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CANOPY CHARACTERISTICS, YIELD, RADIATION USE EFFICIENCY AND QUALITY OF OILSEEDS UNDER REDUCED SUNLIGHT

H.P. Jyothi Prakash*, M.R. Umesh, N. Manjunatha, A.S. Kamble and B. Rajanna

University of Agricultural Sciences, Raichur, Karnataka, India.

*Corresponding author E-mail : jyothiprakash.hp@gmail.com

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ABSTRACT

Oilseeds have a distinct morpho-physiological and agronomic response to reduced sunlight, but their capacity to adapt to the levels of shading due to intercropping systems is not sufficiently understood. To examine such adoptive capacity of the sunflower, groundnut and soybean crops a field experiment was conducted at Raichur, Karnataka during *Kharif* 2023. Split-plot design was adopted replicated three times. Treatments consists of oilseeds were in main plot and shade levels at 30%, 60% restriction of incident light and no shade as subplots. White shade net was erected at 25 days after sowing and maintained up to maturity to reduce 30 and 60% of the incident light reaching crop canopy. The results indicated that relative water content was greater in 60% shade. Whereas, canopy temperature, dry matter, yield per plant, grain and stover/haulm yield were higher under no-shade. Shade has reduced yield of all the oilseeds tested, the least yield reduction was in groundnut (15%) and soybean (30%), highest in sunflower (50%) compared to no-shade. Significantly higher radiation use efficiency was noticed in soybean under 60% shade. Seed oil yield was affected by shade but protein content was not affected by shade. Overall results imply that soybean and groundnut were best adopted to reduced sunlight therefore will be suitable as component crops in the mixed/intercropping systems.

Key words : Grain yield, Oilseeds, Shade tolerance, Radiation use efficiency, Sunlight.

Introduction

Light is an indispensable resource for crop growth that controls growth rate, organ development or structure, function, and behaviour. Adopt and acclimatize to the light environment is also critical to plant survival and efficiency in production. The photosynthetically active radiation is major factor regulating photosynthesis and other physiological processes which are ultimately govern the dry matter production (Lemaire *et al.*, 2007). In general, plants under the high light intensity are known to reduce the photosynthetic rate under the shade. Selection of species that perform stable photosynthesis inputs are more attention in a cropping system. Increasingly, intercropping is being adopted as a lower input cost system that maximises profits (Fletcher *et al.*, 2016; Khanal *et al.*, 2021). Oilseeds are known for differential tolerance to reduced sunlight in crop combinations. An intercrop having different growth habit and canopy can easily be accommodated under various light intensities will be a more advantage to achieve higher and stable productivity in natural environments.

Farmers adopt intercropping primarily to increase their product diversity and farm income stability through the effective use of land and other resources. The cost and price of the constituent crops also influence the profitability of intercropping (Khanal *et al.*, 2021). As the price, in both an economic and cost-to-production sense, becomes too great, farmers are seeking innovative ways to reduce synthetic with least competition. Oilseeds including soybean, canola, and sunflower are generally categorized as moderately shade-tolerant crops. They can tolerate partial shading and still produce a reasonable yield, although their growth and productivity may be reduced compared to plants grown in full sunlight. Factors such as the duration and intensity of shade, as well as the specific genetic traits of the oilseed variety, play a role in determining its shade tolerance. Under tropical conditions, evaluation of different oilseeds based on shade tolerance capacity in turn suitability to the intercropping system was not properly documented. Therefore, the objectives of the present experiment was to test the performance of oilseeds in terms of yield and RUE under differed densities of shading, to explore responses of the morphological and physiological traits to shading and to reveal the relationship between the yield performance and responses of the morphological traits under reduced sun light.

