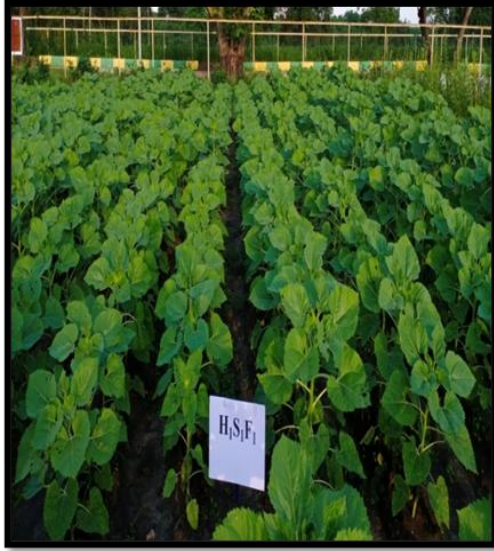
At 0 to 30 DAS crop fertilized with 150 per cent RDF recorded significantly greater CGR ($0.95 \text{ g m}^{-2} \text{ day}^{-1}$) over 100 per cent RDF ($0.79 \text{ g m}^{-2} \text{ day}^{-1}$) and was on par with 125 per cent RDF ($0.91 \text{ g m}^{-2} \text{ day}^{-1}$).

At 31-60 DAS, it was also observed that 150 per cent RDF ($17.74 \text{ g m}^{-2} \text{ day}^{-1}$) maintained its superiority over 100 per cent RDF ($12.27 \text{ g m}^{-2} \text{ day}^{-1}$) and was on par with 125 per cent RDF ($17.11 \text{ g m}^{-2} \text{ day}^{-1}$) which in turn were comparable with each other. Whereas, at 61 DAS to maturity there was no significant differences in CGR. Awais *et al.* (2015) opined that improvement in the CGR could be attributed to more vegetative growth due to increased photosynthesis at higher fertilizer rates. These results validate the findings of Nasim *et al.* (2011) who also indicated the positive effects of nitrogen on CGR of sunflower crop. Mondal *et al.* (2017) reported that greater LAI caused higher light

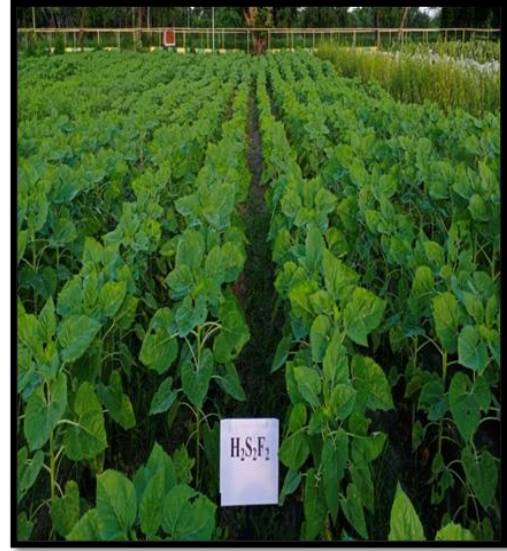
Table 14. Crop growth rate ($\text{g m}^{-2} \text{ day}^{-1}$) at different growth stages as influenced by spacing and fertilizer levels of sunflower hybrids

Treatment	H ₁ : RSFH-12-700		H ₂ : RSFH-12-705		H ₃ : RSFH 1887		
	S ₁	S ₂	S ₁	S ₂	S ₁	S ₂	Mean
0-30 DAS							
F ₁ : 100% RDF	0.95	0.77	0.82	0.68	0.82	0.69	0.79
F ₂ : 125% RDF	1.09	0.87	1.01	0.83	0.89	0.75	0.91
F ₃ : 150% RDF	1.14	0.92	1.05	0.85	0.93	0.78	0.95
Mean	1.06	0.85	0.96	0.79	0.88	0.74	0.88
Mean of H	0.96		0.87		0.81		
Mean of S	0.97 (S ₁)		0.79 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.01	0.01	0.02	0.02	0.04	0.03	0.05
C.D. @ 5%	0.04	0.05	0.06	NS	NS	NS	NS
31-60 DAS							
F ₁ : 100% RDF	14.94	11.80	12.59	10.20	12.14	11.95	12.27
F ₂ : 125% RDF	20.57	16.99	19.32	15.76	16.46	13.53	17.11
F ₃ : 150% RDF	21.65	16.95	20.51	16.40	16.47	14.47	17.74
Mean	19.05	15.25	17.47	14.12	15.02	13.32	15.71
Mean of H	17.15		15.80		14.17		
Mean of S	17.18 (S ₁)		14.23 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.45	0.37	0.46	0.65	0.79	0.65	1.12
C.D. @ 5%	1.76	1.29	1.34	NS	NS	NS	NS
61 DAS-maturity							
F ₁ : 100% RDF	4.21	3.57	5.80	4.51	5.95	3.42	4.58
F ₂ : 125% RDF	7.09	5.40	6.20	5.07	3.91	3.26	5.16
F ₃ : 150% RDF	6.46	5.43	6.56	5.34	4.23	4.63	5.44
Mean	5.92	4.80	6.19	4.97	4.70	3.77	5.06
Mean of H	5.36		5.58		4.23		
Mean of S	5.60 (S ₁)		4.52 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.29	0.36	0.59	0.62	1.0	0.84	1.46
C.D. @ 5%	NS	NS	NS	NS	NS	NS	NS

S₁: 60 cm × 30 cm; S₂: 75 cm × 30 cm



F₁: 100 % RDF



F₂: 125 % RDF



F₃: 150 % RDF

Plate 4. Plant stand of sunflower hybrids grown under different fertilizer levels at 30 DAS

interception which further enhanced CGR in mustard crop. At all the crop growth stages, combined effect of sunflower row spacing, fertilizer rate and hybrids had non significant effect on CGR.

4.2.13 Net assimilation rate (NAR) ($\text{g m}^{-2} \text{ day}^{-1}$)

The data on net assimilation rate (NAR) of sunflower was recorded at 31-60 DAS only and it was not significantly influenced by hybrids and row spacing except fertilizer rates (Table 15). Net assimilation rate was significantly influenced by fertilizer rate at 31-60 DAS. Application of 150 per cent RDF ($16.33 \text{ g m}^{-2} \text{ day}^{-1}$) recorded significantly higher NAR values and was on par with application of 125 per cent RDF ($16.28 \text{ g m}^{-2} \text{ day}^{-1}$) and significantly superior over 100 per cent RDF ($14.46 \text{ g m}^{-2} \text{ day}^{-1}$). Nasim *et al.* (2012) opined that higher net assimilation rate was observed with increased nitrogen consumption due to higher light utilization efficiency of sunflower crop. Furthermore, it might be due to increasing leaf area and photosynthesis by higher nutrient availability. Combined effect of row spacing, fertilizer rates and hybrids had no significant effect on NAR.

4.2.14 Relative growth rate ($\text{g g}^{-1} \text{ day}^{-1}$)

Relative growth rate (RGR) increased from initial stage from 30 to 60 DAS and reached minimum value at maturity. The data pertaining to relative growth rate at 0 to 30, 31 to 60 and 61 DAS to maturity was influenced by different treatments (Table 16).

Hybrid RSFH-12-700 ($0.058 \text{ g g}^{-1} \text{ day}^{-1}$) recorded maximum value of RGR than RSFH-12-705 ($0.055 \text{ g g}^{-1} \text{ day}^{-1}$) and RSFH 1887 ($0.053 \text{ g g}^{-1} \text{ day}^{-1}$) at 30 DAS. At 31-60 DAS and 61 DAS to maturity, RGR values did not reach the level of significance. The relative growth rate was not significantly influenced by row spacings at both 60 and 75 cm.

At 0-30 DAS and 31 to 60 DAS, application of 150 per cent RDF (0.058 and $0.009 \text{ g g}^{-1} \text{ day}^{-1}$, respectively) recorded significantly higher RGR values and was also similar with application of 125 per cent RDF (0.056 and $0.100 \text{ g g}^{-1} \text{ day}^{-1}$, respectively) and significantly superior over 100 per cent RDF (0.052 and $0.095 \text{ g g}^{-1} \text{ day}^{-1}$, respectively). At later stages, there were no significant differences due to fertilizer levels on RGR. Application of graded fertilizer rates improved RGR due to good crop growth attained by crop under good supply of nutrients. Ravichandran and Srinivasan (2017) reported that application of fertilizers resulted in enhanced RGR due to the more number

Table 15. Net assimilation rate ($\text{g m}^{-2} \text{ day}^{-1}$) as influenced by spacing and fertilizer levels of sunflower hybrids

Treatment	H ₁ : RSFH-12-700		H ₂ : RSFH-12-705		H ₃ : RSFH 1887		Mean
	S ₁	S ₂	S ₁	S ₂	S ₁	S ₂	
31-60 DAS							
F ₁ : 100% RDF	15.40	15.31	13.88	13.78	13.54	14.85	14.46
F ₂ : 125% RDF	16.20	15.99	16.34	16.03	16.82	16.32	16.28
F ₃ : 150% RDF	15.81	15.99	17.34	16.81	16.25	15.79	16.33
Mean	15.60	15.56	15.20	15.67	16.43	16.55	15.85
Mean of H	15.78		15.70		15.60		
Mean of S	15.73 (S ₁)		15.65 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.57	0.39	0.50	0.68	0.87	0.71	1.23
C.D. @ 5%	NS	NS	1.47	NS	NS	NS	NS

S₁: 60 cm × 30 cm; S₂: 75 cm × 30 cm

Table 16. Relative growth rate ($\text{g g}^{-1} \text{ day}^{-1}$) at different growth stages as influenced by spacing and fertilizer levels of sunflower hybrids

