"Affectionately
Dedicated To My
Beloved Parents,
Who Strived
To Make Me
What I Am!"

.....Popat

EFFECT OF PLANTING DENSITY OF SUNFLOWER INTERCROPPED WITH REDGRAM ON LIGHT USE EFFICIENCY OF INTERCROPPING SYSTEM UNDER RAINFED CONDITIONS

A thesis submitted to the
MAHATMA PHULE KRISHI VIDYAPEETH,
Rahuri-413 722 (Maharashtra)

in partial fulfilment of the
requirements for the
degree

of

MASTER OF SCIENCE (AGRICULTURE)

in

AGRICULTURAL METEOROLOGY

by

POPAT SOPANRAO LAKUDZODE
B.Sc. (Agri.) First class

CENTRE OF ADVANCED STUDIES IN AGRICULTURAL METEOROLOGY
(United Nations Development Programme)
COLLEGE OF AGRICULTURE CAMPUS,
PUNE - 411 005

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1992

CANDIDATE'S DECLARATION

I hereby declare that the thesis entitled, "EFFECT OF PLANTING DENSITY OF SUNFLOWER INTERCROPPED WITH REDGRAM ON LIGHT USE EFFICIENCY OF INTERCROPPING SYSTEM UNDER RAINFED CONDITIONS", or part thereof, has not been submitted by me or any other person to any other University or Institute for a Degree or Diploma.

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Place: Pune
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Dr. A.S. Jadhav
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C E R T I F I C A T E

This is to certify that the thesis entitled, "EFFECT OF PLANTING DENSITY OF SUNFLOWER INTERCROPPED WITH REDGRAM ON LIGHT USE EFFICIENCY OF INTERCROPPING SYSTEM UNDER RAINFED CONDITIONS," submitted to the Faculty of Agriculture, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri, District: Ahmednagar, Maharashtra State, in partial fulfilment of the requirement for the degree of MASTER OF SCIENCE (AGRICULTURE) in Agricultural Meteorology, embodies the results of a piece of bona fide research work carried out by Shri. Popat S. Lakudzode, under my guidance and supervision and that no part of the thesis has been submitted for any other diploma, degree or publication in any other form.

The assistance and the help received during the course of this investigation and sources of literature referred to have been duly acknowledged.

Place : Pune
Date : 19-12-1992.

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Place : Pune — *(V.M. Khaire)*

Date : 21 DEC 1992

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Date : 19-12-1992

CONTENTS

CONTENTS (Continued.....)

CONTENTS (Continued.....)

Page

CONTENTS (Continued.....)

CONTENTS (Continued.....)

CONTENTS (Continued.....)

LIST OF TABLES

(Continued....)

LIST OF TABLES (Continued.....)

LIST OF FIGURES

(Continued......)

LIST OF PLATES

ABBREVIATIONS USED

BSH	Bright Sunshine Hours
°C	Degree Celsius
C.D.	Critical Difference
cm	Centimetre
d	day
et al.	et alii (and so on)
etc.	et cetera (and so on)
E	Einstein
Epan	Pan Evaporation
Fig.	Figure
g	gram (s)
ha	hectare
h	hour (s)
i.e.	id est, (that is)
IPAR	Intercepted Photosynthetically Active Radiation
kg	Kilogram (s)
K_2O	Potash (potassium oxide)
LAI	Leaf Area Index
LER	Land Equivalent Ratio
LUE	Light Use Efficiency
m	metre
MJ	Mega Joule
N	Nitrogen
No.	Number
P	Phosphorus
PAR	Photosynthetically Active Radiation
P_2O_5	Phosphorus Pentoxide

PLER	Partial Land Equivalent Ratio
q	Quintal
RG	Redgram
R.H.	Relative Humidity
Rs.	Rupees
S.E.±	Standard Error
SF	Sunflower
TPAR	Transmitted Photosynthetically Active Radiation
viz.	Videlicet (namely)
Wt.	Weight
@	At the rate of
%	per cent
μ	Micron

ABSTRACT

EFFECT OF PLANTING DENSITY OF SUNFLOWER INTERCROPPED WITH REDGRAM ON LIGHT USE EFFICIENCY OF INTERCROPPING SYSTEM UNDER RAINFED CONDITIONS

by

POPAT SOPANRAO LAKUDZODE
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Post Graduate Institute,
College of Agriculture, Pune-411 005
Mahatma Phule Krishi Vidyapeeth,
Rahuri - 413 722
1992

Research Guide	:	**Dr. A.S. Jadhav**
Department	:	**Agricultural Meteorology**

The present investigation, "Effect of planting density of sunflower intercropped with redgram on light use efficiency of intercropping system under rainfed conditions", was carried out at the Agricultural College Farm, Pune, during *kharif*, 1991. The experiment was laidout in a randomized block design with four replications. Six cropping systems, *viz.*, sole sunflower, sole redgram, intercroppings of 2 SF (45 x 15 cm) + 2 RG, 2 SF (45 x 22.5 cm) + 2 RG, 2 SF (45 x 30 cm) + 2 RG, 2 SF (45 x 45 cm) + 2 RG were under study. The gross and net plot size was 5.4 x 5.4 m and 3.6 x 3.6 m, respectively. The various growth observations were recorded at an interval of 14 days from the 28^{th} day after sowing onwards. The micrometeorological observations were recorded at an interval of 7 days from the 20^{th} day after sowing.

The IPAR was significantly the highest under sole sunflower upto the 62^{nd} day. In sunflower, wider intra-row spacings of 30 and 45 cm under intercropping systems intercepted slightly more PAR than narrow intrarow spacings of 15 and 22.5 cm during flowering and grain filling period. The IPAR was significantly the lowest under sole redgram during sunflower growing period and significantly the highest after harvest of sunflower. The IPAR by redgram was improved with increase in intrarow spacing of sunflower under intercropping systems after harvest of sunflower.

The LUE of sunflower in association with redgram did not differ much from the LUE of its sole crop. The association of redgram with sunflower at 30 and 45 cm intra-row spacings of sunflower produced LUE equivalent to that of sole redgram after harvest of sunflower indicating that sunflower + redgram association at 30 and 45 cm intra-row spacings could equally be good for light interception because of complementary interactions resulting in higher yield and monetary benefits.

The sunflower + redgram intercroppings at 22.5, 30 and 45 cm intrarow sunflower spacings significantly increased sunflower seed yield equivalent, net monetary returns and benefit:cost ratio when compared to sole cropping of either sunflower or redgram owing to complementary interaction. The yield advantage under these intercropping systems was to the tune of 31, 32 and 40 per cent, respectively. It would therefore, be suggested to adopt sunflower + redgram intercropping at any of the intrarow sunflower spacings of 22.5 or 30 or 45 cm.

Pages	1 to 109

1. INTRODUCTION

1. INTRODUCTION

The increasing population pressure on the land in our country necessitates higher production and productivity of oilseeds and pulses. Therefore, importance should be given for the efficient utilization of natural resources, *viz.*, solar radiation, soil moisture and nutrients. Out of the various agronomic practices, intercropping is one of the means to achieve higher productivity and resource utilization per unit space and time by growing two or more than two crops simultaneously.

The national per capita consumption of pulse is 42 g d^{-1}, and of oils and fats is 10 g d^{-1}, while the recommended level for per capita per day consumption of pulse is 100 g and of oils and fats is 30 g. This low consumption of pulses and oils and fats is associated partly with low productivity. The deficit production of oilseeds in our country necessitates import of vegetable oil to the tune of Rs. 1000 crore per year. Therefore, diversion of resources and efforts to increase production of pulses and oilseeds from per unit area is not only the concern of oilseeds mission and 20 points programme but also of the farmer at the grass-root level.

Sunflower and redgram are the most important and profitable monsoon season crops. Area under sunflower, in India, is 694.2 thousand hectare with an annual production of 301.4 thousand ton. Area under this crop in Maharashtra is 324.8 thousand hectare with the annual production of 135.5 thousand ton (Anonymous, 1986). While the productivity of this crop, in India, is around 450 kg ha^{-1} and in Maharashtra is 400 kg ha^{-1}. The low productivity of this crop both in India and Maharashtra is mainly attributed to lack of high yielding varieties/hybrids, lack of optimum plant population, inadequate fertilizers use, poor facilities of irrigation and pest control, *etc.* However, sunflower is best suited in multiple cropping programme, particularly under intercropping because of its short duration, photo-insensitivity and fairly drought tolerant ability and can therefore, be adopted in wide range of soil and climatic conditions.

The area under redgram in India is 3206.0 thousand hectare with the production of 2420.4 thousand ton. The area under this crop, in Maharashtra is 756.4 thousand hectare with a production of 451.3 thousand ton (Anonymous, 1986). The productivity of this crop in Maharashtra is 600 kg ha^{-1} as against 750 kg ha^{-1} national average productivity.

Mixed/intercropping systems have a built in mechanism of risk bearing against bad weather (Raheja, 1973). Intercropping ensures supply of balanced food and feed, cash needs of marginal farmer without extra expenses and efforts. Experimental evidences have also proved that the yield stability is greater with intercropping than sole cropping (Rao and Willey, 1980). Intercropping with legumes also results in contribution of a part of nodular N_2 fixed to the associated non-legumes.

Sunflower and redgram are a popular choice of mixed/intercropping system during monsoon season. Intercropping of sunflower with medium to long duration redgram has been reported to increase total productivity (Jadhav *et al.*, 1991). The work regarding agronomic management practices is available on sunflower and redgram intercropping. However, the research work on this intercropping with regard to intercepted PAR and light use efficiency (LUE) is very limited and needs a scientific inquest.

Grain yield is the product of light interception, the efficiency of conversion of intercepted light to dry matter and the partitioning of dry matter to grain (Gifford and Evans, 1981). This would suggest that further increase in potential grain yield must come from improvement in light interception, light use efficiency, aeration, moisture and plant nutrients. Hence, due importance must be given to improve the means of exploitation of solar energy for agricultural production. Out of the various agronomic practices, especially under semi-arid conditions, intercropping helps to achieve higher productivity and resource utilization per unit area and time. Intercropping means growing of two or more crops differing in height, canopy adaptation, growth rates and nutritional requirement simultaneously in such a way that they can be grown with the least competition, utilize land, water, environmental and human resources in a more efficient manner than they do individually and enhance the total crop production and returns.

While studying the temporal complimentarity in intercropping of sorghum/pigeonpea (Natarajan and Willey, 1980a), pearl millet/pigeonpea (Willey and Rao, 1977) maize/pigeonpea (Sivakumar and Virmani, 1984), groundnut/pigeonpea (Willey *et al.*, 1986), it was found that the intercrops intercept significantly more PAR than either of the sole crops.

The dry matter production is not only the function of amount of light interception but also its uniform distribution within the crop canopies. Important factors affecting light distribution within crop canopies are component crop density, plant arrangements and spacing, relative time of sowing of component crops, effect of applied nitrogen, density and extent of the foliage, leaf area density or leaf area index (LAI), leaf angle and the distribution of leaves. Among these factors, the plant density particularly inter-plant spacing is key factor for maximum light interception. In higher plant density, the crop intercepts more PAR than in lower plant density (Gallo and Daughtry, 1986; Steiner, 1986).

Decreasing plant density of cereal component to accommodate more number of plants of the legume component improves light distribution to the lower legume components. In a study of sorghum at 2,20,000 plants ha^{-1} intercropped with pigeonpea at 37,000 plants ha^{-1}, 90 cm inter-row spacing of sorghum improved the yield of intercropped sorghum by 5% and that of associated pigeonpea by 3%

when compared to 60 cm rows (Freyman and Venkateswarlu, 1977). Further, widening of sorghum interrows to 135 cm gave a 9% increase in sorghum yield over the 60 cm spacing and pigeonpea yield was increased by 11%.

Okigbo (1981) suggested that in intercropping, the competition for light (interception and its distribution) in component crops can be improved by proper choice of crops, genotypes, selecting shade tolerant shorter components, harvesting one of the component sufficiently early so that late harvested component is not affected much and adjusting population density and manipulating planting patterns. Among these factors, plant population and crop geometry play very important role in improving light interception, its distribution within the crop canopy and light use efficiency (LUE).

Srinivas (1991) observed that though sunflower + redgram system was equally efficient in light interception as pearl millet + redgram system, the light use efficiency (LUE) was lower in sunflower + redgram system than that of pearl millet + redgram intercropping system.

The maximum light use efficiency (LUE) is the function of interplant and intraplant spacings and their competition for light and water. Plants show remarkable plasticity in size and form in response to their environment under various densities. There is enough evidence to show that there exist a considerable scope for improving the light use efficiency (LUE) and increasing crop yields by adjusting plant population to near optimum levels in intercropping system under semi-arid conditions. However, literature on such studies in sunflower + redgram intercropping is very meagre and needs a scientific investigation.

