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Physiological evaluation of different safflower genotypes (*Carthamus tinctorius* L.) Through radiation use efficiency technique

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Abstract
The experiment was conducted at MARS, UAS Raichur, Karnataka using thirty different safflower genotypes to understand the genotypic differences for dry matter production as influenced by solar radiation and leaf area index. An attempt was made to develop the light extinction coefficient (k) which was used to simulate the light transmission in safflower plant canopy. Radiation Use Efficiency (RUE) is an important character in understanding and modeling the relationship between plant growth and the physical environment. Plant dry matter accumulation depends on the total carbon fixed during photosynthesis and the fraction of carbon converted into dry matter. The experiment was laid out in randomized block design with two replications using thirty different genotypes of safflower. The light interception, leaf area index was measured during anthesis time and light extinction coefficient (k) was calculated. Dry matter production and yields were recorded at the time of harvesting. Results showed the genotypic differences for all the characters studied. Among the thirty genotypes, the genotype GMU 2894 and GMU 7317 showed higher yields (68.0 g/plant). Moreover, these genotypes also recorded high Radiation Use Efficiency (RUE), more Light Extinction Coefficient (LEC) and Leaf Area Index (LAI) compared to others. Therefore, the higher yield of these genotypes may be attributed to the above physiological characters.

Keywords: Safflower, genotype, light interception, light extinction coefficient, RUE, LAI and seed yield

Introduction
Safflower (*Carthamus tinctorius* L.) is a multi-purpose crop with unexploited potential and wide adaptability. The major producers of safflower in the world are India, United States, Mexico, Kazakhistan, Argentina, China, Ethiopia and Australia. Traditionally, crop was grown mainly for the vegetable oil extracted from its seeds. Moreover, its flower petals were being used for coloring and flavoring foods for the last fifty years. There are many environmental factors, which are responsible for determining the yield in safflower genotypes. A number of crop growth simulation models have been developed using the Radiation Use Efficiency (RUE) concept to forecast crop growth and yield at different environments RUE is the value of the slope of the linear relationship between biomass production and IPAR (Intercepted PAR) (Sinclair and Muchow, 1999) [12].

Light is having the key role in net primary productivity of crops. Light availability for plants varies with plant population, spatial arrangements, especially with canopy structures. The variation in canopy and light availability is a result of foliage structural characteristics (Maddonni *et al*., 2006) [8]. Generally, light interception varies with crop development. Dry matter (DM) production is always positively related to light interception; light interception decreases exponentially from top to bottom of canopy.

Canopy extinction coefficient (*K*) is another important factor in the Beer-Lambert Law. Its value is dictated by canopy structure, species, and planting pattern (Zarea *et al*., 2005) [14]. Several studies have proved that RUE is determined by cultivar, temperature (Andrade *et al*., 1993) [1], water (Jamieson *et al*., 1995) [5], and nutrients (Rodriguez *et al*., 2000; Van postal *et al*., 2011) [11, 13] as well. In addition to the above, the relationship between Leaf area Index and LEC of wheat on canopy extinction coefficient of wheat crop is also reported by Lungaria and Shekh (2006) [7]. However, the yield determination among the safflower genotypes is complex in nature. But the present study was tried to understand the relationship between the light and its related factors which influence on the final yield of thirty safflower genotypes.

Materials and Method

The experiment was conducted at MARS, UAS Raichur, Karnataka, during rabi 2012-2013 using thirty different safflower genotypes in a randomized block design with two replications by fallowing package of practice of safflower crop. The characters namely light interception above and below the canopy and leaf area index were measured by using the Aquparcepta meter in each genotype during the anthesis time. The intercepted radiation or light Intercepted (LI) by the canopy and light extinction coefficient (LEC) was calculated by using the following formula.

Light Interception (LI) = $I_o - I$,
Light Extinction Coefficient (k) = $\ln (I/ I_0) / LAI$.

Where, I_o is the solar radiation or light interception above the canopy and I is the light interception below the canopy i.e. the radiation reaching to the ground and LAI is leaf area index.
The distribution of assimilate in different parts of plant i.e. dry matter production and seed yield was recorded at the time of harvest.
The character Radiation Use Efficiency (RUE) is the grams of biomass production per unit of light (g MJ^{-1}) and it was calculated by the formula - Total dry matter produced (TDM) / light interception by the canopy.