Treatment	H ₁ : RSFH-12-700		H ₂ : RSFH-12-705		H ₃ : RSFH 1887		
	S ₁	S ₂	S ₁	S ₂	S ₁	S ₂	Mean
0-30 DAS							
F ₁ : 100% RDF	0.055	0.055	0.050	0.051	0.049	0.051	0.052
F ₂ : 125% RDF	0.059	0.059	0.056	0.057	0.052	0.054	0.056
F ₃ : 150% RDF	0.061	0.061	0.058	0.058	0.053	0.055	0.058
Mean	0.058	0.058	0.055	0.055	0.051	0.053	0.055
Mean of H	0.058		0.055		0.053		
Mean of S	0.055 (S ₁)		0.056 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.001	0.001	0.001	0.001	0.001	0.001	0.002
C.D. @ 5%	0.003	NS	0.002	NS	NS	NS	NS
31-60 DAS							
F ₁ : 100% RDF	0.098	0.098	0.093	0.093	0.092	0.096	0.095
F ₂ : 125% RDF	0.100	0.100	0.100	0.100	0.099	0.098	0.100
F ₃ : 150% RDF	0.100	0.100	0.101	0.100	0.100	0.099	0.100
Mean	0.099	0.099	0.098	0.097	0.097	0.097	0.098
Mean of H	0.099		0.098		0.097		
Mean of S	0.098 (S ₁)		0.098 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.001	0.001	0.001	0.002	0.002	0.002	0.003
C.D. @ 5%	NS	NS	0.003	NS	NS	NS	NS
61 DAS-maturity							
F ₁ : 100% RDF	0.008	0.008	0.012	0.011	0.012	0.008	0.010
F ₂ : 125% RDF	0.009	0.009	0.010	0.010	0.008	0.008	0.009
F ₃ : 150% RDF	0.009	0.009	0.010	0.010	0.008	0.009	0.009
Mean	0.008	0.008	0.011	0.010	0.009	0.008	0.009
Mean of H	0.009		0.010		0.009		
Mean of S	0.010 (S ₁)		0.009 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.001	0.001	0.001	0.001	0.001	0.001	0.002
C.D. @ 5%	NS	NS	NS	NS	NS	NS	NS

S₁: 60 cm × 30 cm; S₂: 75 cm × 30 cm

of leaves per hill and leaf area per hill. At all the crop growth stages, the combined effect of hybrids, row spacing and fertilizer rate did not significantly influence RGR.

4.3 Yield and yield parameters

The data on head diameter (cm), 100 seed weight (g), seed volume (g/100 ml), threshing percentage (%), grain yield (kg ha⁻¹), stalk yield (kg ha⁻¹), harvest index, oil content (%) and oil yield (kg ha⁻¹) of sunflower hybrids as influenced by row spacing and fertilizer rate are presented as below.

4.3.1 Head diameter (cm)

The head diameter was significantly influenced by fertilizer levels of sunflower hybrids at maturity (Table 17). Significantly greater head diameter was recorded in hybrid RSFH-12-705 (19.88 cm) which was on par with RSFH-12-700 (18.64 cm). Lowest head diameter was observed in RSFH 1887 (16.79 cm). This could be mainly due to genetic make-up of the crop. The results are in line with earlier findings of Ali *et al.* (2013).

It was observed from the data that there was no significant differences observed in terms of head diameter due to row spacing. However, the varied fertilizer rates significantly influenced head diameter. Increased head diameter was favoured by application of graded fertilizer rate. Significantly larger head diameter was noticed in 150 per cent RDF (19.61 cm) and was superior over 125 per cent RDF (18.43 cm) and was lowest by application of 100 per cent RDF (17.24 cm). Waqas *et al.* (2017) opined that improvement in head diameter was attributed to more vegetative growth due to increased plant's metabolic activities. Babu *et al.* (2013) confirmed that higher NP fertilization contributed to better carbohydrates assimilation thereby increased head size. Ali *et al.* (2004), Malik *et al.* (2004) and Nasim *et al.* (2011) also reported that sunflower head diameter was enhanced by increased level of N, P and K. Head diameter was not significantly influenced by combination of spacing and fertilizer levels.

4.3.2 100 seed weight (g)

The data on hundred seed weight was influenced by hybrids (Table 17). Among the sunflower hybrids, RSFH-12-700 (5.84 g) recorded significantly higher seed weight and was on par with hybrid RSFH-12-705 (5.66 g) and lowest in RSFH-1887 (5.07 g). These findings are in conformity with the findings of Ahmad *et al.* (2001) and Bakth *et al.* (2006).

Further, there were no significant differences influenced by different row spacings and fertilizer rate. Individual seed weight being a genetic character, have not been significantly influenced by different treatment combinations except hybrids. All the interactions of hybrid, row spacing and fertilizer rate was found to be significant except hybrids $\times$ row spacing with respect to 100 seed weight.

4.3.3 Seed volume (g/100 ml)

Data on sunflower seed volume (g/100 ml) differed significantly by different hybrids, row spacing and fertilizer levels (Table 17 and Fig. 12). The significant differences among the hybrids were observed in respect with seed volume. The hybrid, RSFH-12-700 (45.29 g/100 ml) recorded maximum seed volume and was significantly superior to RSFH-12-705 (41.73 g/100 ml) and RSFH 1887 (39.24 g/100 ml). Sunflower row spacing had significant effect on seed volume significantly, greater in 60 cm (41.70 g/100 ml) over 75 cm (41.15 g/100 ml) row spacing.

Application of fertilizers at the rate of 150 per cent RDF (42.51 g/100 ml) recorded significantly greater seed volume over 125 per cent RDF (41.05 g/100 ml). However, application of 125 and 100 per cent RDF (40.72 g/100 ml) was found on par with each other. The higher seed volume might be due to higher photosynthetic rate that had resulted in more translocation of photosynthates from source to sink. Interaction viz., $H \times S$, $S \times F$ and $H \times S \times F$ significantly influenced the seed volume except $H \times F$.

4.3.4 Seed filling percentage (%)

Data on sunflower seed filling percentage (%) differed significantly by hybrids and fertilizer levels (Table 17). The significant differences among the hybrids were observed in respect with seed filling percentage. The hybrid, RSFH-12-700 (78.15 %) recorded maximum seed filling percentage and was significantly superior to RSFH-12-705 (74.83 %) and RSFH 1887 (72.47 %). This was due to higher leaf area and dry matter which reflected in production of more number of filled seeds thereby higher seed filling percentage. Similar findings were reported by Lodh (1988). Sunflower row spacing did not show any significant differences with respect to seed filling percentage.

Application of fertilizers at the rate of 150 per cent RDF (77.43 %) recorded significantly greater seed filling percentage over 100 per cent RDF (71.70 %) and on par

Table 17. Yield attributing characters of sunflower hybrids as influenced by row spacing and fertilizer application

Treatment	Head diameter (cm)		100 seed weight (g)		Seed volume (g/100 ml)		Seed filling percentage	
<i>Hybrids (H)</i>								
H ₁ : RSFH-12-700	18.64		5.84		45.29		78.15	
H ₂ : RSFH-12-705	19.88		5.66		41.73		74.83	
H ₃ : RSFH-1887	16.79		5.07		39.24		72.47	
S. Em ±	0.33		0.07		0.21		1.08	
C.D. (P=0.05)	1.27		0.28		0.84		4.20	
<i>Spacing (S)</i>								
S ₁ : 60 cm × 30 cm	18.45		5.03		41.70		75.46	
S ₂ : 75 cm × 30 cm	18.41		5.11		41.15		75.84	
S.Em. ±	0.19		0.05		0.10		1.00	
C.D. (P=0.05)	NS		NS		0.36		NS	
<i>Fertilizer levels (F)</i>								
F ₁ : 100% RDF	17.24		5.49		40.72		71.70	
F ₂ : 125% RDF	18.43		5.53		41.05		76.31	
F ₃ : 150% RDF	19.61		5.55		42.51		77.43	
S.Em. ±	0.21		0.04		0.26		1.03	
C.D. (P=0.05)	0.62		NS		0.76		3.00	
<i>Interaction</i>	S.Em. ±	C.D. @5%	S.Em. ±	C.D. @ 5%	S.Em. ±	C.D. @ 5%	S.Em. ±	C.D. @ 5%
H × S	0.32	NS	0.08	NS	0.18	0.62	1.73	NS
H × F	0.37	NS	0.06	0.19	0.45	NS	1.78	NS
S × F	0.30	NS	0.05	0.15	0.37	1.07	1.45	NS
H × S × F	0.52	NS	0.09	0.26	0.64	1.86	2.52	NS

with 125 per cent RDF (76.31 %). However, application of 150 and 125 per cent RDF was found on par with each other. Seghatoleslami *et al.* (2012) reported that filled seed number per head increased with the increase in fertilizer level due to increased head diameter mainly through increasing plant photosynthesis potential, leaf area index and duration and providing assimilates which it allowed the formation of more filled seeds per head.

Interaction effect of row spacing, fertilizer levels and hybrids on seed filling percentage was found to be not significant.

4.3.5 Threshing percentage (%)

The data on threshing percentage significantly differed among sunflower hybrids, and fertilizer rate (Table 20). The hybrid, RSFH-12-700 (72.58 %) recorded significantly higher threshing percentage over RSFH-12-705 (70.10 %) and RSFH 1887 (68.47 %). Row spacings of 60 cm and 75 cm did not show any significant differences with respect to threshing percentage. Application of fertilizer rate at 150 per cent RDF (72.00 %) recorded maximum threshing percentage and was on par with the application of 125 per cent RDF (70.80 %), but superior to 100 per cent RDF (68.37 %). The interactions between spacings, fertilizer rates and hybrids did not showed level of significance.