With this background in view, the present investigation, *viz.*, "Effect of planting density of sunflower intercropped with redgram on light use efficiency of intercropping system under rainfed conditions" have been undertaken with the following objectives:

1. To determine photosynthetically active radiation (PAR) intercepted by sole and intercropping system.

2. To determine light use efficiency (LUE) of sole and intercropping system.

3. To find out optimum plant density of sunflower intercropped with redgram under rainfed conditions.

2. REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The total agricultural production, in India, has considerably been improved in recent years. The intercropping legumes in high yielding varieties of non-legumes is one of the components for increasing the productivity. Intercropping of pigeonpea in sunflower is one of the important practices in rainfed areas for increasing production of both the pulses and oilseeds in our country. In this chapter, an attempt is made to present a brief review of the research work carried out on the studies of intercropping system involving sunflower and pigeonpea in different seasons in general and under rainfed condition in particular.

Over the last two decades, there has been increasing research interest in measurement of solar radiation in crop canopies and its use in the assessment of plant productivity (Allen and Brown, 1965; Monteith, 1965; Williams *et al.*, 1965; Hesketh and Baker , 1967; Cowan, 1968; Szeicz, 1974; Gallagher and Biscoe, 1978). Hatfield and Carlson (1978) used a line quantum sensor (LAMBDA Instrument Corporation, Lincoln, NE) to measure Photosynthetically active Photon Flux Density (PPFD) in soybean canopies. In this chapter, a brief review of research work carried out on performance of different cropping systems, in respect to intercepted PAR and light use efficiency (LUE) is presented.

2.1 EFFECT OF CROPPING SYSTEMS ON INTERCEPTED PHOTOSYNTHETICALLY ACTIVE RADIATION (IPAR):

Numerous studies have shown a close relationship between light interception and leaf area/leaf area index (LAI) (Denmead *et al.*, 1962; Williams *et al.*, 1962; Donald, 1963; Nilliat *et al.*, 1974; Hughes and Keatinge, 1983; Sivakumar and Virmani, 1984).

Just like leaf area, light interception also depends on plant density. Allen (1974) stated that light interception was higher in higher plant density. While studying the effect of plant spacing on interception of radiation in corn, Denmead *et al.* (1962) and Gallow and Daughtry (1986) found that closer plant spacings intercept more radiation than wider plant spacings. Similar results were obtained in case of soybean (Shibles and Weber, 1966), sorghum (Steiner, 1986) and chickpea (Leach and Beech, 1988) under optimum moisture conditions.

Tamura *et al.* (1976) revealed that in intercropping, the tall growing component crop put forth much more foliage and intercepted most of the light and reduced the light interception of another slow growing component crop which caused reduction in the rate of dry matter accumulation due to continuous shading in intercropping. Similar results were obtained by Willey and Rao (1977), Selvaraj (1978) and Soundarajan (1978).

While studying the temporal complementarity in intercropping of sorghum pigeonpea (Natarajan and Willey, 1980a), pearl millet + pigeonpea (Willey and Rao, 1977), groundnut + pigeonpea (Willey *et al.*, 1986), it was found that the intercrops intercept significantly more PAR than either of the sole crop.

While studying the intercropping of sorghum + pigeonpea (Natarajan and Willey, 1980a), it was observed that prior to sorghum harvest, light interception by the intercrop combination was almost as high as sole sorghum, after sorghum harvest, light interception by the remaining pigeonpea was very poor and suggested increase in pigeonpea yield by increasing population density and better plant distribution.

Willey *et al.* (1981) revealed that intercropping intercepts photosynthetically active radiation (PAR) more efficiently than does the sole crop under rainfed conditions. Similar results were obtained by Sivakumar and Virmani (1984) and Srinivas (1991).

Hughes and Keatinge (1983) while studying the solar radiation interception, dry matter production and yield in pigeonpea in Trinidad, West Indies, noticed linear relationship between the maximum amount of dry matter accumulation by the crop and amount of solar radiation intercepted by the foliage during growth period, analysis of his data also showed that both seasonal interception of solar radiation and efficiency of its conversion to dry matter were reduced in plots which did not receive supplementary irrigation and produced low LAI. Such plots also partitioned a smaller proportion of their dry matter in to grain.

When one component is taller than the other in an intercropping system, the taller component intercepts greater share of light. As a result, the growth rates of the two components will be proportional to the quantity of PAR they intercept provided other growth factors are not limiting and the crops are in their vegetative stages.

Willey *et al.* (1986) concluded that for any given combination of cultivars and stand-density, irrigated crops always intercepted more radiation than the corresponding unirrigated one. Similar findings were observed by Willey *et al.* (1983), Mandal *et al.* (1986) and Leach and Beech (1988).

2.2 EFFECT OF PLANTING DENSITY OF COMPONENT CROPS ON INTERCEPTED PHOTOSYNTHETICALLY ACTIVE RADIATION (IPAR)

A linear relationship has been observed between light interception and leaf area index. (Weigand and Richardson, 1984).

Witt *et al.* (1972) reported that the higher plant density intercepts more radiation than the lower plant density. Similar results were reported by Clegg *et al.* (1974), Gallo and Daughtry (1986) and Steiner (1986).

Willey and Osiru (1972) found that there was virtually complete light interception by the higher plant density of the corn after the onset of the shooting stage. At a lower population density, light interception reaches a plateau or declined during the shooting stage.

Shibles and Weber (1966) found that increased population and decreased plant spacings resulted in increased leaf area index (LAI) and as a result increased solar radiation interception. Leaf area index and rate of leaf area development was more in densely populated crops than in lower population.

Witt *et al.* (1972) reported that light interception by sorghum planted in 51 cm was about 15% greater than in 102 cm row spacing averaged over two seasons. From studies at Nebraska, Clegg *et al.* (1974) found that visible radiation intercepted by sorghum canopies was greater in 51 cm rows than 76 and 102 cm rows. About 80% of the daily incoming PAR was intercepted in higher plant density compared with about 70% interception in lower plant density.

Allen (1974) reported that just like leaf area, light interception was also dependent upon plant density and row direction. His model predicted that NE-SW row orientation may be best since the most light would be absorbed at 10.00 h when moisture stress would be low and least at 14.00 h when moisture stress would be high.

Hipps *et al.* (1983) found that interception of PAR was influenced by LAI, when LAI values were small at that time PAR interception was less but as the plant density increased, LAI increased more than the increase in per cent PAR interception value. A relationship was determined between daily per cent of incident PAR intercepted and LAI, which was valid upto the time of rapid leaf senescence. Steiner (1986) also reported that light interception was higher in a higher plant population.

Leach and Beech (1988) found that net radiation was 5 per cent higher in high plant density as compared to low plant density and 20 per cent more of the incoming PAR was transmitted to the soil surface in lower plant density compared to higher plant density.

2.3 EFFECT OF CROPPING SYSTEMS ON LIGHT USE EFFICIENCY (LUE):

PAR interception and crop growth rate are not very meaningful in the analysis of crop production unless the influence of conversion efficiency on dry matter accumulation is taken into account (Tollenaar and Bruulsema, 1988).

Shibles and Weber (1966) studied the solar radiation interception and dry matter production in soybean grown in various planting pattern. Increased population resulted in increased LAI and a reduction in number of days from emergence to 95 per cent solar radiation interception. Dry matter production was a function of per cent solar radiation interception regardless of planting pattern.

Biscoe and Gallagher (1977) and Monteith (1977) showed that dry matter production early in the season is related to the amount of radiation intercepted by the crop. Likewise Gallagher and Biscoe (1978) showed that for wheat and barley grown at Suttan Boningto and Rothamsted, about 3 g dry matter was produced by each MJ of PAR absorbed until ear emergence. For the whole crop period about 2.2 g of dry matter was produced per MJ of light absorbed.

Intercropping like pearl millet + pigeonpea (Willey and Rao 1977; and maize + pigeonpea (Sivakumar and Virmani, 1980) recorded higher dry matter than sole crops like maize, pearl millet and pigeonpea due to increased interception of PAR and conversion efficiency.

Okigbo (1981) suggested that in intercropping, the competition for light in component crops can be minimized by proper choice of crops, genotypes, selecting shade tolerant shorter component, harvesting one of the component sufficiently early so that late harvested component is not greatly affected and adjusting population density and manipulating planting pattern to minimize the competition and to increase the light use efficiency (LUE).

Reddy and Willey (1981) in growth and resource use studies in an intercrop of pearl millet + groundnut reported that higher intercrop yield appeared to be achieved by an increased efficiency in converting light energy into dry matter and not by any increase in the amount of light energy intercepted. At maximum green LAI (61 DAS) Marshall and Willey (1983) observed energy conversion efficiency of 4.1 g MJ^{-1} in sole millet, 2.5 g MJ^{-1} in sole groundnut and 4.3 g MJ^{-1} in intercropping. This was attributed to more efficient spread of leaf and higher total water use in intercropping.

Sivakumar and Virmani (1984) reported that the higher production efficiency of the maize + pigeonpea intercrop system in the conversion of intercepted PPFD into dry matter over the sole pigeonpea crop is evident. It reflects the increase in leaf area duration and PPFD interception of the intercrop and higher photosynthetic efficiency of the C_4 crop (maize). Up to harvesting of the maize, the maize + pigeonpea intercrop system produced 0.93 g/E, whereas, the sole pigeonpea crop could produce only 0.23 g/E. The corresponding values for maize and sorghum grown as monocrops were 0.82 and 0.62 g/E, respectively.

Gosse *et al.* (1986) showed a linear relationship between intercepted incident solar radiation and rate of crop dry matter accumulation, when nutrient and water supply are not limiting to crop growth, although the slope of linear relationship (*i.e.*, the efficiency with which solar radiation is converted into plant dry matter) may vary with crop species and phase of crop development.

2.4 EFFECT OF COMPONENT CROP DENSITY ON LIGHT USE EFFICIENCY (LUE):

Raghunatha and Jagnnath (1976) reported that light interception efficiency with regard to biological yield was favoured by triangular and square plantings at lower populations and by square planting at higher population in case of sorghum.

Hughes and Keatinge (1983) reported that light use efficiency (LUE) generally remains more in irrigated conditions than in dryland conditions. In irrigated corn the efficiencies of radiation use were 2.4 g MJ^{-1} and 3.3 g MJ^{-1} during vegetative and linear grain filling period, respectively. But in unirrigated plot, LUE were 2.4 and 1.9 g MJ^{-1} during vegetative and grain filling period, respectively. Similar results were reported by Weigand and Richardson (1990).

When water and nutrients are not limiting, light use efficiency can be variable. Values for light use efficiency reported in those studies ranged between 2 and 6 g MJ^{-1} of intercepted PAR. It seems that all three components of this physiological frame work, interception, conversion efficiency and partitioning may be affected by genetic and environmental factors Ferrans *et al.* (1986).

Hughes *et al.* (1987) reported that light use efficiency (LUE) depends on plant density and row geometry. Rate of conversion of intercepted radiation in to dry matter is larger for the erect growth habit than the prostrate growth habit, but it was smaller for crops of 60 plants m^{-2} than those of 30 plants m^{-2}. Similar results were obtained by Leach and Beech (1988) in chickpea. They noted light use efficiency (LUE) of 1.40 ± 0.044 g MJ^{-1} but there was the lowest efficiency with higher plant density and the highest efficiency with lower plant density. There was marginal increase in efficiency attributable to better rectangularity of the plant arrangement which possibly improves water relations (Leach and Beech, 1988).

If energy released by respiration is assumed to be 33 per cent of the net Co_2 assimilation, then the net quantum yield can be taken as 0.043 mole CH_2O per Einstein or 1.29 g dry matter per Einstein (Williams *et al.*, 1962). The largest value of light use efficiency for an annual C_3 crop was 4.9 g MJ^{-1} of PAR absorbed (Fasheun *et al.* 1982).

2.5 EFFECT OF CROPPING SYSTEMS ON GROWTH, *i.e.*, LEAF AREA, LAI AND DRY MATTER PRODUCTION:

Total leaf area is often a useful measurement in bioproductivity studies. It bears an important and direct relationship to the photosynthesis and transpiration. Leaf area is also important in determining the percentage of solar radiation intercepted by an individual plant or crop canopy and thus it influences plant growth and final yields.

While screening the existing literature, it is observed that the growth characteristics of redgram were influenced by adopting intercropping with legume crops or oilseed crops. As the plant density of oilseeds in intercropping system increases then leaf area, leaf area index and dry matter accumulation of intercropping redgram decreases. Dry matter accumulation of intercropping redgram per plant was mostly concerned with the plant population of oilseed crops.