Materials and Methods

The experiment was conducted in *Kharif*, 2023 at Agriculture College Farm, University of Agricultural Sciences, Raichur, Karnataka, India (16°19' N, 77° 31'3 E, 407 m). The soil of the experimental site was clay texture (49.65%) with pH 7.85 and EC 0.22 dS m^{-1}. The available soil nitrogen, phosphorus, and potassium before seeding were 256.8, 26.6 and 299.5 kg ha^{-1}, respectively. The soil organic carbon content and bulk density were 0.54 g kg^{-1} soil and 1.35 Mg m^{-3}, respectively. The research plot was laid out in spilt plot design with four replications. Main plot treatments were oilseed crops sunflower [*Helianthus annuus*] cv. RSFH-1887, groundnut [*Arachis hypogaea*] cv. TMV-2 and soybean [*Glycine max*] cv. Dsb-21. Whereas, and light levels of 30 and 60% reduction of normal light compared with no shade as control were assigned to sub-plots.

The crops were sown on 23rd July, 2023 and raised as per the crop specific package of practices recommended for the region. At 25 DAS, artificially shaded condition was created by shade cloth coverage and maintained upto maturity. Shading nets were erected in a rectangular frame at six feet height above the ground to ensure good ventilation and were large enough to fully cover the corresponded shaded plots. There were two light levels consisted for shade created by shade clothes restricted required shade as per the treatment. No shade plants were grown under natural open sunlight conditions. Shading means to simulate the effect of shade and cut down the PAR at desired level without change in light quality and photoperiod. PAR reduction inside the shade net was calculated by using the following formula (Bhagat *et al.*, 2017).

For biometric observations, five tagged plants from the net plot area used for recording growth parameters and then were harvested separately at maturity. Yield attributes were recorded from these plants. Nitrogen content in the seeds of all the species was estimated by Kjeldahl's method. The seed protein content was calculated by N content multiplied by 6.25 later converted into protein yield based on seed yield and protein content. Canopy temperature was estimated by infrared gun thermometer at 0.5 m above the fully covered plant. Relative water content (RWC) was estimated from 20 leaf discs collected from randomly selected plants of all the species. Relative chlorophyll content (SPAD) of leaves was estimated by using SPAD 502 Plus (Konica Minolta, Inc.)

A SunScan canopy analyzer (Delta-T Device, Cambridge UK) was used to record incident and intercepted light by individual species. Light interception (LI) across crop canopy was recorded on a clear sunny day at 11:00 to 14:00 hours. Data was collected at 15 days interval throughout growing period. The daily incident PAR values were multiplied by corresponding daily LI to compute daily intercepted PAR (Tsubo *et al.*, 2001).

$$\text{Light transmission (\%)} = \frac{\text{Light intensity below the canopy}}{\text{Light intensity above the canopy } (I_t)} \times 100$$

Light interception (%) = 100 – Light transmission

Radiation use efficiency (RUE) was calculated as per procedure by Tsubo and Walker (2004).

$$RUE = \frac{Y_{biomass}}{I_0 \times F}$$

Where, $Y_{biomass}$ was above ground biomass (g m^{-2}), Io was the flux density of the incident photosynthetically active radiation above the crop canopy (MJ m^{-2}) & F is fraction of PAR intercepted. Io = Incident light was calculated as per the procedure of FAO 56 (Table 1).

Statistical analysis

The experimental data were subjected to statistical analysis adopting Fisher's method for analyses of variance as out lined by Gomez and Gomez (1984). The level of significance used in the 'F' test was given at 5%. Least significant difference (LSD) values have been given in the Table 2 at 5% level of significance, wherever the F test was significant. Graphs were made by using Sigmaplot 14.5to compare treatment differences.

Results and Discussion

Weather and crop growth

The experimental site belongs to North Eastern Dry Zone (Zone-2) of Karnataka, which is situated at 16º19' N latitude and 77º 31' E longitude at an altitude of 389 m above the mean sea level.

The germination and establishment were good due to favourable rainfall situation during early stages. Crops

Table 1 : Mean monthly weather parameters, indices and photosynthetically active radiation (PAR).