4.3.6 Seed yield (kg ha⁻¹)

Seed yield of sunflower was significantly influenced by hybrids and fertilizer levels (Table 18 and Fig. 10). The sunflower hybrid RSFH-12-700 (2144 kg ha⁻¹) recorded significantly higher seed yield followed by RSFH 12-705 (1996 kg ha⁻¹) and RSFH 1887 (1855 kg ha⁻¹). The improvement in seed yield of hybrid RSFH-12-700 and RSFH-12-705 were 15.58 % and 7.60 %, respectively over RSFH 1887. The differences among hybrids for seed yield could be attributed to LAI, head diameter, number of seeds per head and 100 seed weight which is in turn depended on the genetic potential and better adaptability of hybrids under present climatic conditions. These results are in confirmity with the findings of Ekin *et al.* (2005) and Ali *et al.* (2007). There were no significant differences observed in terms of seed yield due to different row spacings.

Different rates of fertilizer exerted significant influence on seed yield of sunflower hybrids. Among them, application of 150 per cent RDF (2104 kg ha⁻¹) recorded significantly higher seed yield over 100 per cent RDF (1840 kg ha⁻¹) but was on par with

the application of 125 per cent RDF (2051 kg ha⁻¹). Remarkable improvement in seed yield were 14.34 % and 11.47 % with application of 150 per cent and 125 per cent RDF over 100 per cent RDF.

Syed *et al.* (2006) confirmed that the higher seed yield could be attributed to an improved yield attributing characters viz., head diameter, number of filled seeds and test weight under sufficient supply of fertilizers. Head diameter is the most important character that enhances seed yield by providing maximum florets for higher seed set. Significantly higher dry matter production and its accumulation in different plant parts had an indirect impact on the grain yield and relied on various growth functions viz., plant height, number of leaves, leaf area and leaf area index. The combined effect of growth and yield components was reflected on higher seed yield. These results find support from those of Reddy *et al.* (2002c) and Sarakar and Mallick (2009). Thavaprakash and Malligawad (2002) stated that accumulation of more dry matter in the leaves in treatments with higher supply of N and P produced more leaf area per plant, thereby improving the supply of photosynthates and in turn increasing the seed yield of sunflower. Babu *et al.* (2013) opined that better partitioning of photosynthates from source to sink could have resulted in higher yield attributes that ultimately resulted in higher yield of sunflower. Interaction effect of spacing and fertilizer levels of sunflower hybrids were not significantly influenced on seed yield.

4.3.7 Stalk yield (kg ha⁻¹)

The data on stalk yield was significantly affected by the hybrids and fertilizer levels (Table 18 and Fig. 11). Sunflower hybrid, RSFH-12-700 (3158 kg ha⁻¹) produced maximum stalk yield which is significantly superior over RSFH-12-705 (2894 kg ha⁻¹) and RSFH 1887 (2669 kg ha⁻¹). Higher stalk yield in RSFH-12-700 was attributed to superior growth and yield attributing characters. Sunflower stalk yield was not significantly influenced by row spacing.

Among the rates of fertilizer, application of 150 per cent RDF (3361 kg ha⁻¹) recorded significantly higher stalk yield over 125 per cent RDF (2913 kg ha⁻¹) and 100 per cent RDF (2448 kg ha⁻¹). The magnitude of increase due to application of 150 per cent RDF was 37.29 % and 15.37 % over 100 per cent RDF and 125 per cent RDF plots, respectively. It was highest with the application of 150 per cent RDF due to the higher plant height, number of leaves, leaf area, head diameter and capitulum weight. Waqas *et*

al. (2017) reported that biomass yield enhancement was due to the increment of NPK by efficient photosynthetic activity and nutrient uptake which increased sunflower growth and development. Combined effect of row spacing, fertilizer rate and sunflower hybrids was not significantly influenced on stalk yield.

4.3.8 Harvest index (HI)

The significant results in harvest index were found among the sunflower hybrids, row spacing and fertilizer levels (Table 18). The hybrid, RSFH-12-700 (0.39) recorded higher HI, which was followed by RSFH-12-705 (0.38) and both were significantly superior over RSFH 1887 (0.34). Higher HI in RSFH-12-700 was due to efficient translocation of photosynthates towards seed formation which was expressed in seed yield. Nasim *et al.* (2012) opined that higher HI for a hybrid was due to its genotypic dominance to utilize more photo-assimilates for seed yield formation. Similar results were also reported by Gholinezhad *et al.* (2009).

The remarkable HI difference was observed between row spacings. However, row spacing of 75 cm (0.39) recorded maximum HI as compared to 60 cm (0.36). Gholinezhad *et al.* (2009) reported that increased plant density has resulted in decreased HI due to severe reduction of assimilates distribution to grain. Higher HI in sunflower might be due to minimum plants per unit area which received maximum balanced fertilizer, plenty of sunlight and space, as a result produced large discs with large seed size and maximum number of seed per disc. The results were also supported by Khakwani *et al.* (2014).

Remarkable differences in harvest index were noticed among fertilizer rates. The maximum HI was observed in 125 per cent RDF (0.41) which was significantly higher than 150 (0.37) and 100 per cent RDF (0.34). However, application of 150 and 100 per cent RDF was found to be at par with each other. Higher HI with the application of 125 per cent RDF was due to higher seed yield and optimal NPK supply. Khakwani *et al.* (2014) reported that highest HI under minimum sunflower plants per unit area was due to maximum balanced fertilizers, greater sunlight and space. Waqas *et al.* (2017) also stated that increased HI might be due to optimum supply of the NPK for their magnanimous role in vegetative and reproductive phase of the plant. The results are also in line with the

Table 18. Seed yield, stalk yield and harvest index of sunflower hybrids as influenced by row spacing and fertilizer application (H×S×F) interaction

Treatment	H ₁ : RSFH-12-700		H ₂ : RSFH-12-705		H ₃ : RSFH 1887		
	S ₁	S ₂	S ₁	S ₂	S ₁	S ₂	Mean
Seed yield (kg ha ⁻¹)							
F ₁ : 100% RDF	1944	1953	1810	1814	1701	1819	1840
F ₂ : 125% RDF	2199	2223	2035	2097	1841	1913	2051
F ₃ : 150% RDF	2233	2312	2109	2112	1881	1977	2104
Mean	2125	2163	1985	2008	1808	1903	1998
Mean of H	2144		1996		1855		
Mean of S	1972 (S ₁)		2024 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	23	17	25	29	43	35	61
C.D. @ 5%	91	NS	73	NS	NS	NS	NS
Stalk yield (kg ha ⁻¹)							
F ₁ : 100% RDF	3204	2455	1783	2144	2469	2629	2448
F ₂ : 125% RDF	3385	2973	3351	2895	2547	2326	2913
F ₃ : 150% RDF	3748	3184	3911	3279	2788	3255	3361
Mean	3445	2870	3015	2772	2601	2736	2907
Mean of H	3158		2894		2669		
Mean of S	3021 (S ₁)		2794 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	65	66	132	115	229	187	324
C.D. @ 5%	255	NS	386	NS	NS	NS	NS
Harvest index							
F ₁ : 100% RDF	0.29	0.40	0.44	0.36	0.28	0.29	0.34
F ₂ : 125% RDF	0.40	0.45	0.36	0.40	0.38	0.42	0.41
F ₃ : 150% RDF	0.38	0.43	0.33	0.37	0.36	0.34	0.37
Mean	0.35	0.42	0.37	0.37	0.34	0.35	0.37
Mean of H	0.39		0.38		0.34		
Mean of S	0.36 (S ₁)		0.39 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.01	0.01	0.02	0.01	0.03	0.02	0.04
C.D. @ 5%	0.03	0.03	0.04	NS	NS	NS	NS

S₁: 60 cm × 30 cm; S₂: 75 cm × 30 cm

Table 19. Seed yield, stalk yield and harvest index of sunflower hybrids as influenced by row spacing and fertilizer application

Treatment	Seed yield (kg ha ⁻¹)		Stalk yield (kg ha ⁻¹)		Harvest index	
<i>Hybrids (H)</i>						
H ₁ : RSFH-12-700	2144		3158		0.39	
H ₂ :RSFH-12-705	1996		2894		0.38	
H ₃ : RSFH-1887	1855		2669		0.34	
S. Em ±	23		65		0.01	
C.D. (P=0.05)	91		255		0.03	
<i>Spacing (S)</i>						
S ₁ : 60 cm × 30 cm	1972		3021		0.36	
S ₂ :75 cm × 30 cm	2024		2794		0.39	
S.Em. ±	17		66		0.01	
C.D. (P=0.05)	NS		NS		0.03	
<i>Fertilizer levels (F)</i>						
F ₁ : 100% RDF	1840		2448		0.34	
F ₂ : 125% RDF	2051		2913		0.41	
F ₃ :150% RDF	2104		3361		0.37	
S.Em. ±	25		132		0.02	
C.D. (P=0.05)	73		386		0.04	
<i>Interaction</i>	S.Em. ±	C.D. @5%	S.Em. ±	C.D.@ 5%	S.Em. ±	C.D.@ 5%
H × S	29	NS	115	NS	0.01	NS
H × F	43	NS	229	NS	0.03	NS
S × F	35	NS	187	NS	0.02	NS
H × S × F	61	NS	324	NS	0.04	NS