Osiru and Willey (1972) and Lakhani (1976) reported that when the component crops are present in an approximately equal proportion, productivity and efficiency appears to be determined by the more aggressive crops, usually the cereals.

Willey and Osiru (1972) reported that in general, overall mixture density, type of component crops and their relative proportions are important in determining the yield and production efficiency of cereal-legume intercropping systems. Similar results were obtained by Lakhani (1976) and Selvaraj (1978). Sivakumar and Virmani (1980) reported that long leaf area duration resulted in more rapid built up of LAI in maize + pigeonpea intercropping system as compared to sole crops. Beneficial effect of more LAI and long leaf area duration reflecting in higher dry matter and tiller production was reported by Reddy and Willey (1981).

Nnko and Doto (1978) reported reduction in growth and dry matter production of shorter components like groundnut, soybean, safflower when associated with taller components like maize, sorghum, sunflower, millet. Similar results were noticed by Choudhari and Misangu (1979) and Edje (1980).

Deshpande (1980) reported that the taller components particularly cereals, shade the shorter components (legumes) and a high density causes reduced growth and yield of companion legume. Similar results were reported by Nikam *et al.* (1984), Gardiner and Craker (1979) and Barve (1990).

Gardiner and Craker (1979) reported that the growth and yield of legume component is reduced markedly when intercropped with higher density of the cereal component. In a maize + bean intercropping system, increasing maize density 3 folds from 18,000 to 55,000 plants ha^{-1} caused reduction of 24 per cent in LAI and 70 per cent in seed yield of associated bean.

Hunsal and Malik (1987) reported that sole crop of redgram produced the highest dry matter per plant, whereas, in intercropping with sorghum was adversely affected as the densities of sorghum increases.

Siddeswaran *et al.* (1987) carried out the study with sorghum and sunflower combinations and the effect was consistent throughout the crop growth period. Amongst the associated crops, sunflower produced the maximum dry matter followed by sorghum. Sunflower because of its vigorous growing habit, starting stiff competition with finger millet suppressed its growth and produced maximum dry matter by intercepting maximum available light.

rate of leaf area production slackened earlier in the higher population densities but continued to increase in the lower densities.

Fischer and Wilson (1975) reported that the development of LAI is influenced by plant density. In medium and higher density plantings, LAI increases until full emergence of the flag leaf and then declines. The reduction in LAI became more rapid in the later stages of grain filling. In lower density planting, maximum LAI occurred at later stage than that occurred at other densities.

Steiner (1986) reported that the higher plant density plot had slightly higher peak LAI than the lower plant density. But the difference in leaf area is significant after flowering stage of the crop. Similar results were obtained by Shibles and Weber (1965). They also found that increased population results in increased LAI.

2.6.3 Effect of Plant Density on Dry matter Production:

Williams *et al.* (1965) observed that the higher plant density intercepted more radiation than lower plant density. Numerous studies have shown a linear relationship between intercepted PAR and rate of crop dry matter production when nutrient and water supply are not limiting to crop growth. (Monteith, 1977; Biscoe and Gallagher, 1977; and Gosse *et al.*, 1986.

Shible and Weber (1965) found that as the plant density increased, leaf area and LAI increased that intercepts more radiation as a result dry matter production increased in high plant density.

Kostrej and Repka (1972) found that with increase in plant density, total dry matter m^{-2}, dry matter per plant, the proportion of plant dry matter in the roots and green leaves decreased and that in stems and dead leaves increased. Itnal *et al.* (1977) observed that the dry matter accumulation per plant of

2.6 EFFECT OF PLANTING DENSITY OF COMPONENT CROPS ON GROWTH:

2.6.1 Effect of Plant Density on Leaf Area:

When water was not a limiting factor for growth, high plant populations with maximum ground cover, generally, resulted in improved use of incoming radiation and nutrients. With dryland farming, however, water usually restricted plant growth during all or part of the growing season. For dryland conditions, cultural practices must balance all factors of production with available water. Hence, this investigation was conducted to obtain a better information on the plant densities influencing dry land production.

Thompson (1982) suggested that as the plant density of sunflower increased no effect on bud appearance and physiological maturity was observed. But there was a significant initial difference in ground cover, which disappeared by 35^{th} day. The leaf area per plant decreased.

Terbea and Stoenescu (1984) conducted an experiment in which eleven hybrid sunflower varieties were grown in the field at population densities of 20,000, 40,000 and 70,000 plants per hectare. They noticed that increasing population density decreased leaf area per plant.

2.6.2 Effect of Plant Density on LAI:

The development of leaf area index (LAI) can be described by "S" shaped growth curve from emergence through maturity of the plants. The curve has an initial exponential growth phase, followed by a linear phase and finally attains maximum growth phase then growth diminishes and maintenance occurs.

Williams *et al.*, (1965) reported that LAI and rate of leaf area development was more in densely populated crop than in lower populated crop. However, the sorghum was higher with lower plant population and it decreased with increase in plant population.

Steiner (1986) reported that in dry growing season, higher plant population increased seasonal ET by about 9% and shifted the partitioning of ET to the vegetative period. Higher plant population of sorghum results to higher dry matter and lower grain yield. Lower plant population results in lower dry matter and higher grain yield.

Tollenaar and Bruulsema (1988) found that total above ground dry matter accumulation and grain yield at physiological maturity increased substantially with increase in plant density of maize upto certain limit but rate of dry matter accumulation did not vary among plant densities during the grain filling period.

2.7 EFFECT OF CROPPING SYSTEMS ON YIELD, LAND EQUIVALENT RATIO (LER) AND ECONOMICS:

Intercropping systems are beneficial than sole cropping systems. Osiru and Willey (1972) in their study of maize intercropped with cowpea at densities ranging between 10,000 and 40,000 plants ha^{-1} found that at the lowest mixture density, the intercrop maize yield was 2300 kg ha^{-1}, 15% less than the sole maize and increased to 4600 kg ha^{-1}, 8% less than sole maize at 40,000 plants ha^{-1}. Pod yield of intercrop cowpea with the lowest density of maize was 941 kg ha^{-1}, a reduction of 41% of sole cowpea yield at optimum density. At the highest overall density, intercrop cowpea yield was 700 kg ha^{-1}, *i.e.*, a yield reduction of 66%. LER value rise with increasing mixture density from the lowest to highest. The LER values were 0.91, 1.14, 1.20 and 1.26.

Willey *et al.* (1981) reported that the overall mixture densities and the relative proportions of component crops are important in determining yields and productive efficiency of cereal-legume intercropping system. When the components are present in approximately equal numbers, productivity and efficiency appears to be determined by the more aggressive crops usually the cereal. In a sorghum + bean intercropping, the optimal density of either crop of 2,00,000 plants ha^{-1} gave and LER of 1.41 this was due to increase in intercrop sorghum yield, the intercrop bean yields remained unchanged.

Syarifuddin et al., (1973) conducted field trials on maize varieties grown at five plant densities ranging between 10,000 to 1,50,000 plants ha^{-1} intercropped with same population of mung, bean or soybean and concluded that increasing densities of maize increased the maize yield but caused progressive decrease in legume yields.

Soundarajan and Palaniappan (1979) reported that pearl millet suppressed the growth and branching of intercropped redgram and the reduction in yield was more pronounced due to increase in the population of pearl millet.

oallen (1979) concluded that the yield of maize with low and high population with intercropping of constant soybean population did not differ significantly. Higher population of maize resulted in reduced yields of soybean than lower plant population of maize.

Freyman and Venkateswarlu (1977) and Natarajan and Willey (1980a) observed that when intercrop sorghum densities varied from 55,000 to 2,20,000 plants ha^{-1} and combined with constant pigeonpea density of 37,000 plants ha^{-1} the intercrop sorghum yield response was linear. In contrast, the intercrop pigeonpea yield decreased with rising sorghum density. The highest LER value was obtained at the lowest sorghum density which decreased with rising sorghum density. Refey *et al.* (1986) observed that redgram yields in intercropping systems were appreciably lower than its pure stand.

Biradar *et al.*(1988) reported that in general, income was higher when redgram was intercropped with sunflower as compared to either of the sole crops.

Jadhav *et al.*(1991) observed that intercropping of pearl millet and sunflower with pigeonpea under dry land conditions, produced as much grain yield as sole crops of pearl millet and sunflower, respectively. Seed yield of pigeonpea genotypes, however, decreased drastically under intercropping systems compared to their respective sole crop yields.

Salomibina *et al.* (1992) reported that Morden variety of sunflower intercropped with groundnut in three planting densities of 55,555, 66666 and 74074 plants ha^{-1} and constant groundnut plant density of 3,33,333 plants ha^{-1} tended to yield more at higher density (74074 plants ha^{-1}) than at lower density (55,555 plants ha^{-1}) in intercropping system. Conversely intercropped groundnut yielded better under low than high density of the sunflower. LER increased with decrease in sunflower density and constant groundnut density.

2.8 EFFECT OF COMPONENT CROP DENSITY ON YIELD:

In general, under irrigated conditions, sorghum is found to produce greater yields in higher plant densities than lower plant density. If soil moisture is limiting, lower plant density produce superior yields. Thus, irrigation and seasonal rainfall with available soil moisture affects the choice of plant density for obtaining optimal yields (Bond *et al.*, 1964).

Bond *et al.* (1964) found that under normal dry land farming conditions lower plant density, generally produce more yield than higher plant population. Similar results were reported by Anonymous (1979-80) and steiner (1986).

Pawar and Sarnaik (1975) observed that the beneficial effects of greater plant population in sorghum were evident in increased grain and fodder yields.

The spacings of 45 x 10 cm (2,22,222 plants ha^{-1}) resulted in significantly more grain and fodder yields than 45 x 15 cm (1,48,148 plants ha^{-1}).

Upadhyay and Srinivas (1976) reported from their experiment on plant density levels of sunflower (varying from 74074 to 4,44,444 plants ha^{-1}) that the response of the reciprocal of grain yield to varying plant densities was linear.

Umrani (1981) observed that there were competitive effect of one crop over the other crop as density of one crop increased in pearl millet + pigeonpea intercropping. Increased plant density of pearl millet from 75,000 to 2,25,000 plants ha^{-1} depressed the yields of pigeonpea when plant density of pigeonpea increased from 25,000 to 75,000 plants ha^{-1}, there was a reduction in the yield of pearl millet.

2.9 EFFECT OF CROPPING SYSTEMS ON YIELDS CONTRIBUTING CHARACTERS:

Soundarajan and Palaniappan (1979) in their pearl millet + redgram intercropping suggested that intercrop suppressed the growth and branching of pigeonpea and reduction was more pronounced due to pearl millet. As the density of pearl millet increased in cropping system the number of pods per plant, 1000 grain weight and weight of grains per plant decreased in pigeonpea.

Hefni *et al.* (1985) conducted an experiment on interplanted maize at different densities as an intercrop with soybean at same density. They observed that number of grains per plant, 1000 grain weight and weight of grains per plant decreased with increase in plant density of maize. In soybean also number of pods per plant, 1000 grain weight and weight of grains per plant decreased with increased maize density.

Dandwate (1987) conducted the experiment at Rahuri during summer season and revealed that number of pods per plant, 1000 grain weight and weight of grains per plant was more in sole crop of redgram than redgram in the intercropping system.

Putnam *et al.* (1990) conducted an experiment in sunflower + groundnut intercropping system in which plant density of sunflower was increased and groundnut density was maintained constant in all the treatments. It was observed that number of grains per plant, 1000 grain weight and weight of grains per plant of groundnut decreased with increase in plant density of sunflower.

2.10 EFFECT OF COMPONENT CROP DENSITY ON YIELD CONTRIBUTING CHARACTERS:

Stickler and Wearden (1965) and Lutz *et al.*, (1971) observed that the weight of grains per earhead and 1000 grain weight tend to decrease at high plant density.

Rao and Reddy (1982) reported that increasing plant density of sunflower from 55,555 to 74,074 and 1,11,111 plants ha^{-1} increased the LAI and seed yields of sunflower but decreased head diameter and number of seeds per head.

Leon and Moreno (1982) reported that when sunflower were grown at plant population ranging from 25,000 to 1,00,000 plants ha^{-1}, seed yield was not affected by treatments (range 1.716 - 2.129 t ha^{-1}), straw production increased and capitulum diameter decreased. High sowing density of sunflower decreased the 1000 seed weight and oil content but increased seed yield ha^{-1}.

Terbea and Stoenescu (1984) reported that growing sunflower in the field at population densities of 20,000, 40,000 and 70,000 plants ha^{-1}, decreased leaf area per plant, 1000 grains weight, seed yield per plant and head diameter. Sunflower grown in 35 and 50 cm plant spacing, stem diameter, head diameter and 1000 seed weight were higher in 50 cm plant spacing. While seed yield and seed oil percent were maximum at 35 cm plant spacing. Plant height, stem diameter, number of seeds per head, head diameter and 1000 seed weight increased with increasing plant spacing.

