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Effect of intercepted radiation and planting geometry on growth and yield of safflower and linseed intercropping system under rainfed condition

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Abstract

A field experiment was led at Main Agricultural Research Station, Raichur, Karnataka for *Rabi* period of 2015-16 under rainfed condition in medium dark soil to study the Effect of intercepted radiation on growth and yield of safflower and linseed intercropping system under different planting row proportion. The outcomes revealed that, among different intercropping systems safflower + linseed (2:2) recorded altogether higher light interception which was comparable to safflower + linseed (1:2) in 30 cm row proportion. The growth indices like plant height, number of primary and secondary branches, TDMP (Total Dry Matter Production) were significantly higher observed in sole safflower and linseed this might be owing to there is no inter and intraspecific computation between two different species whereas, the leaf area and leaf area index was recorded significantly higher in safflower + linseed in 1:2 rows proportions. The safflower + linseed (1:2) recorded significantly higher safflower equivalent yield (1686 kg ha^{-1}) fallowed by by safflower + linseed (1:1) row proportion (1450 kg ha^{-1}). Higher net returns and B:C was recorded in safflower + linseed in 1:2 row ratio (23,212 ha^{-1} and 2.22) followed by sole linseed (19,376 ha^{-1}) and sole safflower (1:1) (18,979 ha^{-1}).

Keywords: Intercropping system, LAR, LTR, Linseed, Safflower, Rainfed condition

Introduction

Changes in the efficiency of light interception and in the costs for light harvesting along the light gradients from the top of the plant canopy to the bottom are the major means by which efficient light harvesting is achieved in intercropping system. In the current review analysis, leaf, shoot, canopy level plant height and number of primary and secondary branches of safflower and linseed determine the plant light harvesting. In the interception of light (LI) by a canopy, difference between the solar incident radiation and reflected radiation by the soil surface (Villalobos *et al.*, 2002) [19]. It is a determining factor in crop development and provides the energy needed for fundamental physiological processes such as photosynthesis and transpiration. Only 50% of the incident radiation is employed by the plant to perform photosynthesis (Varlet-Gancher *et al.*, 1993) [18]. The quantity of radiation intercepted is influenced by leaf angle, the leaf surface affecting light reflection, the thickness and chlorophyll concentration, which affect the light transmission, the size and shape of the leaf phyllotaxis and the elevation of the sun and distribution of direct and diffuse solar radiation. In addition, plant age- and size-dependent alterations in light harvesting efficiency are also examined. At the leaf level, the variations in light harvesting are driven by alterations in leaf chlorophyll content modifies the fraction of incident light harvested by given leaf area that determines the amount of leaf area formed with certain fraction of plant biomass in the leaves. At the shoot scale, foliage inclination angle distribution and foliage spatial aggregation are the major determinants of light harvesting, while at the canopy scale, branching frequency, foliage distribution and biomass allocation to leaves modify light harvesting significantly. In addition, branching frequency decreases and canopies become flatter in lower light. Such dynamic modifications in plant light harvesting play a key role in plant stand development and productivity. Overall, the current study analysis that plant population in intercropping system harvest more energy as a compared to sole crop whereas, the growth and yield of a crop more noticed in sole crop compared to different row combination. Enhanced light harvesting can be achieved by various combinations of traits, and these suites of traits vary during plant ontogeny.

Materials and Methods

A field experiment was conducted during *rabi* of 2015-16 at Main Agricultural Research Station, University of Agricultural Science, Raichur, Karnataka on medium black soil under rainfed agro eco-system. The soil was medium in organic carbon (5.3 g/kg), low in available nitrogen (115.28 kg/ha), high phosphorous (59.21 kg P_2O_5/ha) and high potassium (473.55 kg K_2O /ha) with pH (7.78) (Table: 1).

Table 1: Physical and chemical properties of soil of the experimental site.