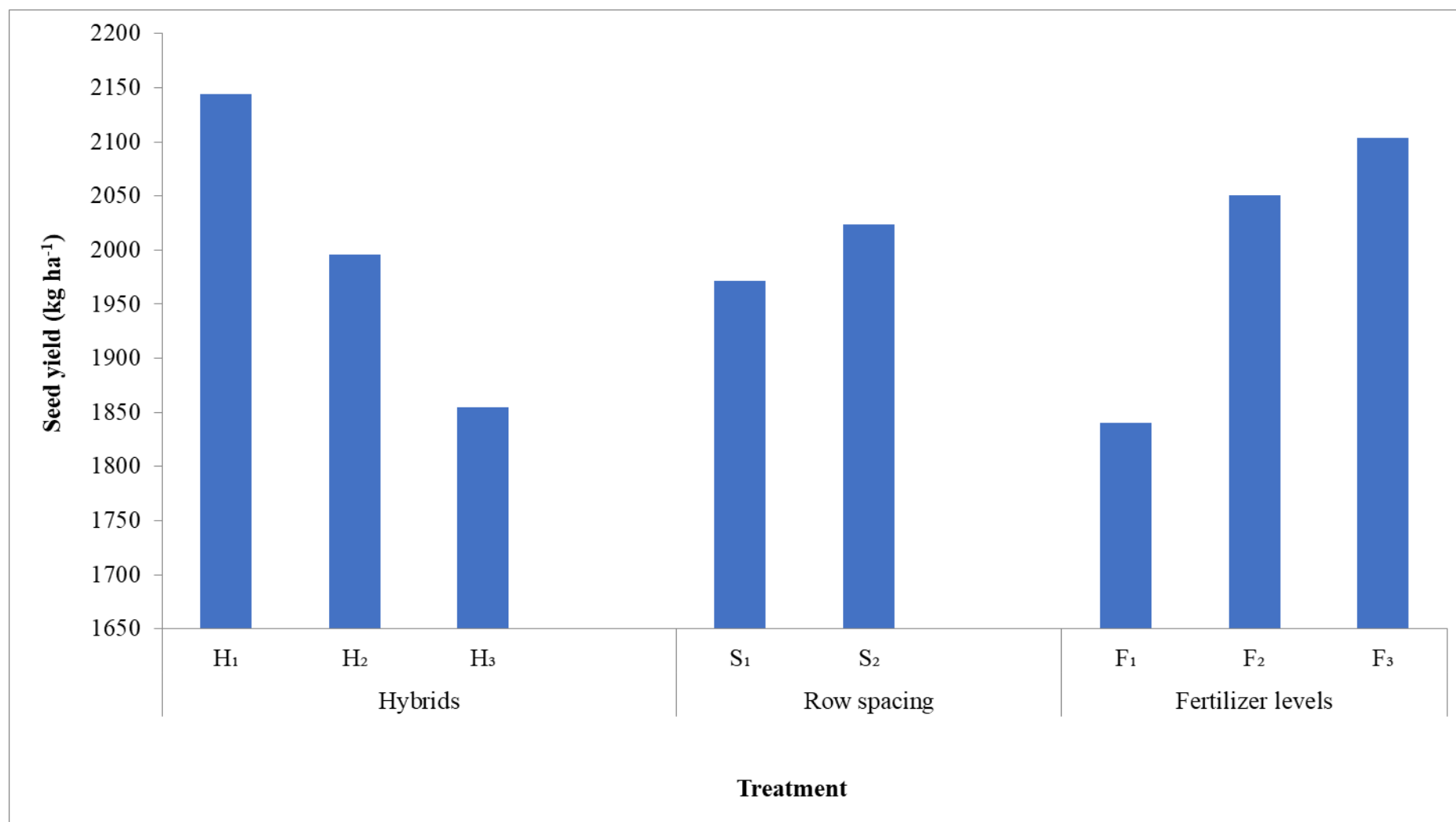


Fig. 10. Seed yield (kg ha⁻¹) of sunflower hybrids as influenced by spacing and fertilizer levels

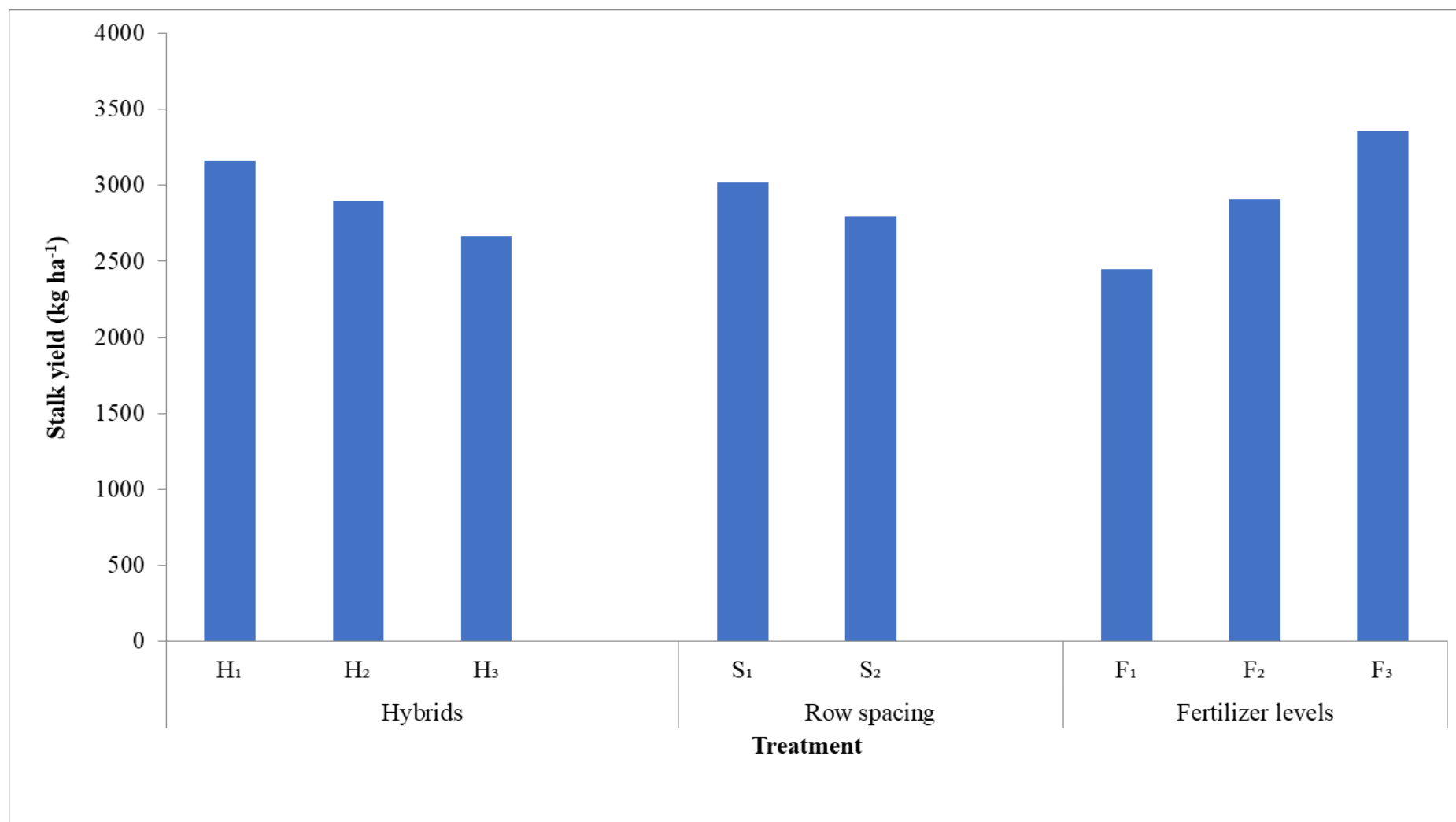


Fig. 11. Stalk yield (kg ha⁻¹) of sunflower hybrids as influenced by spacing and fertilizer levels

work of Thavaprakash *et al.* (2003). Interaction effect of row spacing, fertilizer levels and hybrids on harvest index was found to be not significant.

4.4 Quality parameters

4.4.1 Oil content (%)

Seed oil content of sunflower hybrids was significantly influenced by hybrids and fertilizer rates (Table 20 and Fig. 12).

Among the sunflower hybrids, RSFH-12-700 recorded highest oil content (38.42 %) over other two hybrids. While, RSFH-12-705 (36.94 %) and RSFH 1887 (36.31 %) were found to be on par with each other. Kaleem *et al.* (2011) reported that differential oil content in sunflower hybrids was due to their genetic potential as well as interactive effects of environmental variables during achene development and physiological maturity of the crop. Khan *et al.* (2012) also reported that the differences may be due to its genetic superiority over other hybrids. There was no significant effect of row spacing on seed oil content of all the hybrids. However, seed oil content was significantly influenced by different rates of fertilizers. Application of 150 per cent RDF (38.00 %) recorded significantly higher oil content but it was on par with 125 per cent RDF (37.42 %) and both were significantly higher than 100 per cent RDF (36.27). Mollashahi *et al.* (2013) reported that application of higher dose of N increased oil content in seed by increased vegetative growth and production of more carbohydrate in plant thereby transferring to seeds and also higher levels of K fertilizer increased the oil content. These results are in agree with Scheiner *et al.* (2002) who reported that reduction of seed oil content due to N addition was relatively small (2 to 5 %) and was over compensating by the seed yield at the responsive site. Interaction effect of row spacing, fertilizer levels and hybrids on oil content was found non-significant.