Narwal and Malik (1985) reported that in sunflower, leaf area per plant was greater at low plant density (5 plants m^{-2}) which resulted in higher 1000 seed weight, number of seeds per plant than high plant density (11 plants m^{-2}).

Cardinali (1985) observed that as the sunflower plant density increased from 10,000 to 50,000 plants ha^{-1} then leaf area per plant, number of seeds per plant and 1000 seed weight decreased and LAI stabilized at high densities.

2.11 EFFECT OF CROPPING SYSTEMS ON SUNFLOWER SEED YIELD EQUIVALENT:

Jadhav *et al.* (1992) noticed that pearl millet + redgram intercroppings, irrespective of fertilizer application, significantly increased pearl millet grain yield equivalent compared to pearl millet + black gram or green gram intercropping owing to larger difference in maturity periods of component crops under former intercropping which helped in better utilization of available resources like nutrients, moisture and sunlight over the time. Considering the competitive nature of green gram or black gram, redgram will be more suitable as intercrop in pearl millet.

2.12 EFFECT OF CROPPING SYSTEMS ON NET MONETARY RETURNS AND BENEFIT COST RATIO:

Biradar et al., (1988) reported that, in general, net monetary return was higher when redgram was intercropped with sunflower as compared to either of the sole crops. Replacement population (67:33) of redgram and sunflower recorded higher yields and resulted in more net monetary returns and greater benefits than the sole crops of sunflower or redgram maintained at full (100:100) population in intercropping.

salomibina *et al.* (1992) reported in sunflower + groundnut intercropping systems that the net monetary returns ha^{-1} were maximum in the intercrop treatments involving paired and skipped rows at sunflower densities of 55,555 and 74,074 plants ha^{-1}. Sole sunflower was less expensive to cultivate (Rs. 2,074 ha^{-1}) than the intercrop system (Rs. 4,816 ha^{-1}) and also gave significantly less net monetary returns. The net monetary returns from the sole crop of groundnut was statistically at par with that of intercrop treatments. Its cultivation cost was Rs. 3,681 ha^{-1}. The indices of relative net monetary returns were statistically similar among the various intercrop treatments and were all greater than unity (1.57 - 1.93). It shows that intercropping at any density and planting pattern of sunflower was more profitable than the sole crop.

Jadhav *et al.* (1992) reported that pearl millet + redgram intercropping, irrespective of fertilizer application, significantly, increased net monetary returns and benefit:cost ratio compared to pearl millet + black gram or green gram intercroppings. This was attributed to the difference in the maturity periods of component crops in former intercropping which helped for improved use of above and below ground resources by the component crops resulting in better yields of both the crops and consequently increased net monetary returns and benefit:cost ratio.

3. MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present investigation on the "Effect of planting density of sunflower intercropped with redgram on light use efficiency of intercropping system under rainfed conditions" was carried out during monsoon season, 1991. The details of the materials used and methods adopted in the present investigation are given in this chapter under the following heads.

3.1 DETAILS OF THE EXPERIMENTAL MATERIALS:

3.1.1 Experimental Site:

The experiment was laid out on the survey No. 53 A of the plot No. 525-527 of D Division of Agricultural College Farm, Pune-5 during the monsoon season of 1991.

3.1.2 Soils:

Topography of the experimental field was uniform and levelled. The experimental soil was Vertisol (deep black) in nature with an uniform depth upto 100 cm. It was well drained. The soil samples of 0-30 cm depth from five different locations were collected before the start of the experiment. The composite sample was prepared and analyzed for physical and chemical properties. Similarly, single value physical constants were determined for this depth. The data regarding physical and chemical properties and single value physical constants of experimental soil, alongwith methods used are presented in Table 1.

Table 1. Physical and chemical properties and soil moisture constants of the experimental field

Characters	Depth (cm) 0-30	Method used
A) Physical composition:		
Coarse sand (%)	8.48	International pipette
Fine Sand (%)	13.10	Method (Piper, 1966)
Silt (%)	24.60	
Clay (%)	49.50	
Organic matter (%)	0.90	Organic carbon (%) x 1.724
Calcium carbonate (%)	3.14	
Textural class	clayey	
B) Chemical composition:		
Available nitrogen (kg ha^{-1})	142.62	Modified alkaline permagnate method (Sahrawat and Burton, 1982)
Available P_2O_5 (kg ha^{-1})	13.60	Calorimetric method (Jackson, 1973)
Available k_2O (kg ha^{-1})	380.48	Flame photometer method (Hanway and Heidal, 1967)
Organic carbon (%)	0.52	Walkley and Black Rapid Titration method (Piper, 1966)
C) Other Studies:		
Soil pH (Soil:water, 1:2.5)	7.6	Buckman's glass electrode method (Piper, 1966)
Ec (mmhos cm^{-1})	0.23	Wheatstone bridge method (Piper, 1966)
D) Soil moisture constants:		
Moisture at field capacity (%)	34.62	Field method (Dastane, 1972)
Moisture at permanent wilting point (%)	18.30	Sunflower method (Dastane, 1972)
Bulk density (g cm^{-3})	1.24	Core sampler method (Dastane, 1972)

The physical and chemical composition of the soil revealed that the experimental soil was low in available nitrogen and phosphorus and fairly rich in available potash. It was neutral to slightly alkaline in reaction and clayey in texture.

3.1.3 Climatic Conditions and Location:

3.1.3.1 General:

Pune comes under the plain zone (transitional belt) and is situated on elevation of 558 m above the mean sea level on 18°-22' N latitude and 73°-51' E longitude. The average annual rainfall of this place is 714 mm, which is received mostly from the South-west monsoon. Of the total annual precipitation, about 75 per cent is received during the period between June and September, while the remaining quantity is received mostly in the months of October and November. Little rain is received during summer season, hence, assured irrigation is needed for growing summer crops.

At Pune the mean maximum temperature in April and May ranges between 34°C and 40°C. The lowest minimum temperature is observed in December and January when it varies from 6°C to 10°C.

3.1.4 Cropping History of the Experimental Field:

The cropping history of the experimental field for the previous four years is presented in Table 2.

Table 2. Cropping history of experimental plot

Years	Season	Crop grown	Fertilizers (kg ha^{-1})		
			N	P_2O_5	k_2O
1987-88	*Kharif*	Sorghum	120	60	60
	Rabi	Wheat	120	60	60
	Summer	Fallow	-	-	-
1988-89	*Kharif*	Sunflower	60	30	0
	Rabi	Fallow	-	-	-
	Summer	Groundnut	25	50	0
1989-90	*Kharif*	Sorghum	120	60	60
	Rabi	Chickpea	25	50	0
	Summer	Fallow	-	-	-
1990-91	*Kharif*	Pearl millet	50	25	0
	Rabi	Fallow	-	-	-
	Summer	Fallow	-	-	-
1991-92	*Kharif*	Present investigation		As per treatments	

3.1.5 Seeds and Selection of Variety:

Sunflower (Var. Morden):

It is selection from the variety "Cernianka-65", released in 1979 in Karnataka State. It has wider adaptability. Being early and dwarf, it is suitable for mixed/intercropping and multiple cropping systems. It is drought tolerant in nature and is suitable to all seasons. Seeds are deep black in colour with higher (> 30%) husk content. It possess higher level of self fertility. The 100 seed weight is 4-5 g. Diameter of flower head is about 12-15 cm. Plant height ranges from 90-120 cm. It is susceptible to rust and leaf spot diseases. Its duration is about 80-90 days. Oil content is 38-42%. Its average yield is 6-8 q ha^{-1}. The certified seeds of sunflower were obtained from the Director of Farms, MPKV, Rahuri.

Redgram (Var. BDN-2):

It is a selection from the Bori II-132-A-1 and was released in 1978-79 in Maharashtra. The plant height is 100-115 cm with green stem sometimes light pigmented at base. Flowers are yellowish in colour Pods are 3-4 seeded, maroon blotched. Seeds are white and medium in size (9 g per 100 seeds). It is tolerant to *Fusarium wilt*. Suitable for medium to deep black soils (Vertisols). Its duration to maturity is about 150-160 day. Average yield is 10-12 q ha^{-1}. The certified seeds of redgram were obtained from the Director of Farms, MPKV, Rahuri.

3.1.6 Fertilizers:

Nitrogen was given through urea containing 46 per cent N and phosphorous through single super phosphate containing 16 per cent P_2O_5.

3.1.7 Seed Treatment:

The redgram seeds were treated with *Rhizobium* culture to enhance nodulation.

3.1.8 Plant Protection:

The redgram was sprayed twice with 0.07% endosulphon to control pod borer.

3.2 METHODS:

3.2.1 Experimental details:

The experiment was laid out in a Randomized Block Design (RBD) with four replications (Fig.1). The details of the treatments along with the symbols used are given below.

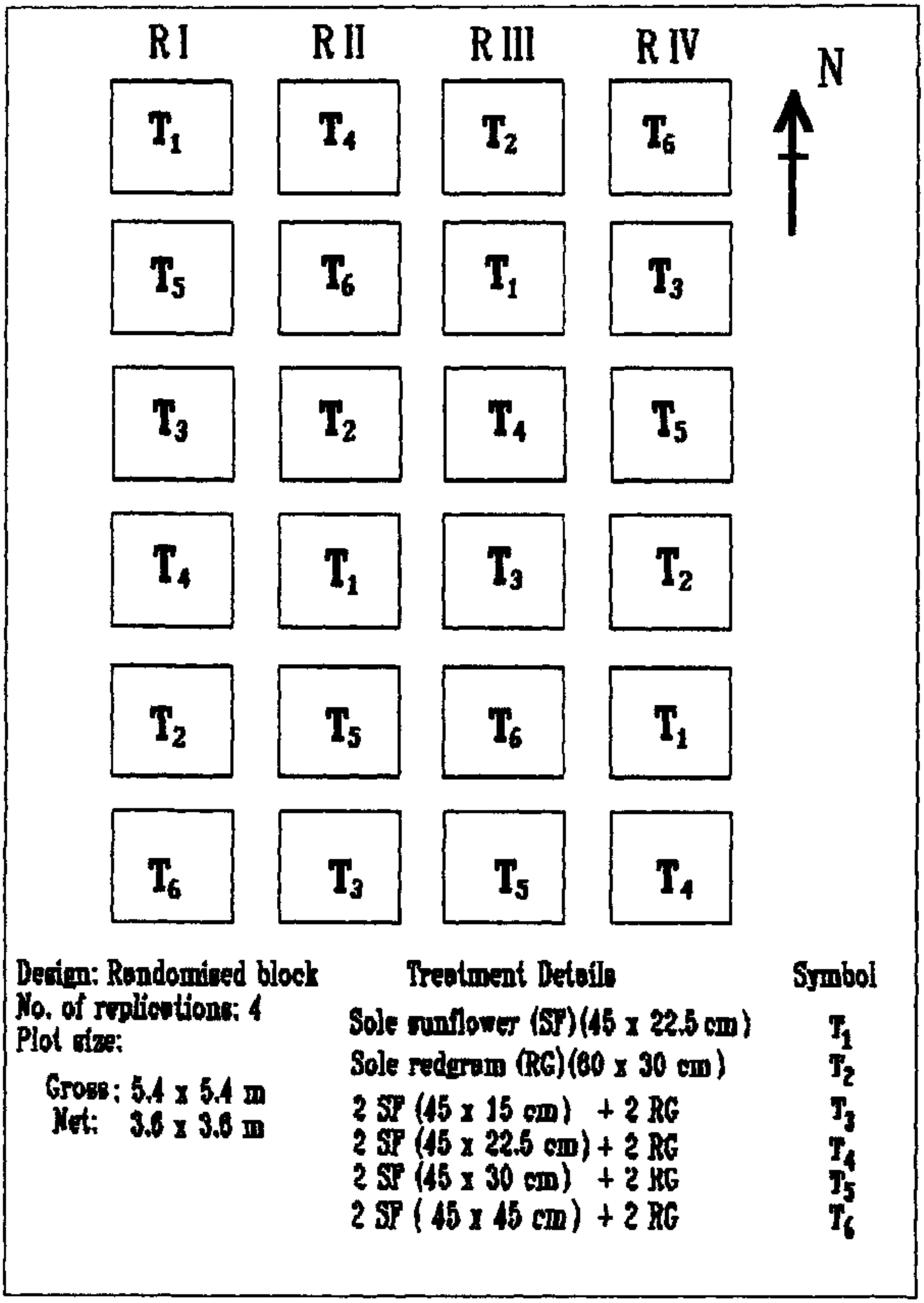

Fig. 1. Plan of layout

Treatment details	Plant population/ha		Symbol
	sunflower	redgram	
Sole sunflower (45 x 22.5 cm)	98,765	-	T_1
Sole redgram (60 x 30 cm)	-	55,555	T_2
Sunflower:redgram (2:2) (45 x 15 cm):(45 x 15 cm)	74,074	74,074	T_3
Sunflower:redgram (2:2) (45 x 22.5 cm):(45 x 15 cm)	49,382	74,074	T_4
Sunflower:redgram (2:2) (45 x 30 cm):(45 x 15 cm)	37,037	74,074	T_5
Sunflower:redgram (2:2) (45 x 45 cm):(45 x 15 cm)	24,691	74,074	T_6

3.2.2 The Other Details of the Experiment are as follows:

a. Total number of plots - 24

b. Plot size : Gross - 5.4 x 5.4 m
: Net - 3.6 x 3.6 m

c. Method of sowing - Dibbling

d. Date of dibbling - 27-06-1991

3.2.3 Field Operations:

The details of the various cultural operations carried out in the experimental plot during monsoon season of 1991 are presented in Table 3.