Month	Max. temperature (°C)	Min. temperature (°C)	Rainfall (mm)	ΣGDD (°C days)	Sunshine hours	ΣPAR (MJ m^{-2})
January	30.7	16.5	0	422.2	7.7	9.2
February	33.8	17.3	0.0	434.3	8.6	10.4
March	35.3	19.8	12.4	544.1	7.2	9.6
April	38.1	23.6	82.6	625.4	8.5	9.8
May	37.7	25.4	128.4	668.3	8.0	8.5
June	38.1	24.9	39.4	644.5	5.5	6.4
July	32.0	22.8	198.4	539.9	2.0	4.7
August	33.7	22.8	61.6	566.6	5.4	7.5
September	31.8	22.6	70.8	515.6	4.1	7.2
October	33.4	21.0	0	533.5	6.5	9.0
November	32.2	21.1	11.8	499.6	4.3	6.8
December	30.6	18.2	2.6	445.7	4.8	7.0

Table 2 : Leaf relative chlorophyll values, canopy temperature, relative water content (RWC), yield attributes and grain quality of different oilseeds grown under reduced sunlight.

Treatments	SPAD at 60 DAS	Canopy temperature (°C)	RWC at 60 DAS	Seed yield (g $plant^{-1}$)	100-seed weight (g)	Seed protein content (%)	Oil yield (kg ha^{-1})
Shade levels (S)							
30% shade	45.76	26.23	82.68	12.62	19.12	35.16	474.24
60% shade	44.08	25.00	84.60	10.44	19.51	35.22	326.84
No shade	52.85	28.27	80.37	23.54	20.71	35.73	753.01
LSD (p = 0.05)	4.39	2.36	NS	3.33	NS	NS	105.04
Oilseed species (M)							
Sunflower	44.09	23.30	74.11	28.25	8.35	34.80	253.24
Groundnut	40.52	24.85	84.29	7.69	34.70	27.44	747.04
Soybean	58.07	25.44	89.28	10.65	16.29	43.88	553.72
LSD (p=0.05)	2.70	NS	4.70	6.56	2.37	1.33	109.18
M x S	NS	NS	NS	8.05	NS	NS	NS

did not experience moisture stress as they were supplemented with irrigation during dry spells. The crops were free from major pest and diseases as necessary plant protection measures were taken. Maximum rainfall received during the year 2023 was 608 mm of which highest in July (198.4 mm) and May (128.4 mm) (Table 1). During the year 2023, the maximum air temperature was ranged between 30.6°C and 38.1C and minimum air temperature was between 16.5°C and 25.4°C and found that there was no much deviation from the normal value. Maximum number of Growing Degree Days (GDD) were observed during May (668.3) days while sunshine hours were recorded during February (8.6 hours). However, maximum incident solar radiation and PAR were recorded during October (610.2 and 292.9 MJ m^{-2}).

Canopy characters

Canopy characters were differed significantly during the crop growth period due to artificial reduced sunlight levels and oilseeds species (Table 2). The leaf chlorophyll content of oilseeds was increased gradually with higher light levels and the maximum values of SPAD (52.85) were recorded under no shade and lower under 60% shade condition (44.80). The SPAD readings under different shades in winged bean recorded lower SPAD values in higher shade levels (Raai *et al.*, 2020). Angadi *et al.* (2022) reported that SPAD readings of unshaded plants were 5.3-30.5% higher than those of shaded plants (39.3-50.07%). Among the oilseeds, significantly higher SPAD values at 60 DAS were recorded in soybean

(65.50) under no shade and lower in pigeon-pea (44) under 60% shade condition.