Particulars	Value obtained	Method adopted
I. Physical properties		
1. Fine sand (%)	7.20	
2. Silt (%)	28.60	
3. Clay (%)	64.20	
II. Chemical properties		
1. Soil pH (1:2.5)	7.78	pH meter (Piper, 1966)
2. Electrical conductivity (ds m^{-1})	0.21	Conductivity bridge (Jackson, 1967)
3. Organic carbon (%)	0.53	Wet oxidation method (Jackson, 1967)
4. Available nitrogen (kg ha^{-1})	115.28	Alkaline permanganate method (Subbaiah and Asija, 1956)
5. Available phosphorus (kg ha^{-1})	59.21	Olsen's method (Jackson, 1967)
6. Available potassium (kg ha^{-1})	473.55	Flame photometry method (Jackson, 1967)

Safflower (cv. S-144) and linseed (cv. NL-115) were intercropped in 1:1, 1:2, 2:1 and 2:2 row proportions and both crops were grown as sole crop at their recommended row spacing (60 cm for safflower and 30 cm for linseed), along with mixed cropping of safflower and linseed were also included. The experiment was laid out in randomized complete block design and replicated four times. Both the crops were sown simultaneously and recommended dose of fertilizer were applied to sole crops and in intercropping system, the components crops received fertilizer at the time of sowing in proportion to their plant density in the form of urea, DAP and MOP. The crops were sown as per the row proportions during second fortnight of October. The rainfall received during 2015-16 was 677.5 mm, while during cropping period was 95.5 mm (Table: 2). LAR was recorded from the canopies of sole crops, intercrops and intercropping system was measured by Lux meter between 12:30 and 1:00 pm and LAR was averaged for the system based on row proportions. The yield was computed in terms of safflower equivalent yield, gross returns as well as B:C to assess the system productivity and viability.

Table 2: Monthly meteorological data for the experimental year 2015-16 Meteorological Observatory, Main Agricultural Research Station, University of Agricultural Sciences, Raichur.

Month	Rainfall (mm)		Temperature (°C)				Relative humidity (%)	
			Mean maximum		Mean minimum			
	1932-2014	2015-16	1932-2014	2015-16	1932-2014	2015-16	1932-2014	2015-16
April	70.7	114.2	39.9	37.3	22.6	24.4	77.0	68.0
May	71.5	18.7	39.7	39.9	22.5	26.8	80.0	66.0
June	182.7	38.7	35.3	36.3	22.3	24.9	82.0	77.0
July	62.5	42.0	33.4	36.3	20.5	24.6	79.0	77.0
August	21.2	51.4	32.9	34.6	19.1	24.3	79.0	80.0
September	4.0	316.6	32.2	39.1	16.2	23.4	76.0	88.0
October	1.2	65.4	31.5	33.4	16.8	23.0	77.0	80.0
November	1.1	2.0	31.3	31.9	18.5	21.1	62.0	79.0
December	44.3	2.2	30.5	32.0	22.6	18.4	56.0	83.0
January	13.0	1.4	31.3	31.2	24.4	17.7	53.0	75.0
February	42.9	0.0	32.5	35.5	25.3	21.6	60.0	62.0
March	113.8	24.9	36.5	37.9	23.3	22.7	79.0	66.0
Total	628.9	677.5	-		-		-	

Results and Discussion

Growth components of safflower and linseed

Plant Height

Safflower when grown with linseed with 1:1 row proportion attributed to higher values plant height and dry matter production and its accumulation in reproductive parts per plant was recorded in sole safflower. Similar results were found by Singh (2007) reported higher dry matter production when sunflower grown in sole as well as intercropped with french bean. While in linseed crop, sole linseed was recorded significantly higher plant height and dry matter production due no competition for resources from the main crop.

Leaf area (LA)

Leaf area of safflower differs significantly due to intercropping system. The higher leaf area was observed in safflower + linseed (33.90 dm^2 $plant^{-1}$) in 1:2 row proportion as compared to safflower + linseed (32.56 dm^2 $plant^{-1}$) grown in 2:1 row proportion this might due to the higher dry matter production because of higher photosynthesis. Similarly in linseed the higher leaf area was recorded in safflower + linseed (41.14 dm^2 $plant^{-1}$) grown in 1:2 row proportion as compared to safflower + linseed (21.00 dm^2 $plant^{-1}$) grown in 1:1 row proportion. Similar report were found by Khapre *et al.*, (1993) [8] revealed that, leaf area being photosynthetic surface plays an important role in determining the total biomass production and quantity of photosynthates available for grain productions.