3.2.3.1 Fertilizer application:

Sole sunflower and sunflower + redgram intercropings were fertilized with 50 kg N and 25 kg P_2O_5 ha^{-1}, whereas sole redgram was fertilized with 12.5 kg N and 25 kg P_2O_5 ha^{-1}. The fertilizers were applied as a basal dose at the time of dibbling by placement.

Table 3. Schedule of field operations carried out during *kharif*, 1991

Sr.No.	Name of operations	Frequency	Date of operation
A)	Preparatory Tillage Operations		
	1. Ploughing	1	10-06-1991
	2. Harrowing	2	19-06-1991 & 20-06-1991
	3. Stubble Collection	1	24-06-1991
	4. Experimental layout	1	25-06-1991
	5. Application of Fertilizers	1	27-06-1991
B)	Seeds and Sowing:		
	1. Seed treatment with *Rhizobium*	1	27-06-1991
	2. Dibbling of sunflower & redgram	1	27-06-1991
c)	Post Sowing Operations:		
	1. Gap filling	1	11-07-1991
	2. Thinning	1	20-07-1991
	3. Hand weeding	2	23-07-1991 & 21-08-1991
D)	Plant Protection Measures:		
	1. Dusting of 10% BHC on sunflower	1	30-08-1991
	2. Spraying of 0.07% endosulphon on redgram	2	30-08-1991 & 20-09-1991
E)	Harvesting:		
	1. Sunflower	1	04-10-1991
	2. Redgram	1	06-12-1991
F)	Threshing and Cleaning:		
	1. Sunflower	1	12-10-1991
	2. Redgram	1	16-12-1991

3.2.3.2 Seed treatment and sowing:

The certified seed of sunflower (Morden) was used for dibbling. The certified seed of redgram (BDN-2) was treated with *Rhizobium* culture @ 250 g per 15 kg seeds to enhance the nodule formation.

The crops were dibbled on June 27, 1991 at the spacings as per treatments.

3.2.3.3 Gap filling and thinning:

The gap filling was carried out 15th day after sowing and thinning after 24th day after sowing.

3.2.3.4 Weeding:

The weeding was done twice on 23rd July and 21st August, 1991.

3.2.3.5 Plant protection:

The sunflower was dusted with 10% BHC @ 20 kg ha^{-1} on 30th August, 1991 as a preventive measure against hairy caterpillar. The redgram was sprayed twice with 0.07% endosulphon on 30th August and 20th September, 1991 as a preventive measure against pod borer.

3.2.3.6 Harvesting:

The sunflower from net plot was harvested separately on 4th October, 1991. It was sundried for about a week and threshing and cleaning was carried out. The redgram from net plot was harvested separately on 06th December, 1991. It was also sundried for about a week and threshed.

3.2.4 Biometric and other Observations:

The details of the biometric observations recorded are given in Table 4.

Table 4. Details of biometric and other observations

Sr. No.	Particulars	Fre-quency	Time of observations (days after sowing)	Sample size
A)	Plant count:			
1.	No. of plants from net plot	1	25	All plants from net plot
B)	Micrometeorological studies:			
1.	Incident photosynthetically active radiation (PAR_0)	21	20,27,34,41,48,55, 62,69,76,83,90,97,104, 111,118,125,132,139,146, 153, At harvest	All plants
2.	Transmitted photosynthetically active radiation (TPAR)	21	First observation at 20 days after sowing, thereafter at 7 days interval upto harvest	All plants
C)	Growth studies:			
1.	Leaf area per plant Sunflower Redgram	 6 11	First observation at 28 days after sowing, thereafter at 14 days interval upto harvest	2 plants
2.	Leaf area index (LAI) Sunflower Redgram	 6 11	First after 28 days thereafter at 14 days interval upto harvest	2 plants
3.	Dry matter per plant Sunflower Redgram	 6 11	First after 28 days thereafter at 14 days interval upto harvest	2 plants
D)	Yield contributing characters:			
1.	Number of seeds per plant	1	At harvest	5 plants
2.	Weight of seeds per plant (g)	1	At harvest	5 plants
3.	Thousand seed weight (g)	1	At harvest	All plants from net plot
E)	Yields:			
1.	Biological yield (q ha^{-1})	1	At harvest	All plants from net plot
2.	Grain yield (q ha^{-1})	1	At harvest	All plants from net plot
3.	Stalk yield (q ha^{-1})	1	At harvest	All plants from net plot

3.2.4.1 Sampling technique:

The various biometric observations were recorded on five randomly selected plants from each net plot. For this purpose, five rows were first selected at random and one plant in each of these rows was selected randomly for recording observations. Bamboo pegs were fixed near the observational plants for identification. Biometric observations on these plants were recorded at an interval of 14 days from 28 day after sowing onwards.

3.2.4.2 Plant count:

The plant count was recorded by counting all the plants from each net plot on 25^{th} day after sowing.

3.2.4.3 Micrometeorological studies:

3.2.4.3.1 Measurement of the components of photosynthetically active radiation (PAR):

The various components of PAR, *viz.*, incident and transmitted radiation were measured at an interval of 7 days at solar noon hour between 11.30 -13.00h with the help of a line quantum sensor. To eliminate the effect of solar elevation, the measurements were made simultaneously in all treatments at around midday (Sivakumar and Virmani, 1984).

The line quantum sensors were connected to data logger and the values were recorded instantaneously from the data logger. Two values were recorded from each plot for accuracy and their average was considered.

3.2.4.3.2 Determination of intercepted photosynthetically active radiation (IPAR):

IPAR was calculated according to Gallo and Daughtry (1986).

Incident PAR

Transmitted PAR

Plate 1. Measurements of incident and transmitted PAR.

For measuring the transmitted PAR in sunflower + redgram intercropping systems, two line quantum sensors were used. One sensor was kept across the sunflower rows while other sensor was kept across the redgram rows facing towards the sun. Immediately after measuring the transmitted PAR, one sensor was used to measure the incident PAR. Average of two sensors was taken to calculate the transmitted PAR. Finally the intercepted PAR (IPAR) was calculated by substracting the transmitted PAR from the incident PAR as follows.

$$IPAR = PAR_0 - TPAR$$

where,

IPAR = Intercepted PAR

PAR_0 = Incident PAR

TPAR = Transmitted PAR

Finally per cent IPAR was calculated from above data.

3.2.4.3.3 Light use efficiency (LUE):

The light use efficiency was determined as under.

$$LUE = \frac{\text{Amount of total dry matter produced (g m}^{-2}\text{)}}{\text{Amount of cumulative light absorbed (MJ m}^{-2}\text{)}}$$

Cumulated IPAR was determined with the assumption that the daily total PAR is 0.5 of daily total solar radiation (Szeicz, 1974; Sivakumar and Virmani, 1984). The daily solar radiation data from the Meteorological Observatory, Pune which is very close to the experimental plot was used to calculate incident PAR values for each day.

3.2.4.4 Growth studies:

3.2.4.4.1 Leaf area per plant:

All the leaves of two plants selected for the dry matter study from the respective net plot, were stripped off and were classified in to three categories, *viz.*, small, medium and large. From each category, one representative leaf was traced on graph paper and its area was worked out. This area was multiplied by number of leaves from respective category. The total leaf area per plant was worked out by summing the leaf area of three categories.

Leaf area in intercropping system was determined by combining the leaf area of component crops.

3.2.4.4.2 Leaf area index (LAI):

The leaf area index was calculated from the data of leaf area per plant by using the following formula (Watson, 1947).

$$LAI = \frac{\text{Leaf area per plant}}{\text{Land area per plant}}$$

(expressed in the same units)

LAI in intercropping system was determined by combining the LAI of components crops.

3.2.4.4.3 Dry matter per plant:

For dry matter studies, two plants were uprooted at random from each net plot at each sampling. These plants were separated into leaves, stem and earheads and were kept in paper bags for sundrying and thereafter in oven at 60°C ± 2°C temperature for drying, till constant weight was recorded.

To workout dry matter production of the cropping system as a whole, the dry matter production per plant of sunflower and redgram was multiplied by number of plants of sunflower and redgram, respectively in net plot. Then dry matter of sunflower and redgram was added and it was divided by net plot size and finally worked out on one m^2 basis.

3.2.4.5 Post harvest studies:

The post harvest studies were carried out after the harvest of the crop on five observation plants.

3.2.4.5.1 Yield contributing characters:

Yield contributing characters were recorded as per the details given below.

3.2.4.5.1.1 Number of seeds per plant:

The heads of five observational plants were threshed separately and number of seeds were counted. The number of seeds per plant was then computed.

3.2.4.5.1.2 Weight of seeds per plant:

The weight of seeds of five heads was recorded and seeds weight per plant was worked out.

3.2.4.5.1.3 Thousand seed weight:

A random sample of seeds from a net plot produce was drawn. Then 1000 seeds were counted and their weight was recorded.

3.2.5 Yield:

3.2.5.1 Biological yield:

The biological yield was obtained by summing the weight of dried heads and dried stalks in case of sunflower. The biological yield of redgram was obtained by summing the weights of dried pods and weight of dried stalks.

3.2.5.2 Seed yield:

The net plot produce of both the component crops was harvested separately. It was dried in sun for a period of about one week. The heads or pods of net plot produce were threshed separately and seed weight of net plot was recorded. After adding seed weight of five observational plants in the seed weight of net plot, seed yield on per hectare basis was worked out.

3.2.5.3 Stalk yield:

The stalks of both sunflower and redgram were harvested separately from net plot and sun dried for a week and then their weights were recorded. After adding stalk weight of five observational plants in the stalk weight of net plot, stalk yield on per hectare basis was computed.

3.2.5.4 Harvest Index (HI):

The percentage of economic yield compared with the above ground biomass is called as harvest index (Salisbury and Ross, 1986). The harvest index was calculated by using the following formula

$$\text{Harvest Index (HI)} = \frac{\text{Seed yield}}{\text{Biological yield}} \times 100$$

3.2.6 Details of Instruments:

3.2.6.1 LI-191 line quantum sensor:

The LI-191 SA sensor is designed for measuring PAR (photosynthetically active radiation) in applications where the radiation to be measured is specially non-uniform (such as within plant canopies). To achieve this, the sensor features a sensing area that is one meter in length. The LI-191 SA has the quantum (photon) response through the wave length range of 400-700 nm for PPFD (Photosynthetic Photon Flux Density) as generally preferred for PAR measurements and has an output in units of mole where,

$$1\ \mu\ mol\ m^{-2}s^{-1} = 1\mu\ Em^{-2}s^{-1} = 6.02 \times 10^{17}\ photon\ m^{-2}s^{-1}$$

The LI-191 SA line quantum sensor which specially averages radiation over its one meter length, minimizes the error and allows one person to easily make many measurements in a short period of time. The sensor was connected to the LI-1000 dedicated data logger.

Since the sensing area is a flat acrylic diffuser, the response of a given angle of incidence is fairly constant as the azimuth angle around the sensor is varied. It is specified at less than ± 2% at a 45° angle of elevation for 360° of sensor rotation.

Specifications:

Absolute calibration	:	± 10% traceable to NBS. The LI-191 SA is calibrated via transfer calibration using a reference LI-191 SA Quantum sensor. Transfer error is ± 5% (Included in the ± 10%).
Sensitivity	:	Typically 3 µA per 1000 µ mol m^{-2} s^{-1}.
Linearity	:	Maximum deviation of 1% upto 10,000 µ mol m^{-2} s^{-1}.