Canopy temperature is often used to indicate vegetative water status and as indirect measure of transpiration rate and sensible heat transport from vegetation. In this present study, significantly higher canopy temperature was recorded when plants grown under the open sunlight (28.27) and lower in 60% shaded level (25.00) (Table 2). This might be due to higher light intensity has resulted in higher transpiration rate and lower water content of the leaves under no shade condition. Thus, relative water content of the leaves was significantly greater in plants grown under 60 % shaded level and lower RWC was recorded in no shaded condition (Table 2).

This discrepancy may be attributed to the higher light intensity, resulting in an elevated transpiration rate and reduced water content in leaves under open conditions. Similar result of reduced transpiration and stomatal conductance under shade was reported by Chauhan *et al.* (2013). Ghassemi–Golezani *et al.* (2013) observed that soybeans under 75% shade exhibited higher relative water content than those under 35% shade and lower in no shade conditions. Manoj *et al.* (2019) also noted that lablab, pigeon pea, black gram and cowpea grown under shade had higher RWC as compared to plants grown without shade. Among the oilseeds, groundnut exhibited significantly higher canopy temperatures (27.20), while sunflower had the lowest (25.40).

Yield and yield attributes

Artificial reduced sunlight had significantly impact on grain yield of all the species selected for the study. Species grown under the no shade have out yielded over reduced light either at 30 and 60% shade (Table 2). The magnitude of grain yield reduction across species and shade levels was 33 to 50% over no shade. It was varied among the tested species. This increase in grain yield was primarily attributed to higher DM accumulation in leaves, which likely supplied the necessary photosynthates to the reproductive organs, particularly the seeds (Ewansiha *et al*., 2014). Chen *et al.* (2020) also reported shade effects on peanuts, recording significantly higher pods per plant and 100-kernel weight under open sunlight without shade.

All the oilseed species have shown significantly reduced grain yield under 30 and 60% shade as compared to no shade plants (Table 3). However, irrespective of shade levels soybean and groundnut showed significantly higher grain yield and lower grain yield recorded in sunflower, respectively. This is in agreement with the findings of Fagwalawa and Yakasai (2013), who reported that 27% of the reduced sunlight decreased grain yield of cowpea upto 91% as compared to 100% sunlight. Pavan *et al.* (2009) reported that significantly (p=0.05) greater seed yield was recorded with direct sown pigeonpea grown under open sunlight conditions at 90 cm × 20 cm spacing. In Spite of repetitive plant protection measures, severe incidence of leaf feeding insects was observed in shade as relative humidity was higher, which has resulted in lower seed yield of sunflower irrespective of shade. Light had also significantly effect on the biomass yield across species. It was maximum number plants grown under no shade over 30 and 60% shade. Among the oilseeds the stover/stalk yield was found non-significant however, significantly higher biomass was accumulated in no shade (5266 kg ha^{-1}) followed by 30% shade (4269 kg ha^{-1}) and least in 60% shade (3405 kg ha^{-1}). This might be due to higher total biomass production from different plant parts at harvest under no shade in pigeon-pea and lablab. Similar findings of higher yields under no shaded compared to reduced sunlight conditions have been reported by Gomez *et al.* (2013). Typically, plants adapted to high light intensity tend to exhibit reduced photosynthetic rates under higher shaded conditions (Ray *et al*., 2004). Therefore, selecting species capable of maintaining stable photosynthesis across varying light intensities can confer a significant advantage, ensuring consistent and high productivity in natural environments. All tested oilseeds showed significantly higher yield components under non-shaded compared to 30% and 60% shade levels. However, sunflower and groundnut recorded significantly

Table 3 : Grain and stover yield of different oilseeds grown under artificial shade and no shade condition.