Leaf area index (LAI)

Leaf area index of safflower significantly differed due to intercropping system. The significantly higher LAI were recorded in safflower + linseed (1:2) (1.90) (Fig: 1) and lowest in safflower + linseed (1:2) (0.15) whereas in case of linseed, the higher LAI were recorded in safflower + linseed (1:2) (0.25) and lowest were recorded in safflower + linseed (2:1) (0.22) this might be due to the productivity of a crop depends on the ability of plant cover to intercept the incident radiation, which is a function of leaf area available, the architecture of vegetation cover and conversion efficiency of the energy captured by the plant into biomass. Most production strategies are directed towards maximizing the interception of solar radiation. In the case of crops, this implies adapting agricultural practices in such a way as to obtain complete canopy cover as soon as possible. Deficiencies in water and nutrient inputs may reduce the rate of leaf growth, reducing yield below optimum levels due to insufficient energy capture (Gardner *et al.*, 1985) [4]. The similar result revealed that leaf area index is depend on the plant population (Varlet-Grancher *et al.*, 1989) as well as on the leaf shape and inclination to the canopy.

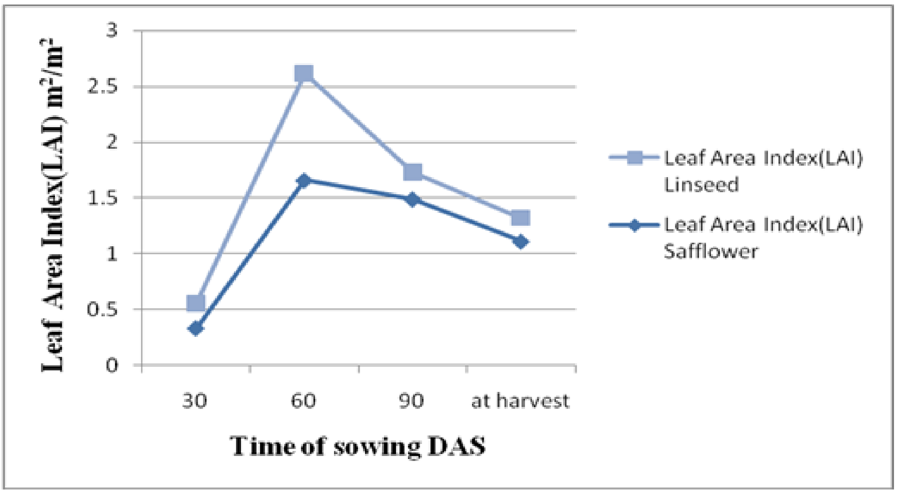

Fig 1: Typical presentation of the variation in the active (green) Leaf Area Index over the growing season for a Safflower and Linseed crop.

The leaf area index (LAI) is other concept for estimate the crop's ability to capture the light energy. LAI is often treated as a core element of ecological field and modeling studies. LAI is broadly defined as the amount of leaf area (m^2) in a canopy per unit ground area (m^2) Watson (1947). Because it is a dimensionless quantity, LAI can be measured, analyzed and modeled across a range of spatial scales, from individual tree crowns or clusters to whole regions or continents. As a result, LAI has become a central and basic descriptor of vegetation condition in a wide variety of physiological, climatological, and biogeochemical studies. LAI is a key vegetation characteristic needed by the global change research community. For example, LAI is required for scaling between leaf and canopy measurements of water vapour and CO_2 conductance and flux, and for estimates of these variables across the global biosphere–atmosphere interface. Because solar radiation covers the entire surface of the ground, the LAI is a robust measure of leaf area per unit of solar radiation available.

Light Interception (LI)

In the interception of light (LI) by a canopy, difference between the solar incident radiation and reflected radiation by the soil surface (Villalobos *et al.*, 2002) [19], is a determining factor in crop development and provides the energy needed for fundamental physiological processes such as photosynthesis and transpiration. Sun light intercepted by tree canopy, relative to total incoming sunlight is called as the light interception. It is a determining factor in crop development and provides the energy needed for fundamental physiological processes such as photosynthesis and transpiration. The present study revealed that safflower + linseed (2:2) mixed row proportion shows greater light interception compared to rest other treatments and it is decreased with sole safflower and sole linseed this might be due to overlapping of number of leaves and number of branches in sole copping system which resulted in diffused solar radiation in lower portion of the plant. Similarly, Varlet-Grancher *et al.*, 1989 found that efficiency of interception of PAR depends on the leaf area of the plant population as well as on the leaf shape and inclination to the canopy.

Thorpe (1978) revealed that incident solar radiation, which is the main factor influencing the efficiency of interception of a canopy corresponds to the capacity of the plant population in photosynthesis and the transpiration processes.

The review by Brougham (1957) [2] indicated that only 43% of light is intercepted by arecanut monocrop, while it can be increased to 95% with mixed crops.