Line quantum sensor

Treatments effect

Plate 2. Line quantum sensor and plant growth under different treatments.

Stability :	< ± 2% change over one year period.
Response time :	10 µs.
Temperature: dependence	± 0.15 per cent per °C maximum.
Cosine correction :	Acrylic diffuser.
Azimuth :	< ± 2% error over 36° at 45° elevation.
Sensitivity : variation over length	± 7% maximum using a 1" wide beam from an incandescent light over source.
Sensing area :	1 meter L x 12.7 mm W (39.4" x 0.50")
Detector :	High stability silicon photovoltaic detector (blue enhanced)
Sensor housing :	Weather-proof anodized aluminium case with acrylic diffuser and stainless steel hardware.
Size :	116 L x 2.54 W x 2.5 cm D (45.5" x 1.0" x 1.0").
Weight :	1.8 kg (4.0 lb).
Cable length:	3.1 m (10.00 ft.)

3.2.6.2 LI-1000 DataLogger:

The LI-1000 DataLogger is a 10 channel datalogger that functions both as a data logging device and a multichannel, autoranging meter. The electronics of the LI-1000 have been optimized for highly accurate measurement of LI-COR radiation sensors which have a current signal. The LI-1000 is also well suited to measure low impedance voltage sensors such as thermocouples, and sensors with a pulsed output (tipping bucket rain guages, etc.). A wide variety of other sensors for environmental and industrial test and measurement can also be measured with the LI-1000.

Specifications:

Analog inputs	:	Eight total analog inputs configured as voltage or current channels.
Current inputs	:	Eight channels; two sealed BNC connectors and six channel accessed directly through 37 pin D connector or by connecting the 1000-05 Terminal Block 1000-06A AC Terminal Block, or the 1000-10 Thermocouple Terminal Block.
Voltage inputs	:	Six single-ended channels accessed directly through 37 pin D connector or by connecting 1000-05 Terminal Block, 1000-06 AC Terminal Block or 1000-10 Thermocouple Terminal Block. Channel 1 and 2 can also be configured for voltage measurement by placing an input impedance resistor in the sensor cable.
Pulse counting inputs	:	Two pulse counting channels switch closure to ground (200hz); external signal driving (1 Khz). Inputs have hysteresis so there is no minimum rise time.

Analog to Digital Converter:

Type	:	Voltage to frequency
Resolution	:	14 bit (1 part in 16,000)
Scan rate	:	4 channels per second. (200 ms integration time (for 50/60 Hz noise rejection)
Voltage accuracy	:	± 0.3% of full scale reading (25°C). ± 0.55% (0 to 55°C)
Current accuracy	:	± 0.2% of full scale reading (25°C). ± 0.45% (0 to 55°C)
Temperature coefficient	:	± 0.01% of reading per °C.
Linearity	:	0.05%
Normal mode rejection	:	> 60 dB at 50 or 60 Hz

Voltage input noise (25°C)

Typical	:	± 2.5 μV
Maximum	:	± 5 μV

60 second average

Typical	:	± 0.4 μV
Maximum	:	± 0.08 μV

Current Input Noise (25°C)

Typical	:	± 25 picoamps
Maximum	:	± 50 picoamps

60 second average

Typical	:	± 4 picoamps
Maximum	:	± 8 picoamps

3.2.7 Sunflower Seed Yield Equivalent:

Sunflower seed yield equivalent was obtained by a sum of actual seed yield of sunflower under intercropping and the converted seed yield of redgram into sunflower equivalent on price value basis. The price of sunflower seeds taken into consideration is given under gross monetary returns.

3.2.8 Economic Studies:

3.2.8.1 Gross monetary returns:

The gross monetary returns were worked out by considering the following prices during the year of experimentation.

Crop	Price (Rs. q^{-1})	
	Seed	Stalk
Sunflower	1100	-
Redgram	900	45

3.2.8.2 Cost of cultivation:

The cost of cultivation was worked out by considering the prices of inputs as given in Appendix-I.

3.2.8.3 Net monetary returns:

The net monetary returns were worked out by substracting cost of cultivation from the gross monetary returns.

3.2.8.4 Benefit : cost ratio Rs. per Rs. invested:

The benefit : cost ratio was worked out by using the following formula.

$$\text{Benefit : cost ratio} = \frac{\text{Gross monetary returns}}{\text{Cost of cultivation}}$$

3.2.8.5 Land equivalent ratio (LER):

The LER is one of the variables for the analysis of intercropping system. In sunflower and redgram intercropping systems, the LER was worked out as:

$$\text{LER} = \text{PLER (Sunflower)} + \text{PLER (Redgram)}$$

The partial LERs of Sunflower and Redgram were worked as:

$$\text{PLER (Sunflower)} = \frac{\text{Yield of Sunflower under intercropping}}{\text{Yield of Sunflower under sole cropping}}$$

$$\text{PLER (Redgram)} = \frac{\text{Yield of Redgram under intercropping}}{\text{Yield of Redgram under sole cropping}}$$

3.2.9 Statistical Analysis and Interpretation of data:

The data recorded was statistically analysed by using the technique of analysis of variance (Fisher, 1970) and test of significance was carried out as given by Cochran and Cox (1967) and Panse and Sukhatme (1985). In the tabular data in the text, C.D. values have been given for comparison only in cases where 'F' test was significant. When it was not significant, figures for S.E. ± are only given. Suitable graphical illustrations of data have been given at the appropriate places. The statistical analysis was carried out by the computer available at Centre of Advanced Studies in Agricultural Meteorology (CASAM), College of Agriculture, Pune-411 005.

4. RESULTS AND DISCUSSION

4. RESULTS AND DISCUSSION

A field experiment on "Effect of planting density of sunflower intercropped with redgram on light use efficiency (LUE) of intercropping system under rainfed conditions" was carried out during *kharif, 1991.* The results of the investigation are presented and discussed in this chapter.

4.1 CLIMATIC CONDITIONS DURING THE EXPERIMENTAL PERIOD:

In order to get an idea about climatic conditions prevailed during the period of the present investigation, the weather data obtained from the Agricultural Meteorological observatory situated at the Agricultural College Farm, Pune-411 005 are presented in Table 5.

Table 5. Mean weekly meteorological data for the period from June, 1991 to December, 1991

Met. week No.	Month and Date	Mean Temp. °C Max.	Mean Temp. °C Min.	Humidity (per cent) RHI	Humidity (per cent) RHII	Mean wind velocity km h^{-1}	Rain-fall (mm)	No. of rainy days	Pan-evapo-ration (mm)	Bright sun-shine hours (h)
1	2	3	4	5	6	7	8	9	10	11
22	28-05 to 03-06	39.1	23.3	73.0	35.0	8.6	41.1	3	7.3	7.9
23	04-06 to 10-06	30.5	22.4	87.0	77.0	9.7	387.4	5	3.2	3.5
24	11-06 to 17-06	30.9	23.8	79.0	62.0	12.2	19.4	1	6.0	7.2
25	18-06 to 24-06	30.5	23.1	81.0	64.0	13.2	15.0	2	5.2	7.1
26	25-06 to 01-07	31.1	22.3	83.0	64.0	8.5	75.3	2	5.0	6.9
27	02-07 to 08-07	29.1	23.3	83.0	69.0	10.9	6.2	0	4.4	4.2
28	09-07 to 15-07	28.5	22.0	87.0	78.0	8.6	43.0	3	3.1	1.0

(Continued.....)

Table 5 (Continued....)

1	2	3	4	5	6	7	8	9	10	11
29	16-07 to 22-07	27.0	22.0	91.0	78.0	9.9	63.4	6	3.4	0.4
30	23-07 to 29-07	26.5	21.8	91.0	86.0	11.7	75.1	5	2.6	1.0
31	30-07 to 05-08	27.9	21.8	87.0	76.0	8.7	13.9	2	2.9	2.2
32	06-08 to 12-08	27.4	21.0	89.0	75.0	8.4	11.9	2	2.7	2.6
33	13-08 to 19-08	27.5	21.4	90.0	81.0	8.8	46.3	4	2.5	2.0
34	20-08 to 26-08	27.3	21.3	89.0	79.0	9.3	10.1	1	2.9	2.5
35	27-08 to 02-09	28.1	20.7	86.0	65.0	9.0	3.8	0	3.7	5.0
36	03-09 to 09-09	28.9	20.7	86.0	65.0	9.0	0.0	0	4.1	5.9
37	10-09 to 16-09	31.7	20.5	89.0	56.0	5.5	0.0	0	4.4	6.8
38	17-09 to 23-09	30.8	20.9	89.0	62.0	4.8	91.4	3	3.9	4.7
39	24-09 to 30-09	32.1	21.9	89.0	56.0	4.9	29.1	2	3.8	4.6
40	01-10 to 07-10	33.1	20.3	90.0	36.0	2.9	0.0	0	3.8	8.0
41	08-10 to 14-10	34.1	18.6	90.0	31.0	4.1	0.0	0	4.2	8.1
42	15-10 to 21-10	33.6	18.0	90.0	33.0	4.1	0.0	0	4.7	8.9
43	22-10 to 28-10	33.3	14.1	85.0	24.0	4.1	0.0	0	4.7	9.6
44	29-10 to 04-11	33.1	11.4	80.0	25.0	5.4	0.0	0	5.8	8.9
45	05-11 to 11-11	32.2	14.2	90.0	27.0	3.4	0.0	0	3.7	8.6
46	12-11 to 18-11	31.3	16.4	85.0	45.0	5.7	0.0	0	3.6	6.6
47	19-11 to 25-11	29.6	17.2	90.0	48.0	4.4	0.0	0	2.6	6.9
48	26-11 to 02-12	31.3	13.4	93.0	33.0	2.7	0.0	0	3.5	9.0
49	03-12 to 09-12	30.3	10.7	93.0	27.0	3.5	0.0	0	3.9	9.0
50	10-12 to 16-12	28.2	9.1	85.0	30.0	4.7	0.0	0	4.4	8.9
51	17-12 to 23-12	29.7	10.0	90.0	30.0	3.7	0.0	0	3.6	9.0
52	24-12 to 31-12	27.8	9.1	95.0	37.0	3.9	0.2	0	3.5	8.0

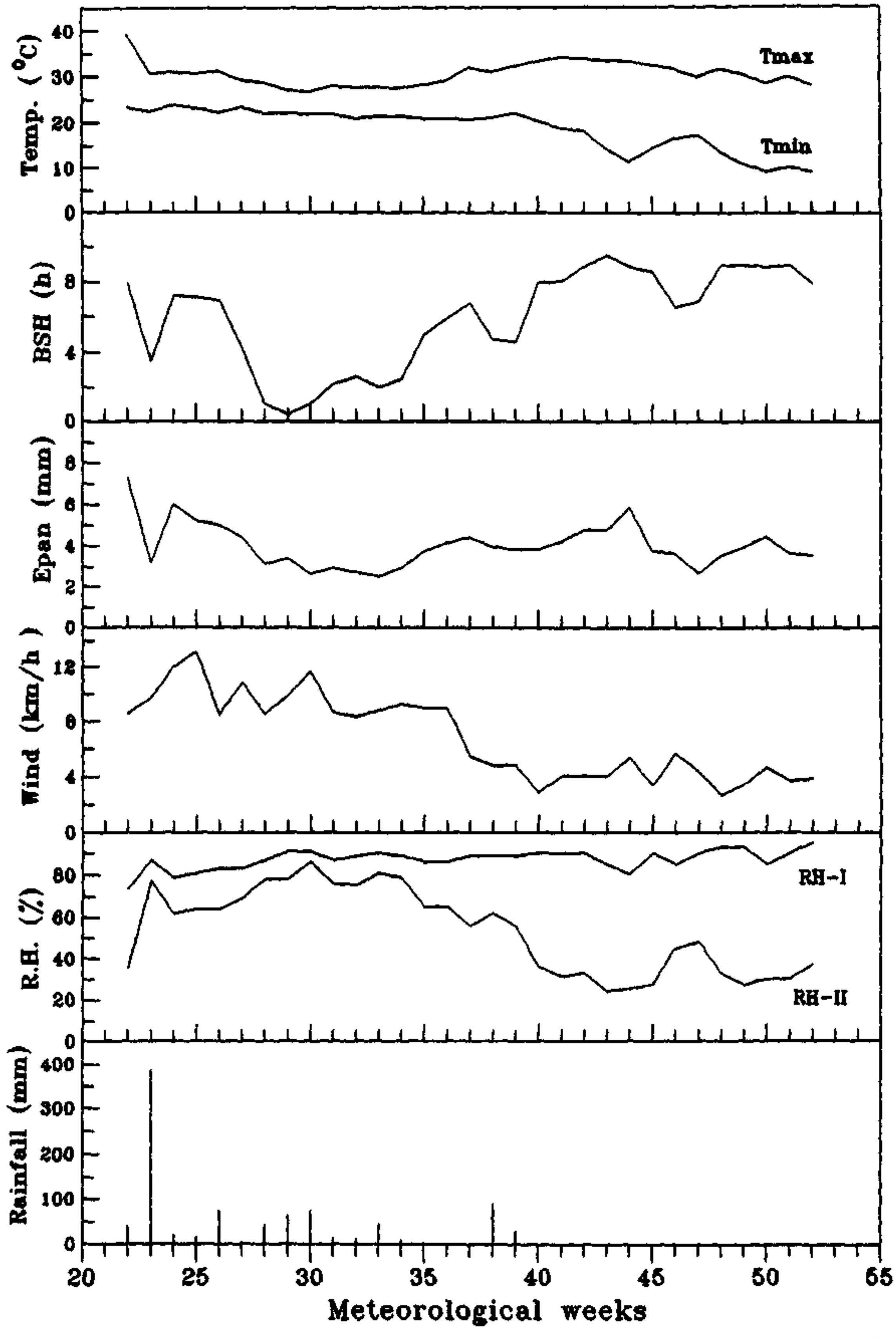

Fig. 2. Mean weekly meteorological data for the period from June, 1991 to December, 1991

4.1.1 Temperature:

The data depicted in Fig. 2 show that the mean maximum and minimum temperatures during the course of investigation ranged between 26.5 and 39.1°C and 9.1 and 23.8°C, respectively. The maximum temperatures were more during the month of June and first week of July, then it decreased upto August end, started rising in the month of September and remained higher upto November end, thereafter it decreased. The minimum temperatures showed somewhat similar trend like that of maximum temperature. They also declined from the November end onwards. Thus, the minimum and maximum temperatures were quiet favourable for growth and development of both sunflower and redgram crops.