Results and Discussion

In this experiment, the genotypes showed differences for all the characters evaluated (Table 1). Maximum light interception was recorded by the genotype GMU-3148 (2298.0) followed by GMU-4480 (2286.0) and GMU 332 (2285.5) and minimum was observed by the genotype GMU 3955 (1516.0) followed by GMU – 2576 (1533.5) and GMU 602 (1538.5). LAI was maximum in the genotype GMU 4480 (3.4) followed by GMU-5142 (3.20), GMU- 1284 (3.15), GMU -2596 (3.15) and the minimum was observed in the genotype GMU 1404 (1.76) followed by GMU 2913, GMU 2894, GMU 2576 (1.85). LEC was maximum in the genotype GMU 5136 (0.675) followed by the genotype GMU-2913 (0.671) and minimum LEC was found in GMU 3955 (0.255) followed by GMU 602 (0.279) AND GMU 2576 (0.299).
RUE value was found maximum of 0.061 gMJ^{-1} in genotype GMU-2894 followed by GMU 7317 (0.060 gMJ^{-1}) and lowest was in GMU-5135 (0.027 g MJ^{-1}). Maximum seed yield was recorded in the genotype GMU 2894 (68.50) followed by GMU 7317 (68.00). Kinary *et al.* (1989) [6] and Costa *et al.* (2000) [3] reported RUE values and yield relation in rice genotypes. In growing canopies, foliar traits (such as leaf area index and leaf mass per unit area) are the important factors in leaf light harvesting capacity and photosynthetic potentials (Niinemets and Sack, 2006) [9]. The variation in the yield of safflower genotypes is mainly because of efficiency of radiation utilizing capacity of the individuals. In our experiments GMU-7317 had maximum light extinction coefficient and maximum yield and RUE values.
The mean values of different morphological characters and yield of safflower genotypes were presented in Table 2. Among all the genotypes, the genotype GMU-3158 recorded the highest plant height (96.6 cm) while the genotype GMU-5735 recorded the minimum plant height (39.4cm). On the other hand, the genotype GMU 3158 was on par with GMU 5130 and GMU 2835 for plant height. Similar results were also been observed by Johnson *et al.* (2001).
The genotype GMU-3158 shown maximum number of branches per plant (12.1) followed by GMU- 5735 (12.0), GMU-3252(11.1) and GMU-2835(11.0). The lowest number of branches was observed in GMU-2894 (6.6) and GMU-184 (7.1). For leaf area, the genotype GMU 602 (104 dm^2) recorded the highest followed by the genotypes GMU 5735 (96.6 dm^2), GMU 3158 (93.54 dm^2), GMU 1156 (92.93 dm^2) and GMU 332 (92.43 dm^2) and the lowest leaf area recorded in genotype GMU 3834 (23.50 dm^2). The genotypeGMU-2894 (129.5 g/plant) produced highest dry matter followed by GMU-7318 (118.0 g/plant), GMU-602(114.0 g/plant), GMU-2835 (109.0 g/plant) and GMU 7317 (118.0 g/plant) and the lowest dry matter production was recorded in GMU-5735 (49.0 g/plant) and GMU 3838 (49.5g/plant).
The genotype GMU-2894 (68.5g/plant) recorded the highest seed yield followed by GMU-7317 (68.0 g/plant) GMU-2835(67.50 g/plant) and GMU-602 (63.50 g/plant) and lowest yield was recorded by GMU-2925 (37.50 g/plant).
Pearson correlation coefficient analysis revealed that seed yield was positively correlated with radiation use efficiency and dry matter. Among the characters, light interception was positively correlated with leaf area index and light extinction coefficient. Radiation use efficiency was positively correlated with dry matter production.

Table 1: Mean physiological characteristics of safflower genotypes evaluated

Genotypes	Light Interception (LI, MJ)	Leaf Area Index (LAI)	Light Extinction Coefficient (LEC (k))	Seed Yield (g/plant)	RUE
GMU-3148	2291.0	2.22	0.643	47.50	0.036
GMU-589	2082.5	2.30	0.614	57.50	0.046
GMU-1284	2232.5	3.15	0.532	43.50	0.025
GMU-332	2285.5	3.10	0.544	52.50	0.039
GMU-5097	2500.5	2.95	0.528	45.50	0.034
GMU-2925	2192.5	2.75	0.566	37.50	0.038
GMU-2503	2199.0	2.90	0.537	60.00	0.036
GMU-5130	2227.0	3.00	0.514	55.50	0.031
GMU-7317	1966.0	1.95	0.618	68.00	0.060
GMU-2913	2038.5	1.85	0.671	53.50	0.032
GMU-4093	2138.5	2.49	0.610	40.50	0.037
GMU-5136	2132.0	2.20	0.675	39.00	0.028
GMU-4546	2137.5	2.25	0.606	45.50	0.032
GMU-3834	2069.5	2.20	0.616	60.00	0.024
GMU-1156	2045.0	2.12	0.420	51.50	0.034
GMU-5735	2114.5	2.08	0.629	60.00	0.023
GMU-5135	2128.0	3.05	0.497	45.50	0.027
GMU-4167	2108.5	2.98	0.495	40.00	0.044
GMU-184	2123.5	2.92	0.477	41.50	0.029