Light Absorption Ratio (LAR)

Safflower + linseed grown in (2:2) were recorded significantly higher LAR due to wider spacing which helped to intercept more light (Table 3). This implied that lower light utilization efficiency. Safflower + linseed (2:2) row proportion recorded significantly higher LAR. The higher LAR values in intercropping implied the highest light utilization efficiency or light absorption ratio (LAR) as compared to sole crop of safflower and linseed. The highest solar radiation utilization (LAR) was noticed when safflower intercropped with linseed (2:2) row proportion. This was because of more number of leaves, the combined leaf canopy might have made better spatial use of light or a combined root system might have made better spatial use of nutrients and or water. More light interception was observed in safflower + chickpea intercropping system as compared to sole safflower Mohsen zafaranieh and Jafar Valizadeh (2014) [11].

Table 3: Growth of safflower and linseed and light interception in safflower and linseed intercropping systems as influenced by different row proportion

Treatment	Growth components				Light interception (%)		
	Safflower		Linseed		30 DAS	60 DAS	90 DAS
	Plant height (cm)	Dry matter production at harvest (g ha^{-1})	Plant height (cm)	Dry matter production at harvest (g ha^{-1})			
T_1 – Safflower + linseed (1:1) 30 cm rows	82.74	106.51	41.25	7.20	61.90	68.72	75.44
T_2 – Safflower + linseed (1:2) 30 cm rows	67.24	111.66	43.69	12.40	71.05	80.85	80.90
T_3 – Safflower + linseed (2:1) 30 cm rows	80.20	108.79	35.91	10.82	68.41	74.40	74.80
T_4 – Safflower + linseed (2:2) 30 cm rows	63.20	96.86	38.10	8.48	83.40	83.52	83.90
T_5– Mixed cropping of safflower and linseed (100:20)	80.30	114.17	38.78	8.74	63.16	68.52	73.75
T_6 – Sole safflower (60 cm x 30 cm)	76.60	121.21	-	-	51.90	61.84	67.50
T_7 – Sole linseed (30 cm x 5 cm)	-	-	45.61	14.61	59.84	68.84	72.44
S.Em.±	2.30	3.30	0.76	0.24	2.70	2.31	2.60
CD (P=0.05)	7.09	10.17	2.34	0.73	8.33	7.11	8.02

Yield of safflower and linseed

Seed yield of safflower was influenced significantly due to intercropping systems with different row proportions and plant population. Sole safflower recorded significantly higher seed yield (1398 kg/ha) it was on par with mixed cropping of safflower and linseed (1298 kg/ha) and safflower + linseed (1:2) row proportion (1289 kg/ha). Reduction in yield of safflower due to various intercropping combinations were in the order of safflower + linseed (1:2), safflower + linseed (1:1), safflower + linseed (2:2) and safflower + linseed (2:1) (Table 4). Variation in the safflower yield might be due to several causes *viz*., variation in population levels, planting geometry, crop combinations, inter and intra species competition for light, moisture, nutrients, space *etc.* Superior values of yield in solitary stand of safflower might be attributed to competition free environment and optimum population level compared to intercropping treatments. Owing to higher population levels per unit area under intercropping systems resulted in inter and intra species competition for available resources. The results are in conformity with the findings of Manjithkumar *et al.* (2009) and Gobade *et al.* (2015) [5], where they, reported that yield of safflower and other *rabi* crops were always highest in sole cropping system as compared to other different intercropping system.

Table 4: Seed yield of safflower (kg ha^{-1}), Seed yield of linseed (kg ha^{-1}), Safflower equivalent yield (kg ha^{-1}) and economics as influenced by different row proportion.

Treatment	Safflower seed yield (kg ha^{-1})	Linseed seed yield (kg ha^{-1})	Safflower equivalent yield (kg ha^{-1})	Gross returns (ì ha^{-1})	Net returns (ì ha^{-1})	B:C
T_1 – Safflower + linseed (1:1) 30 cm rows	1124	163	1450	36242	17638	1.94
T_2 – Safflower + linseed (1:2) 30 cm rows	1289	199	1686	42158	23212	2.22
T_3 – Safflower + linseed (2:1) 30 cm rows	755	138	1031	25770	8123	1.46
T_4 – Safflower + linseed (2:2) 30 cm rows	852	146	1144	28596	11343	1.65
T_5– Mixed cropping of safflower and linseed (100:20)	1298	61	1419	35483	18239	2.05
T_6 – Sole safflower (60 cm x 30 cm)	1398	-	1398	34949	18979	2.18
T_7 – Sole linseed (30 cm x 5 cm)	-	716	1433	35817	19376	2.17
S.Em.±	73	13.96	78	-	1093	0.11
CD (P=0.05)	224	43.01	240	-	3368	0.35