4.1.2 Relative Humidity (RH):

The data depicted in Fig. 2 show that the mean maximum relative humidity (RH-I) ranged between 73 and 95 per cent at 0730 h and mean minimum relative humidity (R-II) between 24 and 86 per cent at 1430 h. RH-I started increasing from June onward and remained high throughout the season with minor decrease in 3rd and 4th week of October. As against that RH-II had more variable character. It increased in the first week of June and then remained high upto September. It decreased sharply in the 1st week of October and remained low. Thereafter, it slightly increased in 2nd and 3rd week of November.

4.1.3 Wind Speed:

The wind velocity ranged between 2.7 to 13.2 km h^{-1} during the crop growth period. It was quiet high during June and July. The wind speed declined from second fortnight of September.

4.1.4 Rainfall:

932.6 mm of rainfall was received in 41 rainy days during the crop growth period. 462.9 mm of rainfall was received in 11 rainy days from the 22nd to 25th meteorological weeks which was useful for undertaking the sowing operations of sole sunflower and redgram and their intercropping systems during 26th meteorological week. The adequate and well distributed rainfall was received upto August end which corresponded with the growing period of sunflower, this resulted in better growth and development of sole as well as intercropped sunflower giving better yields. After harvest of the sunflower, 120.5 mm of rainfall was received in five rainy days in the 38th and 39th meteorological weeks which helped in growth and development of sole as well as intercropped redgram, therefore, the yield of redgram was also quiet satisfactory. However, the rainfall in the month of September was less than normal (200 mm). Therefore, season had a negative skewness in the distribution of rainfall with total rainfall (932.6 mm) more than normal (714.6 mm). But monsoon season ended with deficient rains in September.

4.1.5 Pan Evaporation:

The pan evaporation was higher during the early crop growth period in the month of June. It was low during the months of July and August. It increased slightly during 1st and 2nd week of September and then remained high in October and November; thereafter it declined and remained low.

4.1.6 Bright Sunshine Hours:

The crop had experienced bright sunshine during initial crop growth period in June but it was quiet low during July and whole of August due to cloudy conditions. During the maturity period of sunflower, in September, sunshine hours increased to some extent resulting in better seed development. The bright sunshine hours were comparatively more (BSH > 6.0) during growth and development of redgram which helped in for better pod and seed development.

4.2 STUDIES ON RADIATION INTERCEPTION:

The data regarding the mean intercepted photosynthetically active radiation (IPAR) as influenced periodically by different treatments are presented in Table 6 and graphically depicted in Fig. 3.

Intercepted photosynthetically active radiation (IPAR) was monitored at a regular interval of 7 days from 20 days after sowing upto the harvest of the component sole and intercrops. It is obvious from the data presented in Table 6 that the mean IPAR was low (12.70%) on the 20th day owing to slow crop growth and exposure of the soil. The intercepted PAR was 53.83% on the 41st day indicating rapid increase due to expansion in leaf area. The maximum interception of 82.60% was recorded on the 76th day which remained somewhat constant upto the harvest of the sunflower. It decreased after harvest of sunflower on the 104th day and thereafter, it gradually increased and reached maximum of 75.52% on the 139th day because of increase in leaf area of redgram and interception by pods. The intercepted PAR decreased thereafter, due to senescence of leaves.

The intercepted PAR was significantly the lowest under sole redgram during the growing period of sunflower upto the 83rd day because of its slow growth and less canopy coverage, whereas, the intercepted PAR was significantly the highest under sole sunflower upto the 62nd day owing to higher LAI and its faster growth. Natarajan and Willey (1980b), under sorghum + pigeonpea intercropping, Willey and Rao (1977) under pearl millet + pigeonpea intercropping

Table 6. Mean intercepted photosynthetically active radiation (per cent) as influenced periodically by different treatments

Treatments	20	27	34	41	48	55	62	69	76
	Days after sowing								
Sole sunflower	21.52	55.39	78.12	82.60	87.68	93.26	95.38	91.88	89.72
Sole redgram	2.48	11.47	17.47	21.62	24.32	27.88	31.57	42.58	62.02
2 SF (45x15 cm) + 2 RG	16.06	40.52	49.17	54.99	62.04	68.93	78.08	83.86	85.55
2 SF (45x22.5 cm) + 2 RG	14.47	39.14	47.38	54.83	62.12	69.37	85.08	86.75	85.78
2 SF (45x30 cm) + 2 RG	12.44	37.19	47.01	54.49	62.38	70.68	85.35	86.92	86.07
2 SF (45x45 cm) + 2 RG	9.25	34.56	45.98	54.42	64.49	76.74	85.53	87.60	86.48
S E ±	0.70	0.87	0.52	0.66	0.54	3.12	1.73	2.11	3.81
C D at 5%	1.94	2.42	1.46	1.85	1.51	8.66	4.81	5.85	10.56
General mean	12.70	36.38	47.52	53.83	60.51	67.81	76.83	79.93	82.60

Treatments	83	90	97	104	111	118	125	132	139	146	153	160
	Days after sowing											
Sole sunflower	86.28	76.96	59.32	-	-	-	-	-	-	-	-	-
Sole redgram	67.58	83.67	90.87	90.90	94.13	94.00	90.40	87.61	86.54	74.77	68.75	58.2[illegible]
2 SF (45x15 cm) + 2 RG	84.55	80.42	69.24	50.80	55.07	62.04	63.13	65.66	67.45	65.80	63.04	59.16
2 SF (45x22.5 cm) + 2 RG	84.72	82.07	74.10	52.88	61.07	64.71	65.64	67.83	72.04	69.30	65.46	61.10
2 SF (45x30 cm) + 2 RG	85.16	82.62	75.05	54.64	63.79	66.67	67.82	69.74	74.97	71.80	67.52	63.36
2 SF (45x45 cm) + 2 RG	86.12	83.51	77.49	63.05	69.46	71.17	73.27	75.94	76.54	74.94	71.56	6[illegible].0[illegible]
S E ±	3.33	3.13	3.86	2.64	3.27	2.12	3.08	3.14	2.75	2.92	2.91	3.47
C D at 5%	9.24	-	10.69	7.33	9.08	5.88	8.55	8.70	7.64	8.10	-	-
General mean	82.40	81.54	74.34	62.45	68.70	71.72	72.05	73.36	75.52	71.33	67.27	61.88

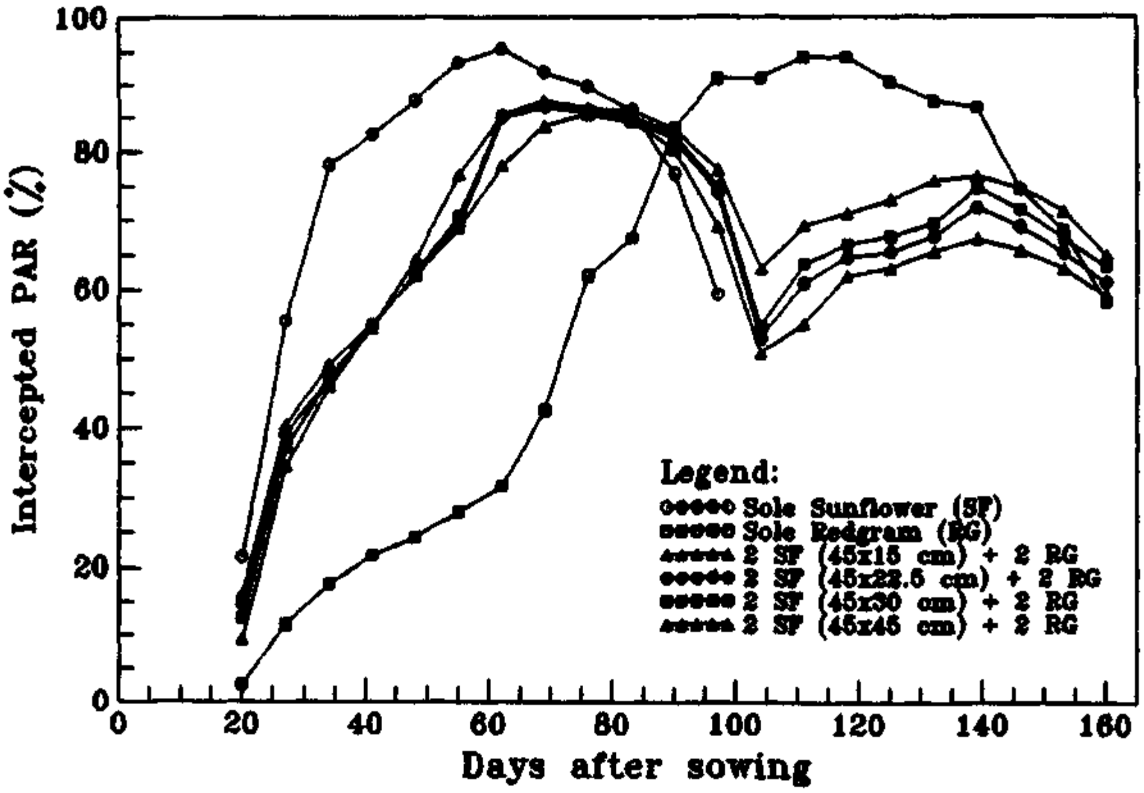

Fig. 3. Mean intercepted photosynthetically active radiation (per cent) as affected periodically by different treatments

also recorded less intercepted PAR by sole redgram during early crop growth period and more intercepted PAR values under sole cereal crops because of their faster growth. The sole sunflower continued to intercept more PAR than did the different intercroppings and sole redgram upto the 83rd day but the differences were not significant. The reverse trend was recorded on the 90th and 97th days because of the early senescence of the leaves in sole sunflower. The intercropping of 2 SF (45 x 15 cm) + 2 RG intercepted significantly more PAR than redgram associated with sunflower in square geometry during early crop growth period upto the 34th day because of competition for solar radiation due to more plant density under former intercropping. However, wider intrarow spacings of sunflower (30 and 45 cm) intercepted slightly more PAR than narrow intrarow spacings (15 and 22.5 cm) of sunflower though the differences were not significant from the 55th to the 69th day.

However, after harvest of the sunflower, the sole redgram intercepted more PAR than its association with sunflower in different plant densities upto the 139th day because of more leaf area production under sole redgram. The intercepted PAR under sunflower + redgram intercroppings improved with increase in the intrarow spacings after harvest of sunflower, though the differences were not significant, showing complementary interaction under wider intrarow sunflower spacing, owing to higher leaf area and LAI. The intercepted PAR was the lowest under sole redgram at harvest because of the senescence of leaves. These findings are similar to those reported by Willey *et al.* (1981), Natarajan and Willey (1980b), in sorghum + pigeonpea intercropping, Willey and Rao (1977) in pearl millet + pigeonpea intercropping, Willey *et al.* (1986) in groundnut + pigeonpea intercropping and Srinivas (1991) in sunflower + pigeonpea and pearl millet + pigeonpea intercropping systems.