	Oilseed species (M)		
Shade levels (S)	**Sunflower**	**Groundnut**	**Soybean**
	Seed yield (kg ha^{-1})		
30% shade	404	1517	2688
60% shade	213	998	2186
No shade	1414	2015	3408
S	246		
M	282		
S x M	NS		
	Stalk yield (kg ha^{-1})		
30 % shade	4153	3797	4889
50 % shade	3304	3279	3633
No shade	5374	4462	5565
	LSD (P=0.05)		
S	52		
M	NS		
S x M	NS		

higher & lower numbers of seeds per plant, respectively, regardless of shade levels. These results align with those of Zhang *et al.* (2011), who noted that soybean pods per plant, seeds per pod, 100-seed weight and effective branch numbers per plant decreased under shade stress, while branched pods per plant and seeds per plant increased. Fagwalawa and Yakasai (2013) also showed grain yield components in various cowpea varieties were higher under 100% light intensity compared to 40 and 20% intensity.

Radiation use efficiency

Under field conditions the interception of the incoming PAR by leaves is a major process of biomass production. Bio-mass yield-based radiation use effectiveness has a sign of canopy growth and the light interception and was considerably affected by artificial reduced sunlight and oil seeds (Fig. 1). Higher energy accumulated in biomass by way of effective utilization of radiation (RUE) was observed in sunflower grown below 60 % shade (4.6 gMJ^{-1}). It was further decreased in pigeon-pea (72 and 51%), cowpea (75 and 58%), blackgram (82 and 71%) and lablab (84 and 72%) under no shade and 30 % shade, respectively. ground biomass and greater fractional PAR interception during the pod filling stage. The higher seed yield was also related to RUE. However, grain yield-based RUE was considerably smaller when lablab (0.35 g MJ^{-1}) and black-gram (0.40 g MJ^{-1}) grown under no shade. The results were also with the findings of Sandana *et al.* (2012) who reported that intercropped beans (77%) and groundnut (79%) have greater RUE compared to sole crop RUE. It was mainly due to lower PAR interception by the canopy per unit of dry matter thereby improving the RUE. Mishra *et al.* (2009) developed relationship and reported that between dry matter production, light interception and RUE of different wheat varieties were higher correlated.

Grain quality

Crude protein content differed significantly due to oilseeds but artificial shade levels exhibited non-significant difference (Table 1). Crude protein content was significantly influenced due to oilseeds. significantly greater crude protein content was recorded under soybean plants (43.88%) and found to be on par with sunflower (34.80%). Significant lower crude protein content was recorded under groundnut plants (27.44%). Artificial shade levels not exhibited significant differences with respect to crude protein content due to oilseeds. Crude protein content was found to be non-significant due to interaction effect of artificial shade levels and oilseeds.

Oil yield was significantly influenced by both artificial shade levels and oilseed varieties (Table 2). Plants grown without shade recorded a significantly higher oil yield (753.01 kg ha^{-1}), while those grown under 60 % shade level exhibited the lowest oil yield (326.84 kg ha^{-1}). Plants grown under 30 % shade level demonstrated intermediate oil yield (474.24 kg ha^{-1}). groundnut exhibited the highest oil yield (747.04 kg ha^{-1}), whereas sunflower had the lowest (253.24 kg ha^{-1}). soybean yield (553.72 kg ha^{-1}) fell in between these values.