4.4.2 Oil yield (kg ha⁻¹)

The data pertaining to oil yield differed significantly by hybrids and fertilizer levels (Table 20 and Fig. 13). Oil yield was significantly influenced by sunflower hybrids. The hybrid RSFH-12-700 (820 kg ha⁻¹) recorded maximum oil content and found significantly superior over RSFH-12-705 (740 kg ha⁻¹) and RSFH 1887 (678 kg ha⁻¹). The increase in oil yield owing to RSFH-12-700 and RSFH-12-705 over RSFH 1887 was 20.94 % and 9.14 %, respectively. Differences in oil yield was mainly indicated by oil

Table 20. Oil content, oil yield and threshing percentage of sunflower hybrids as influenced by row spacing and fertilizer application

Treatment	H ₁ : RSFH-12-700		H ₂ : RSFH-12-705		H ₃ : RSFH 1887		
	S ₁	S ₂	S ₁	S ₂	S ₁	S ₂	Mean
Oil content (%)							
F ₁ : 100% RDF	36.99	37.17	35.92	35.95	35.66	35.93	36.27
F ₂ : 125% RDF	38.61	38.91	37.07	37.07	36.32	36.53	37.42
F ₃ : 150% RDF	39.31	39.54	37.67	37.97	36.51	36.90	38.00
Mean	38.30	38.54	37.00	37.00	36.16	36.45	37.23
Mean of H	38.42		36.94		36.31		
Mean of S	37.12 (S ₁)		37.33 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.41	0.40	0.44	0.70	0.76	0.62	1.07
C.D. @ 5%	1.60	NS	1.28	NS	NS	NS	NS
Oil yield (kg ha ⁻¹)							
F ₁ : 100% RDF	715	721	651	654	611	657	668
F ₂ : 125% RDF	845	859	756	779	673	703	769
F ₃ : 150% RDF	872	908	796	804	691	734	801
Mean	811	829	734	746	658	698	746
Mean of H	820		740		678		
Mean of S	734 (S ₁)		757 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	9	8	12	13	21	17	30
C.D. @ 5%	35	NS	36	NS	NS	NS	NS
Threshing %							
F ₁ : 100% RDF	69.63	70.00	67.76	67.88	66.95	68.01	68.37
F ₂ : 125% RDF	72.63	73.07	70.39	71.44	68.43	68.86	70.80
F ₃ : 150% RDF	74.99	75.17	71.52	71.62	68.43	70.13	72.00
Mean	72.42	72.75	69.89	70.31	67.94	69.00	70.39
Mean of H	72.58		70.10		68.47		
Mean of S	70.08 (S ₁)		70.69 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	0.78	0.70	0.83	1.22	1.44	1.18	2.04
C.D. @ 5%	3.06	NS	2.43	NS	NS	NS	NS

S₁: 60 cm × 30 cm; S₂: 75 cm × 30 cm

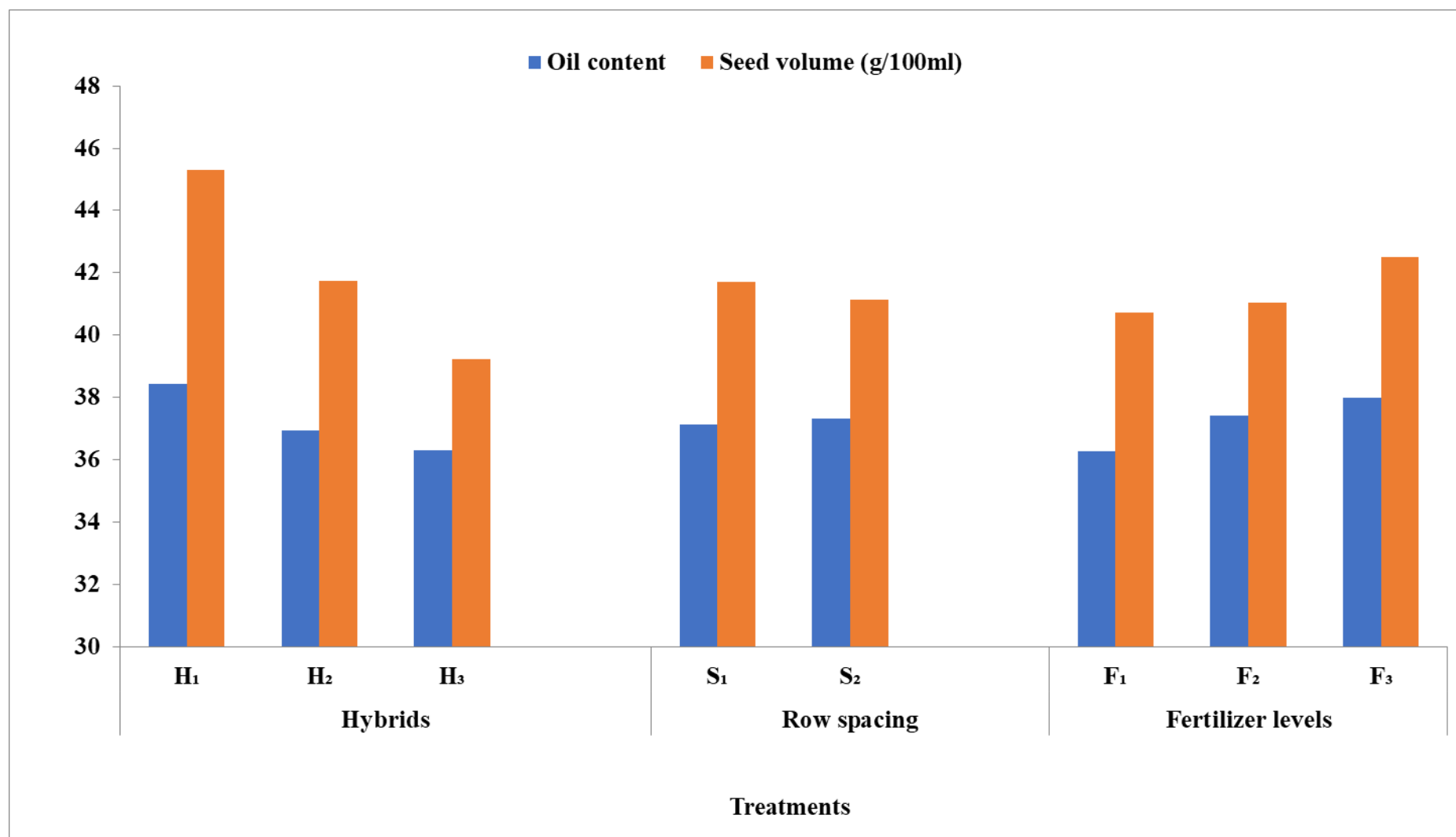


Fig. 12. Oil content (%) and seed volume (g/100 ml) of sunflower hybrids as influenced by spacing and fertilizer levels

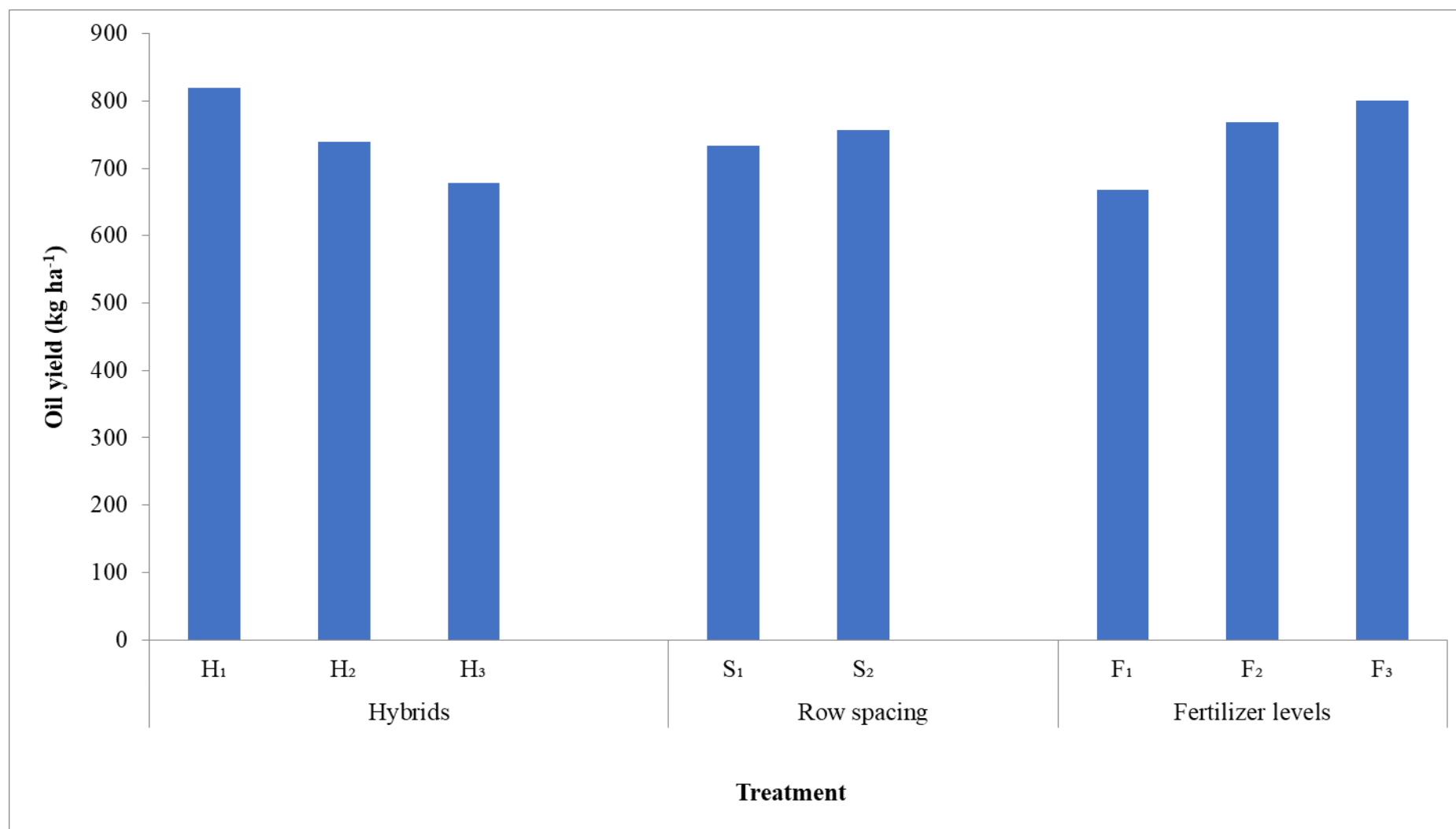


Fig. 13. Oil yield (kg ha⁻¹) of sunflower hybrids as influenced by spacing and fertilizer levels

content and seed yield. Ekin *et al.* (2005) observed differences in oil yield of sunflower and attributed it to variations in seed yield. Similarly, Girme (2009) also reported that higher oil per cent and seed yield that has resulted greater oil yield.