Seed yield of safflower under intercropping system was reduced to an extent of 85 per cent in 2:1, 64.10 per cent in 1:2, 24.37 per cent in 1:1, 8.45 per cent in 1:2 and 7.7 per cent in mixed cropping of safflower and linseed as compared to sole safflower. The reduction in yield was mainly due to varied plant population density. Similarly, Manjithkumar *et al.* (2009) also obtained lower yield of safflower under intercropping systems. The lower seed yield of safflower was produced when it was intercropped with linseed in 2:2 row ratios as compared to the rest of the treatment combinations. Comparable seed yield of safflower could be attributed to comparable performance of yield and growth component of safflower. Safflower when grown with linseed in mixed cropping system attributed to higher values of yield components *viz*., number of seed capitulum^{-1}, seed weight plant^{-1} and test weight. The other factor which indirectly influenced the seed yield are growth attribute *viz.*, number of leaves per plant, leaf area, number of primary and secondary branches per plant, dry matter accumulation and its distribution in various plant parts. Thus, an attempt was made to identify and analyse the growth components which have led to the difference in the seed yield of safflower in light of observation made on yield components, dry matter distribution and growth attributes.

The seed yield of linseed showed significant variations due to intercropping system. Linseed performed better under pure stand compared to intercropping with varying row proportion. Among intercropping system, linseed was superior under safflower + linseed with different row proportion and inferior under mixed cropping with safflower. The variations in linseed yield could be attributed to variation in the yield attributes and population levels. The higher seed yield of linseed was contributed by higher number of capsules plant^{-1}, capsule weight (g), seeds capsule^{-1} and test weight (g). The higher yield of linseed under safflower + linseed (1:2) may be attributed to least competition offered by safflower. These results are in conformity with the findings of Sarkar *et al.* (2003) [14]. They reported that, higher seed yield of linseed when intercropped with lentil. Intercropping of lentil + linseed in 5:1 row ratio resulted bonus yield of linseed.

Table 5: Leaf area index (LAI) of safflower and linseed as influenced by varying row proportion in intercropping system of safflower and linseed.

Treatments	Leaf Area index (LAI)					
	Safflower			Linseed		
	30DAS	60DAS	90DAS	30DAS	60DAS	90DAS
T_1 – Safflower + linseed (1:1) 30 cm rows	0.33	1.53	1.75	0.05	0.12	.014
T_2 – Safflower + linseed (1:2) 30 cm rows	0.40	1.79	1.90	0.08	0.25	0.27
T_3 – Safflower + linseed (2:1) 30 cm rows	0.35	1.64	1.77	0.07	0.22	0.23
T_4 – Safflower + linseed (2:2) 30 cm rows	.023	1.10	1.25	0.05	0.17	0.21
T_5– Mixed cropping of safflower and linseed (100:20)	.036	1.68	1.84	0.04	0.14	0.15
T_6 – Sole safflower (60 cm x 30 cm)	.033	1.49	1.66	-	-	-
T_7 – Sole linseed (30 cm x 5 cm)	-	-	-	0.96	0.22	0.24
S.Em.±	0.01	0.04	0.05	0.01	0.01	0.01
CD (P=0.05)	0.03	0.13	0.16	0.03	0.02	0.03

Safflower Equivalent Yield

Crop equivalent yield is an important index for assessing the performance of different crops under a given circumstance. Based on the price structure, economic yield of component crops is converted into base crop yield *i.e.*, safflower equivalent yield (SEY). Safflower equivalent yield showed marked differences due to intercropping system at varying row proportion. The SEY was significantly higher in safflower + linseed in 1:2 (1686 kg ha^{-1}) as compared to sole crop of safflower followed by the safflower + linseed (1:1) (1450 kg ha^{-1}) (Table 4). The higher SEY in safflower + linseed (1:2) was due to higher yield obtained by both safflower and linseed and higher market price of linseed. These results are in conformity with the finding of Aladkatti *et al.* (2010) and Prasad *et al.* (1993) [13]. Gobade *et al.* (2015) [5] reported higher safflower equivalent yield (SEY) in sorghum + safflower (2:1) (2322 kg ha^{-1}) intercropping system compare to other row proportion. Lower SEY was recorded in safflower + linseed (2:1) (1031 kg ha^{-1}), safflower + linseed (2:2) (1144 kg ha^{-1}) and sole safflower (1398 kg ha^{-1}). This might be due to less plant survival and absence of linseed in case of sole safflower. The productivity of a cropping system is mainly determined by the efficiency of the component crops in utilization of resources. The overall productivity of the intercropping of linseed with safflower relies on the main crop as well as compatibility with other crops.