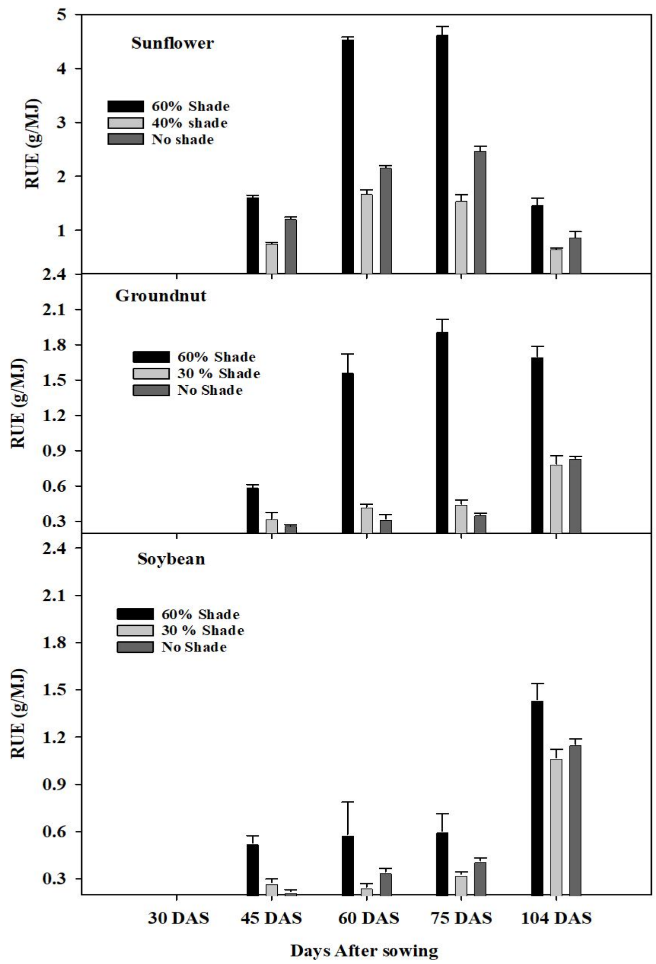

Fig. 1 : Radiation use efficiency (g MJ^{-1}) of oilseeds recorded at different stages of growing period influenced by artificially reduced sunlight. Bars above the bar graph indicate standard error at p=0.05.

The interaction of artificial shade levels and oilseed varieties did not significantly influence oil yield.

Relationship between yield and growth, yield attributes

The relationship between growth parameters, yield parameters and oil yield was worked out (Table 4). Leaf stem ratio of oilseeds was significant and positively correlated with relative water content at 60 DAS (r=0.867) then specific leaf weight at 60 DAS (r=0.916) and leaf weight ratio at 60 DAS (r=0.994). Similarly, these leaf

Table 4 : Correlation between growth, yield components and quality of oilseeds as influenced by reduced sunlight.

Variable	TDM at 60DAS	LI at 60 DAS	RWC at 60DAS	SLW at 60 DAS	LWR at 60DAS	LSR at 60 DAS	Gain yield	Stover yield	Oil yield
TDM at 60 DAS	1.00	0.47	-0.90**	-0.86**	-0.97**	-0.95**	-0.58	0.21	-0.49
LI at 60 DAS			-0.41	-0.10	-0.28	-0.23	-0.82**	-0.66	-0.72*
RWC at 60 day				0.91**	0.87**	0.87**	0.67*	-0.09	0.34
SLW at 60 DAS					0.90**	0.92**	0.36	-0.38	0.21
LWR at 60DAS						0.99**	0.45	-0.36	0.45
LSR at 60 DAS							0.42	-0.39	0.43
Grain Yield								0.65	0.64
Stover yield									0.42
Oil yield									1.00

*Significant 1% **Significant 5% NS: Non-significant

TDM- total dry matter; LI- light interception; RWC- relative water content; SLW- Specific leaf weight; LWR- Leaf weight ratio; LSR- Leaf stem ratio.

weight ratio also significantly related with relative water content at 60 DAS (r=0.869) and specific leaf weight at 60 DAS (r=0.903) of oilseeds. However, leaf weight ratio of grain was not related with specific leaf weight at 60 DAS, total dry matter at 60 DAS. Specific leaf weight at 60 DAS was positively correlated with relative water content at 60 DAS (r=0.909).

Conclusion

In the present study, oilseeds are susceptible to light under moderate shade condition, but the difference in yield and yield components can be noted. soybean and groundnut performed among the tested oilseed species with minimal yield decrease and better shade tolerance compared to sunflower. The reduced sunlight plants had higher RUE than the no shade and shading reduced the availability of radiant energy at the canopy surface. Therefore, these are potential oilseeds for intercropping with tall statured crops that offer a significant amount of shade.

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