There was no significant difference observed in terms of oil yield (kg ha^{-1}) due to plant spacing. The non significant seed yield and oil content recorded under different spacings was also reflected in oil yield.

Oil yield was significantly influenced by different fertilizer rates. Application of 150 per cent RDF (801 kg ha^{-1}) recorded significantly higher oil yield over 100 per cent RDF (668 kg ha^{-1}) but was comparable with 125 per cent RDF (769 kg ha^{-1}). Oil yield is the function of seed yield and oil content in seed, the more seed yield and oil content with application of 150 per cent RDF was reflected in maximum oil yield. Similar results were reported by Mollashahi *et al.* (2013). The combined effect of spacing, fertilizer rate and hybrids was found to be non-significant on oil yield.

4.5 Nutrient uptake

4.5.1 N uptake (kg ha^{-1})

Uptake of N at harvest was significantly influenced by hybrids and fertilizer levels (Table 21 and Fig. 14). RSFH-12-700 (121.3 kg ha^{-1}) recorded maximum nitrogen uptake followed by RSFH-12-705 (119.8 kg ha^{-1}). At harvest, there was no significant difference observed in N uptake due to row spacing. The data at harvest indicated significantly higher uptake of nitrogen with the application of 150 per cent RDF (135.4 kg ha^{-1}) as compared to 125 (110.2 kg ha^{-1}) and 100 per cent RDF (98.4 kg ha^{-1}). Higher N uptake with 150 per cent RDF was mainly due to the sufficient supply of N that resulted in increased dry matter accumulation and nutrient concentration.

The interaction effect was found non-significant due to various treatments on N uptake. This might be due to non significant results with respect to total dry matter accumulation, seed and stalk yield.

4.5.2 P uptake (kg ha^{-1})

P uptake at harvest was significantly influenced by hybrids and fertilizer levels (Table 21 and Fig. 14). RSFH-12-700 (31.4 kg ha^{-1}) recorded maximum phosphorus

Table 21. Uptake of nutrient after harvest of sunflower as influenced by spacing and fertilizer levels

Treatment	H ₁ : RSFH-12-700		H ₂ : RSFH-12-705		H ₃ : RSFH 1887		
	S ₁	S ₂	S ₁	S ₂	S ₁	S ₂	Mean
N uptake (kg ha ⁻¹)							
F ₁ : 100% RDF	105.8	97.4	108.3	103.1	97.2	78.2	98.4
F ₂ : 125% RDF	121.7	108.4	110.4	127.4	101.4	91.9	110.2
F ₃ : 150% RDF	151.0	143.4	135.7	134.0	130.4	118.1	135.4
Mean	110.6	97.0	117.7	121.14	125.6	115.9	114.7
Mean of H	121.3		119.8		102.8		
Mean of S	118.0 (S ₁)		111.3 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	3.8	3.2	2.2	5.5	3.8	3.1	5.4
C.D. @ 5%	15.1	NS	6.5	NS	NS	NS	NS
P uptake (kg ha ⁻¹)							
F ₁ : 100% RDF	29.8	25.8	20.0	22.4	22.5	23.7	24.0
F ₂ : 125%RDF	33.0	31.1	30.3	28.2	23.5	23.0	28.2
F ₃ : 150% RDF	35.7	33.1	34.1	30.7	25.0	28.5	31.2
Mean	27.2	23.5	30.3	29.5	33.6	30.6	
Mean of H	31.4		27.6		24.4		
Mean of S	28.2 (S ₁)		27.4 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	1.1	0.4	0.8	0.7	1.4	1.1	1.9
C.D. @ 5%	4.3	NS	2.3	NS	NS	NS	NS
K uptake (kg ha ⁻¹)							
F ₁ : 100% RDF	124.0	106.4	84.4	93.8	97.8	74.6	96.8
F ₂ : 125% RDF	135.2	126.4	128.2	119.7	103.4	99.6	118.7
F ₃ : 150% RDF	145.0	134.1	144.7	129.0	111.6	126.0	131.7
Mean	98.73	85.02	112.88	113.55	128.03	115.16	108.89
Mean of H	128.5		116.6		102.2		
Mean of S	119.4 (S ₁)		112.2 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	3.3	2.8	4.2	4.8	7.2	5.9	10.2
C.D. @ 5%	12.8	NS	12.2	NS	NS	NS	NS

S₁: 60 cm × 30 cm; S₂: 75 cm × 30 cm

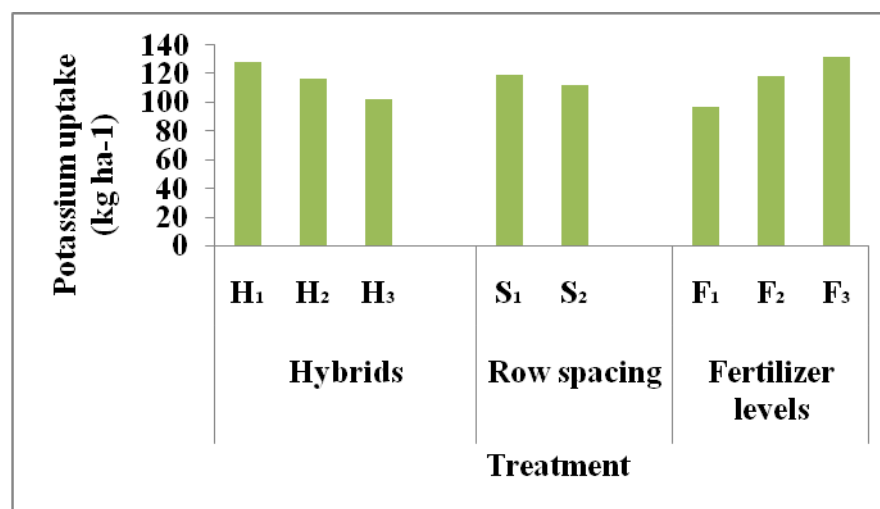
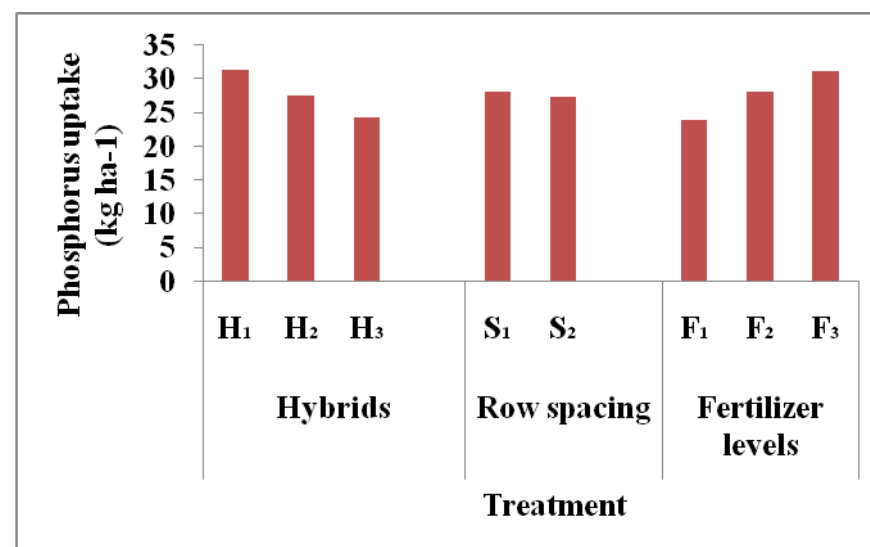
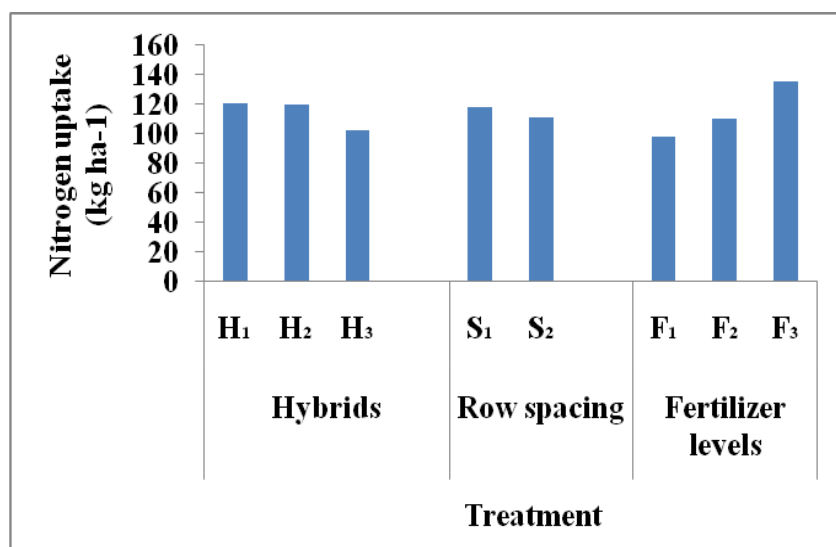


Fig. 14. Uptake of nitrogen, phosphorus and potassium (kg ha⁻¹) of sunflower hybrids as influenced by spacing and fertilizer levels

uptake followed by RSFH-12-705 (27.6 kg ha⁻¹). It is seen from the data that P uptake was not significant at harvest due to row spacing.

Fertilizer rate has exerted significant influence on phosphorus uptake at harvest. Application of 150 per cent RDF (31.2 kg ha⁻¹) recorded significantly higher P uptake over 125 per cent RDF (28.2 kg ha⁻¹) and 100 per cent RDF (24.0 kg ha⁻¹). Higher P uptake with increased fertilizer doses could be related to increased dry matter and their respective content in plant.

Combined effects of row spacing, fertilizer rates and hybrids were not significantly influenced on the phosphorus uptake.