Significantly higher LER was recorded when safflower intercropped with linseed in 1:2 row proportion (1.20) when compared to sole linseed (1.0) and sole safflower (1.0) (Table 1). Result shows that the highest LER value was achieved in safflower density of 8 plants row^{-1} and linseed densities of 16 plants/rows (LER=1.10) which is equal to 10 per cent increase in agricultural profitability compared to monocultures of two crops. The lower LER as 0.81 was obtained in six safflower and 16 linseed plants. Reduction of LER in higher densities can be due to inter-competition between linseed and safflower, which was confirmed by Hemayati *et al.* (2002) [6]. Similarly, Sarkar *et al.* (2003) [14] also reported higher LER under intercropping systems. Tanwar *et al.* (2011) [17] reported that intercropping systems of linseed with chickpea were found more LER and advantageous than sole cropping.

Economics

Significantly higher gross returns was recorded in safflower + linseed in 1:2 (42,158 ha^{-1}) which was on par with safflower + linseed (36,242ha^{-1}) (Table 4). These results confirmed by Deshpande and Sawant (1997) [3], they reported that gross returns was highest under toria + safflower (18,291 ha^{-1}) and mustard+ safflower (20,149 ha^{-1}) intercropping system of 6:2 row ratio followed by toria + safflower (11,151 ha^{-1}) and mustard + safflower (17,210 ha^{-1}) intercropping system of 4:2 row ratio. Significantly lowest gross returns was noticed in safflower + linseed (2:1) (25770 ha^{-1}) these results were also confirmed by Deshpande and Sawant (1997) [3] reported that 6:2 row ratio gave highest gross returns when it intercropped with linseed, lentil and amaranthus.

Significant difference observed with respect to net returns among the various treatments comprising of row proportion. Significantly higher net returns was recorded in safflower + linseed in 1:2 (23,213 ha^{-1}). The higher net returns from these treatments was mainly because of higher yield level of both the crops and higher market price of component crop as compared to other treatment combinations. These results confirmed by Deshpande and Sawant (1997) [3], they reported that net returns was highest under toria + safflower (14,037 ha^{-1}) and mustard + safflower (14,937 ha^{-1}) intercropping system of 6:2 row ratio followed by toria + safflower (11,551 ha^{-1}) and mustard + safflower (12,366 ha^{-1}) intercropping system of 4:2 row ratio. Significantly lower net return was noticed in safflower + linseed (2:2) (8,123 ha^{-1}) (Table 4). Similarly, this result also conformity to result of Yaragattikar

et al. (2002), where safflower + ber gave higher net returns (16,485 ha^{-1}) as compared to sole safflower (5,485 ha^{-1}).
Benefit Cost ratio was varied among the treatments, where higher B:C was recorded in safflower + linseed (2:1) this could be attributed to lower cost of cultivation (Table 4). The higher economical advantage of these intercropping systems was due to higher seed yield from intercrops besides higher market price. Similar results were reported by Singh (1984) and Korwar *et al.* (1998) [9], Deshpande and Sawant (1997) [3] and Yaragattikar *et al.* (2002).

Conclusions

The productivity of a crop depends on the ability of plant cover to intercept the incident radiation, which is a function of the leaf area available, the architecture of vegetation cover and conversion efficiency of the energy captured by the plant in biomass. Water stress and nutrition reduce LAI to a smaller size and greater leaf senescence. The smaller size of LAI agrees with light capture and thus crop growth, decreasing the efficiency of radiation. The measurement of radiation intercepted by a crop for formation of leaf area is an important factor in monitoring crops, water relations studies, and nutrition and in crop simulation models Measurements taken from digital images exhibit practical advantages with respect to the PAR bar, which must be used at solar noon. In contrast, LAI values in the simplest way measured with a planimeter carried out using destructive measurement and individual leaf analysis.

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