GMU-2894	2134.5	1.85	0.556	68.50	0.061
GMU-1404	2058.5	1.76	0.448	52.50	0.037
GMU-3955	1516.0	1.95	0.255	50.00	0.038
GMU-602	1538.5	1.92	0.279	63.50	0.051
GMU-2576	1533.5	1.85	0.299	51.50	0.038
GMU-4480	2286.0	3.40	0.494	62.50	0.036
GMU-2596	2210.5	3.15	0.478	37.50	0.043
GMU-3927	2163.5	3.05	0.510	55.50	0.036
GMU-5142	2203.5	3.20	0.493	46.00	0.029
GMU-2835	2126.0	3.00	0.480	67.50	0.052
GMU-3252	2183.5	1.90	0.428	55.00	0.038
Mean	2092.4	2.52	0.517	52.06	0.037
SE	150.09	2.05	0.031	6.46	0.011
CD (0.05)	433.98	5.81	0.091	18.69	0.041

Table 2: Mean values of different morphological characters and yield of safflower genotypes

Sl. No.	Genotypes	Observations at the time of anthesis				At harvest
		Plant Height (cm)	No. of branches/plant	Leaf Area /plant (dm^2)	Dry matter (g/plant)	Yield (g/plant)
1	GMU-3158	96.6	12.10	93.54	83.0	47.50
2	GMU-589	68.5	10.5	56.07	96.5	57.50
3	GMU-1284	71.2	8.7	88.79	56.0	43.50
4	GMU-332	62.1	11.6	92.43	88.0	52.50
5	GMU-5097	60.4	7.7	73.50	85.5	45.50
6	GMU-2925	72.8	9.2	54.64	84.0	37.50
7	GMU-2503	76.2	10.7	53.66	79.0	60.00
8	GMU-5130	89.3	9.6	80.66	70.0	55.50
9	GMU-7317	68.7	10.5	65.60	118.0	68.00
10	GMU-2913	75.3	8.0	61.85	65.0	53.50
11	GMU-4093	39.3	8.8	43.50	79.0	40.50
12	GMU-5136	50.2	8.3	78.27	59.0	39.00
13	GMU-4546	46.9	8.2	66.63	69.0	45.50
14	GMU-3834	53.4	8.7	23.50	49.5	60.00
15	GMU-1156	64.7	11.2	92.93	69.0	51.50
16	GMU-5735	39.4	12.0	96.60	49.0	60.00
17	GMU-5135	68.5	8.6	75.16	57.5	45.50
18	GMU-4167	69.2	7.3	82.04	92.5	40.00
19	GMU-184	67.5	7.1	60.00	62.3	41.50
20	GMU-2894	70.6	6.6	80.00	129.5	68.50
21	GMU-1404	67.8	7.3	63.68	75.5	52.50
22	GMU-3955	68.2	7.7	69.00	81.3	50.00
23	GMU-602	72.1	8.0	104.00	114.0	63.50
24	GMU-2576	71.1	8.2	78.85	82.0	51.50
25	GMU-4480	45.5	8.2	65.80	82.0	62.50
26	GMU-2596	73.7	9.5	68.30	95.0	37.50
27	GMU-3927	66.7	6.7	73.50	77.5	55.50
28	GMU-5142	77.1	9.4	78.60	64.5	46.00
29	GMU-2835	88.3	11.0	82.20	109.5	67.50
30	GMU-3252	76.4	11.1	74.25	83.3	55.00
	Mean	67.70	9.29	61.05	70.66	52.06
	SE m±	3.93	1.28	8.72	5.42	6.46
	CD (0.05)	11.38	3.71	24.75	15.67	18.69

Table 3: Correlation coefficient among physiological and yield and yield attributing characters

Characters	Light interception (MJ)	Leaf Area Index	Light Extinction Coefficient	Radiation Use Efficiency	Plant Height (cm)	Number of branches /plant	Leaf area /plant (dm^2)	Dry matter (g/plant)	Seed yield (g/plant)
Light interception (MJ)	1.0000								
Leaf Area Index	0.5774**	1.0000							
Light Extinction Coefficient	0.6343**	0.0657	1.0000						
Radiation Use Efficiency	-0.2499	-0.2305	-0.1838	1.0000					
Plant Height (cm)	-0.0313	0.0708	-0.2330	0.2942	1.0000				
Number of branches / plant	0.2178	-0.0004	0.2332	-0.0194	0.1975	1.0000			
Leaf area/plant (dm^2)	-0.0958	0.0070	-0.2954	0.1243	0.2684	0.2441	1.0000		
Dry matter (g/plant)	-0.1865	-0.1477	-0.2223	0.9806**	0.3201	-0.0223	0.1780	1.0000	
Seed yield (g/plant)	-0.2143	-0.2972	-0.0688	0.4802**	0.1029	0.1951	0.0829	0.4410*	1.0000

*Significant at 5% level and ** significant at 1%

Conclusion

The safflower genotypes showed significant differences in the values of light extinction coefficient and maximum yield and RUE. These parameters may help in selecting the superior safflower genotypes for yield. The genotypes GMU-7317, GMU-2315 and GMU-2835 performed better yield and dry matter production compared to others genotypes. Radiation use efficiency and dry matter production was positively correlated with seed yield.

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