4.5.3 K uptake (kg ha⁻¹)

K uptake at harvest was significantly influenced by hybrids and fertilizer levels (Table 21 and depicted in Fig. 14). The K uptake was found to be significant among hybrids. RSFH-12-700 (128.5 kg ha⁻¹) recorded maximum potassium uptake followed by RSFH-12-705 (116.6 kg ha⁻¹). There were no significant differences observed in terms of potassium uptake due to plant spacing at harvest.

Fertilizer levels have exerted significant influence on K uptake. Application of 150 per cent RDF (131.7 kg ha⁻¹) recorded significantly higher potassium uptake than 125 per cent RDF (118.7 kg ha⁻¹) and 100 per cent RDF (96.8 kg ha⁻¹).

The increased nutrient application has resulted in higher nutrients absorption from soil and that led to enhanced nutrient content in plant. These results are in conformity with the findings of Thavaprakash *et al.* (2003). Yadav *et al.* (2009) stated that biomass in sunflower increased with increased nutrient application which was due to higher absorption of all nutrients from the soil which resulted in greater total uptake of nutrients. Gudade *et al.* (2009) reported that nutrient content increased linearly and significantly with successive increasing level of fertilizer. The interaction effect on potassium uptake was non significant due to various treatment combinations.

4.6 Nutrient status of the soil after harvest of the crop

4.6.1 Available nitrogen in soil (kg ha⁻¹)

Data pertaining to available phosphorus after harvest differed significantly by fertilizer levels of sunflower hybrids is tabulated in Table 22. Highest available N was

recorded under hybrid RSFH-12-700 (261.49 kg ha⁻¹) followed by RSFH-12-705 (243.24 kg ha⁻¹) and RSFH 1887 (235.19 kg ha⁻¹). No significant differences were found due to row spacing.

Available nitrogen was found to be significantly influenced by fertilizer levels. Highest amount of available N was found with application of 150 per cent RDF (257.93 kg ha⁻¹) followed by 125 per cent RDF (252.27 kg ha⁻¹). Lowest available nitrogen was noticed with application of 100 per cent RDF (229.71 kg ha⁻¹). Combination of spacing, fertilizer levels and hybrids did not reach the level of significance.

4.6.2 Available phosphorus in soil (kg ha⁻¹)

Data pertaining to available phosphorus after harvest differed significantly by fertilizer levels of sunflower hybrids as tabulated in Table 22. The highest available phosphorus was noticed under hybrid RSFH-12-700 (43.43 kg ha⁻¹) which was followed by RSFH-12-705 (36.72 kg ha⁻¹) and RSFH-1887 (31.26 kg ha⁻¹). Spacing did not significantly influence available phosphorus after harvest of the crop.

Significant differences were found due to fertilizer levels with respect to available phosphorus. More amount of available phosphorus was noticed with application of 150 per cent RDF (42.46 kg ha⁻¹) followed by 125 per cent RDF (40.83 kg ha⁻¹) and 100 per cent RDF (28.13 kg ha⁻¹). All the interaction effects between spacing and hybrids was found non significant except hybrid and fertilizer level (H × F).

4.6.3 Available potassium in soil (kg ha⁻¹)

The data on available potassium was significantly influenced by hybrids and fertilizer levels and their interactions are presented in Table 22.

Among sunflower hybrids, RSFH-12-700 (273.68 kg ha⁻¹) recorded highest available potassium which was on par with RSFH-12-705 (262.54 kg ha⁻¹) and RSFH 1887 (256.54 kg ha⁻¹). There were no significant differences observed in terms of available potassium to plant spacing.

Fertilizer levels have exerted significant influence on available potassium. Application of 150 per cent RDF (270.77 kg ha⁻¹) has recorded significantly higher amount of available potassium and was on par with 125 per cent RDF (267.67 kg ha⁻¹) but superior over 100 per cent RDF (254.32 kg ha⁻¹).

Table 22. Available nutrient status of soil (kg ha⁻¹) after harvest of sunflower as influenced by spacing and fertilizer levels of sunflower hybrids

Treatment	H ₁ : RSFH-12-700		H ₂ : RSFH-12-705		H ₃ : RSFH 1887		
	S ₁	S ₂	S ₁	S ₂	S ₁	S ₂	Mean
Nitrogen							
F ₁ : 100% RDF	249.10	247.83	218.56	222.54	217.71	222.54	229.71
F ₂ : 125% RDF	262.22	265.40	249.09	255.15	243.35	238.42	252.27
F ₃ : 150% RDF	270.63	273.76	254.95	259.13	243.57	245.54	257.93
Mean	260.65	262.33	240.87	245.61	234.88	235.50	246.64
Mean of H	261.49		243.24		235.19		
Mean of S	245.46 (S ₁)		247.81 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	3.54	2.70	3.09	4.67	5.35	4.36	7.56
C.D. @ 5%	13.84	NS	9.01	NS	NS	NS	NS
Phosphorus							
F ₁ : 100% RDF	33.52	34.12	24.01	24.67	27.15	25.27	28.13
F ₂ : 125% RDF	47.43	47.36	41.58	42.51	32.84	33.26	40.83
F ₃ : 150% RDF	49.32	48.85	43.34	44.23	33.63	35.39	42.46
Mean	43.42	43.44	36.31	37.14	31.21	31.31	37.14
Mean of H	43.43		36.72		31.26		
Mean of S	36.98 (S ₁)		37.29 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	1.37	0.47	1.01	0.81	1.76	1.43	2.84
C.D. @ 5%	5.37	NS	2.96	NS	5.13	NS	NS
Potassium							
F ₁ : 100% RDF	259.94	260.94	250.96	251.16	250.34	252.59	254.32
F ₂ : 125% RDF	274.12	280.32	266.68	269.35	256.94	258.62	267.67
F ₃ : 150% RDF	282.42	284.34	267.80	269.32	259.02	261.71	270.77
Mean	272.16	275.20	261.81	263.27	255.43	257.64	264.25
Mean of H	273.68		262.54		256.54		
Mean of S	263.14 (S ₁)		265.37 (S ₂)				
	H	S	F	H × S	H × F	S × F	H×S×F
S.Em. ±	3.29	2.71	3.18	4.69	5.51	4.50	7.79
C.D. @ 5%	12.85	NS	9.29	NS	5.45	NS	NS

S₁: 60 cm × 30 cm; S₂: 75 cm × 30 cm

All the interaction effects between spacing and hybrids was found non significant except hybrid and fertilizer level ($H \times F$).

The significant improvement was due to increased level of NPK fertilization which represented the more available nutrient status of soil. Vandhana (2003) stated that the nitrogen, phosphorus and potassium uptake was highest which could be attributed to higher availability of NPK status in soil leading to balanced fertilization.

4.7 Economics of sunflower cultivation

4.7.1 Cost of cultivation (Rs. ha⁻¹)

The data reported that lower cost of cultivation in 100 per RDF (Rs. 22250 ha⁻¹) than 125 per cent RDF (Rs. 23439 ha⁻¹) and 150 per cent RDF (Rs. 25229 ha⁻¹). The cost of cultivation was same for all the hybrids (Rs. 23639 ha⁻¹).

4.7.2 Gross monetary returns (Rs. ha⁻¹) and Net monetary returns (Rs. ha⁻¹)

Sunflower hybrids have significantly influenced the gross returns and net returns (Table 23). Among different hybrids, RSFH-12-700 gave significantly higher gross returns (Rs. 90096 ha⁻¹) and net returns (Rs. 66406 ha⁻¹) as compared to other two hybrids. Lowest gross returns were recorded in RSFH 1887 (Rs. 77894 ha⁻¹) and net returns (Rs. 30209 ha⁻¹) in RSFH-12-705. It might be due to higher grain yield and oil yield obtained with this hybrid. The results are in conformity with Pattanayak *et al.* (2016). Spacing did not significantly influenced the gross returns and net returns.

Gross returns and net returns were found significant among the fertilizer rates. Application of 150 per cent RDF fetched higher gross returns (Rs. 88387 ha⁻¹) and net returns (Rs. 63158 ha⁻¹) which was on par with 125 per cent RDF with gross returns of (Rs. 86140 ha⁻¹) and net returns of (Rs. 62700 ha⁻¹). Lowest gross returns (Rs. 77261 ha⁻¹) and net returns (Rs. 55011 ha⁻¹) were received from 100 per cent RDF. The increased returns may be due to higher grain yield which was resultant of better utilization of optimum supply of nutrients in adequate quantities. Malik *et al.* (2004) reported that highest net profit was obtained when adequate fertilizers were applied.

Table 23. Economic returns from sunflower hybrids as influenced by row spacing and fertilizer application

Treatment	Cost of Cultivation (Rs./ha)	Gross returns (Rs./ha)		Net Returns (Rs./ha)		BC ratio	
<i>Hybrids (H)</i>							
H ₁ : RSFH-12-700	23639	90046		66406		2.81	
H ₂ : RSFH-12-705	23639	83848		30209		2.55	
H ₃ : RSFH 1887	23639	77894		54254		2.29	
S. Em ±		973		973		0.04	
C.D. (P=0.05)		3802		3802		0.16	
<i>Spacing (S)</i>							
S ₁ : 60 cm × 30 cm	23639	82815		59175		2.50	
S ₂ : 75 cm × 30 cm	23639	85044		61404		2.60	
S.Em. ±		1321		1321		0.06	
C.D. (P=0.05)		NS		NS		NS	
<i>Fertilizer levels (F)</i>							
F ₁ : 100% RDF	22250	77261		55011		2.47	
F ₂ : 125% RDF	23439	86140		62700		2.67	
F ₃ : 150% RDF	25229	88387		63158		2.50	
S.Em. ±		1398		1398		0.06	
C.D. (P=0.05)		4081		4081		NS	
<i>Interaction</i>		S.Em. ±	C.D. @ 5%	S.Em. ±	C.D. @ 5%	S.Em. ±	C.D. @ 5%
H × S		2288	NS	2288	NS	0.10	NS
H × F		2421	NS	2421	NS	0.10	NS
S × F		1977	NS	1977	NS	0.80	NS
H × S × F		3424	NS	2288	NS	0.15	NS

4.7.3 Benefit cost ratio

The higher BC ratio was recorded in hybrid RSFH-12-700 (2.81) followed by RSFH-12-705 (2.55). Lowest BC ratio was recorded in RSFH 1887 (2.29). With respect to BC ratio, there was no significant difference in between spacing and fertilizer levels.

4.8 Correlation study

Data on simple correlation were worked out for yield, growth and yield parameters as influenced by row spacing and fertilizer levels of sunflower hybrids (Table 24). The seed yield exhibited significant positive correlation with growth parameters like plant height at maturity, leaf area at maturity, total dry matter production and capitulum dry weight at maturity indicating that the seed yield is greatly determined by these traits. Among the yield parameters, seed yield showed significant positive correlation with seed filling percentage, oil content and oil yield.

Table 24. Relationship between yield, yield parameters and growth parameters as influenced by spacing and fertilizer levels of sunflower hybrids

	Yield	Plant height	Leaf area	TDMP	Capitulum dry weight	Seed filling %	Oil content	Oil yield
Yield	1.000	-	-	-	-	-	-	-
Plant height	0.858**	1.000	-	-	-	-	-	-
Leaf area	0.972**	0.857**	1.000	-	-	-	-	-
TDMP	0.977**	0.860**	0.985**	1.000	-	-	-	-
Capitulum dry weight	0.912**	0.810**	0.941**	0.928**	1.000	-	-	-
Seed filling %	0.968**	0.826**	0.960**	0.951**	0.921**	1.000	-	-
Oil content	0.967**	0.870**	0.930**	0.925**	0.883**	0.928**	1.000	-
Oil yield	0.997**	0.863**	0.967**	0.972**	0.911**	0.960**	0.981**	1.000

Note: ** significance at P=0.05

SUMMARY AND CONCLUSIONS

V. SUMMARY AND CONCLUSIONS

A field experiment on effect of planting density and fertilizer rate on performance of newly developed sunflower hybrids (*Helianthus annuus* L.) was conducted during *Kharif* 2019 at Main Agricultural Research Station, UAS, Raichur. The experiment was laid out in split-split plot design which consisted of eighteen treatment combinations comprised of sunflower hybrids in main plots and plant densities as sub plots and fertilizer rates as sub-sub plots and were replicated three times. The crop was sown as per treatments with different row spacings. Besides yield data, periodical observations were recorded on growth and yield contributing characters.

The observations on growth and yield attributes were recorded at periodical intervals to evaluate the treatment effects. The relevant findings of this investigation are summarized below.

5.1 Performance of sunflower hybrids

Hybrids differ in their yield potential depending on many physiological processes, which are controlled by both genetic makeup and the environment. Sunflower hybrid RSFH-12-700 recorded significantly higher seed yield (2144 kg ha⁻¹) when compared to RSFH-12-705 (1996 kg ha⁻¹) and RSFH 1887 (1855 kg ha⁻¹). The improvement in grain yield of hybrid RSFH-12-700 and RSFH-12-705 were 15.58 % and 7.60 %, respectively over RSFH 1887. Yield components such as 100 seed weight, seed volume and threshing percentage were significantly higher in RSFH-12-700 (5.84 g, 45.29 g/100 ml and 72.58 %, respectively) over RSFH-12-705 (5.66 g, 41.73 g/100 ml and 70.10 %, respectively) and RSFH 1887 (5.07 g, 39.24 g/100 ml and 68.47 %, respectively).

The observations on plant growth parameters viz., plant height, leaves per plant, leaf area, leaf area index, total dry matter accumulation, dry matter partitioning in leaves, stem and capitulum, SPAD readings and NDVI readings were recorded at 30, 60 DAS and at maturity. Among the sunflower hybrids, significantly higher plant height (181.8 cm), number of leaves (18.1), leaf area per plant (3119.5 cm²) and leaf area index (1.60) were recorded in RSFH-12-700 compared to RSFH-12-705 and RSFH 1887. Similar trend was also observed in respect of total dry matter accumulation, dry matter partitioning in leaves, stem and capitulum, SPAD readings and NDVI readings. It also recorded significantly higher oil content (38.42 %) and oil yield (820 kg ha⁻¹) followed by RSFH-12-705 and RSFH 1887.

There were significant differences observed in terms of nitrogen, phosphorus and potassium uptake among hybrids. Hybrid RSFH-12-700 showed significantly higher available nitrogen, phosphorus and potassium (261.49, 43.43 and 273.68 kg ha⁻¹, respectively) compared to other two hybrids. The highest net returns of Rs. 66406 ha⁻¹ and BC ratio of 2.81 were obtained under RSFH-12-700 hybrid.

5.2 Effect of plant density

Planting density could not exert significant influence on the yield and yield attributing characters. Results on plant height revealed that the height of sunflower continued to increase up to harvest. The rate of increase in height was very fast up to 60 DAS and showed decreasing trend from 60 DAS to maturity. The plant height was maximum at plant spacing of 60 × 30 cm (175.6 cm) than 75 × 30 cm (170.0 cm). The other plant growth parameters viz., number of leaves, leaf area, total dry matter accumulation, dry matter partitioning in leaves, stem and capitulum, SPAD readings and NDVI readings were not influenced by plant spacing.

The other growth parameters viz., LAI, LAD and CGR were favorably influenced by narrow spacing of 60 × 30 cm (1.50, 51.5 days and 17.18 g m⁻² day⁻¹, respectively) over wider spacing of 75 × 30 cm (1.25, 42.9 days and 14.2 g m⁻² day⁻¹, respectively).

The quality of sunflower in terms of oil content and oil yield were not significantly influenced due to various plant densities under study. Similarly, nutrient uptake (N, P and K) and available nutrient status in soil did not differ significantly among the planting density.

5.3 Effect of fertilizer rates

Head diameter, seed volume, seed yield and threshing percentage were significantly higher with the application of 150 per cent RDF (19.61 cm, 42.51 g/100 ml, 2104 kg ha⁻¹ and 72.00 %, respectively) which was superior over 100 per cent RDF (17.24 cm, 40.72 g/100 ml, 1840 kg ha⁻¹ and 68.37 %, respectively) but on par with 125 per cent RDF (18.43 cm, 41.05 g/100 ml, 2051 kg ha⁻¹ and 70.80 %, respectively).

The application of 150 per cent RDF showed significant and favourable effect on various growth characters i.e., plant height, number of leaves, leaf area, leaf area index, total dry matter accumulation, SPAD meter readings over 100 per cent RDF but were on par with 125 per cent RDF.

The physiological parameters viz., LAD, CGR and RGR were significantly higher with the application of 150 per cent RDF than 100 per cent RDF and were on par with the application of 100 per cent RDF.

The maximum oil content and oil yield were obtained with the 150 per cent RDF (38.00 % and 801 kg ha⁻¹, respectively) which were on par with 125 per cent RDF (37.42 % and 769 kg ha⁻¹, respectively) and superior over 100 per cent RDF (36.27 % and 668 kg ha⁻¹, respectively).

Significantly higher uptake of nitrogen, phosphorus and potassium (135.40, 32.64 and 122.55 kg ha⁻¹, respectively) was recorded with the application of 150 per cent RDF as compared to 100 per cent RDF (98.40, 26.56 and 99.49 kg ha⁻¹, respectively) but was on par with 125 per cent RDF (110.20, 28.26 and 104.64 kg ha⁻¹, respectively). Similarly, significantly higher available nitrogen, phosphorus and potassium (257.93, 42.46 and 270.77 kg ha⁻¹, respectively) in soil was found with application of 150 per cent RDF compared to others treatments.

Significantly higher gross returns and net returns (Rs. 88387 ha⁻¹ and Rs. 63158 ha⁻¹, respectively) were recorded with 150 per cent RDF over 100 per cent RDF (Rs. 77261 ha⁻¹ and Rs. 55011 ha⁻¹, respectively) but was on par with 125 per cent RDF (Rs. 86140 ha⁻¹ and Rs. 62700 ha⁻¹, respectively).

CONCLUSIONS

1. The sunflower hybrid RSFH-12-700 produced higher seed yield and net returns which was followed by RSFH-12-705 and RSFH 1887.
2. The planting density of 60×30 cm and 75×30 cm did not exert significant influence on growth parameters, yield and yield attributes.
3. Application of 150 per cent RDF produced higher grain yield over 100 per cent RDF and was on par with 125 per cent RDF.
4. Planting of sunflower hybrid RSFH-12-700 with application of 150 per cent RDF was found productive and remunerative.

Future line of work

The following suggestions on the basis of the results obtained from the present investigation can aid in future investigations.

1. There is a need to study INM practices in sunflower.
2. Study should be conducted under different agro-ecological situation of the zone to make valid recommendation for farmers.
3. Other agronomic practices need to be studied to maximize the yield of sunflower.
4. In addition to investigation on primary nutrients, studies may also be conducted with secondary and micro nutrients.

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VI. REFERENCES

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APPENDICES

APPENDIX- I

Price of input and output

Particulars	Price (Rs.)
I. Inputs	
1. Seeds	
a) Sunflower seed	225 per kg
2. Fertilizers	
a) Urea	6.2 per kg
b) Di-ammonium phosphate	23.6 per kg
c) MOP	12.0 per kg
d) Boron	520 per kg
3. Labour wages	
a) Men	250 per day
b) Women	250 per day
c) Ploughing	1000 per day
d) Harrowing	300 per day
4. Miscellaneous	
a) Marketing and handling charges	3 % of the gross value of the produce
II. Output	
a) Sunflower seed	42 per kg