4.3 STUDIES ON LIGHT USE EFFICIENCY (LUE):

The data regarding total dry matter production g m^{-2} (Table 7) and cumulative intercepted photosynthetically active radiation MJ m^{-2} (Table 8) was considered for determining light use efficiency (LUE). The relationship between total dry matter production and cumulative intercepted PAR is depicted in Fig. 4. The data regarding efficiency of light energy conversion in terms of dry matter produced per unit of light energy intercepted for the 14 day sampling periods in case of the different cropping systems are given in Table 9 and depicted in Fig. 4a.

From the measured intercepted PAR values throughout the growing season in each cropping system, the cumulative intercepted photosynthetically active radiation was calculated and plotted against the dry matter produced throughout

Table 7. Total dry matter production (gm^{-2}) as influenced periodically by different treatments

Treat-ments	Days after sowing										
	28	42	56	70	84	98	112	126	140	154	160
Sole sunflower	54.32	220.99	576.54	756.79	1092.59	1257.29	-	-	-	-	-
Sole redgram	5.55	12.49	26.04	78.47	164.58	368.75	461.81	590.28	822.22	872.92	923.34
2 SF (45x15 cm):2 RG	32.87	136.58	375.93	678.71	1103.71	1275.56	290.74	312.96	443.52	499.99	573.33
2 SF (45x22.5 cm):2 RG	25.15	111.88	313.27	513.89	967.59	1128.27	336.11	408.34	519.44	591.67	672.22
2 SF (45x30 cm): 2 RG	25.46	98.61	254.39	690.28	1035.19	1201.29	363.89	544.45	737.04	861.11	931.11
2 SF (45x45 cm):2 RG	21.61	75.31	237.96	616.98	921.92	1167.16	482.41	596.29	955.56	979.63	1043.33

Table 8. Cumulative intercepted photosynthetically active radiation ($MJ\ m^{-2}$) as influenced periodically by different treatments

Treat-ments	Days after sowing										
	28	42	56	70	84	98	112	126	140	154	160
Sole sunflower	20.45	78.85	151.92	237.07	314.24	358.96	-	-	-	-	-
Sole redgram	3.35	17.03	37.39	69.43	121.77	170.79	248.86	358.23	439.17	496.52	521.33
2 SF (45x15 cm):2 RG	15.85	53.72	106.18	177.58	251.42	298.20	342.51	414.64	476.07	526.98	551.06
2 SF(45x22.5 cm):2 RG	15.06	52.21	104.76	180.73	255.27	303.46	350.77	426.50	490.71	543.87	568.65
2 SF (45x30 cm): 2 RG	13.68	50.15	103.18	179.86	254.87	303.70	532.62	430.89	497.03	551.95	577.56
2 SF (45x45 cm):2 RG	12.96	48.87	103.68	181.15	256.67	303.26	361.81	446.12	516.70	574.41	600.87

Table 9. Light use efficiency (LUE) as influenced periodically by different treatments

Treat-ments	Days after sowing										
	28	42	56	70	84	98	112	126	140	154	160
Sole sunflower	2.65	2.80	3.79	3.19	3.47	3.50	-	-	-	-	-
Sole redgram	1.65	0.73	0.69	1.13	1.35	2.15	1.85	1.64	1.87	1.75	1.77
2 SF (45x15 cm):2 RG	2.07	2.54	3.54	3.82	4.38	4.27	0.84	0.75	0.93	0.94	1.04
2 SF (45x22.5 cm):2 RG	1.66	2.14	2.99	2.64	3.79	3.71	0.95	0.95	1.05	1.08	1.18
2 SF (45x30 cm): 2 RG	1.86	1.96	2.46	3.83	4.06	3.95	1.03	1.26	1.48	1.56	1.61
2 SF (45x45 cm):2 RG	1.66	1.54	2.29	3.40	3.59	3.84	1.33	1.33	1.84	1.70	1.73

the season. The slope of the curve between the cumulative intercepted PAR and dry matter, i.e. gram of dry matter per mega joule intercepted PAR was taken as the light use efficiency of the system.

The relationship between cumulative intercepted PAR and dry matter production of different cropping systems (Fig. 4) suggests that 2 SF (45 x 15 cm) + 2 RG intercropping was comparatively more efficient in conversion of intercepted PAR into dry matter than other cropping systems because of more dry matter production owing to more plant population per unit area with comparatively less intercepted PAR during advanced crop growth stages. The intercropping of 2 SF (45 x 30 cm) + 2 RG was also equally efficient in conversion of intercepted PAR into dry matter than sole component crops and sunflower + redgram association at 22.5 and 45 cm sunflower intrarow spacings. It was interesting to note that though the sole sunflower intercepted more PAR, the light use efficiency (LUE) was equivalent or comparatively less than its

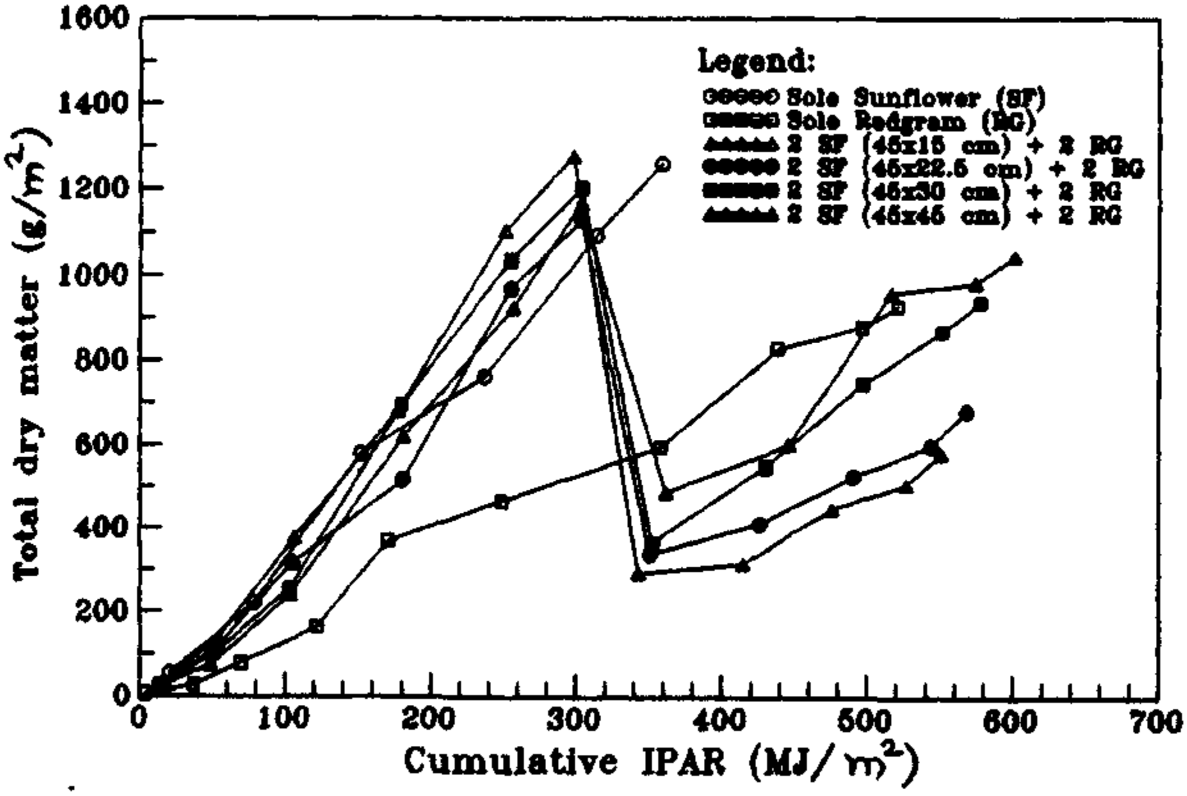

Fig. 4. Mean light use efficiency (LUE) as affected by different treatments

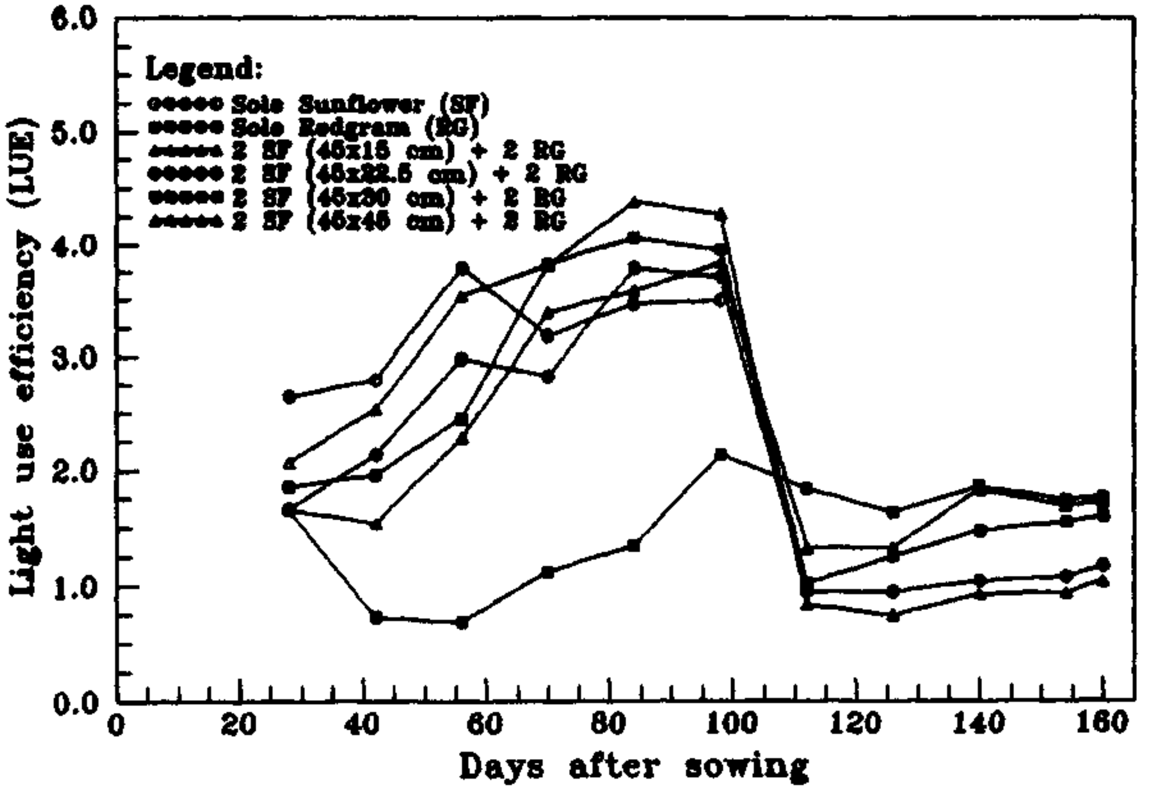

Fig. 4a. Mean light use efficiency (LUE) as affected periodically by different treatments

association with redgram during advanced crop growth stages, upto harvest of sunflower (98 days). This might be due to the fact that there was identical growth of sunflower both under sole and intercropping systems. However, after harvest of sunflower, the values of light use efficiency (LUE) depended upon the growth of redgram. These findings are similar to those reported by Okigbo (1981). The dry matter production of sole redgram was the lowest upto the harvest of sunflower because of less interception of PAR owing to its slow growth and less canopy coverage (Fig. 4).

However, after harvest of sunflower, the dry matter production by sole redgram was comparatively more though the cumulative interception of PAR was comparatively less than its association with sunflower. The intercropping of 2 SF (45 x 45 cm) + 2 RG intercepted comparatively more PAR after harvest of sunflower than sunflower + redgram association at 15, 22.5 and 30 cm intrarow sunflower spacings resulting in production of more dry matter under former intercropping (Fig. 4).

The data presented in Table 9 emphasizes the importance of the use of detailed studies on the relationship between intercepted radiation and dry matter production in the analysis of relative efficiencies of the different crops and cropping systems. This approach has recently been recognized as a more rational means of analysis of growth than the traditional growth analysis techniques (Monteith, 1977). In the present study, this point has been amply illustrated by the differences in the calculated production efficiencies of sole sunflower and redgram crops and sunflower intercropped with redgram at various intrarow spacings grown under uniform agronomic management. Apart from measured growth indices such as LAI and final yields, a useful index of crop productivity can be obtained by computing the light use efficiency (LUE) as shown by this study.

Analysis of the relationship between dry matter production and cumulative intercepted PAR at the various growth stages for the different cropping systems shows that 2 SF (45 x 15 cm) + 2 RG intercropping was equally efficient to that of sole sunflower not only in interception of PAR but also in conversion of intercepted PAR into dry matter due to its complementary interactions in better use of natural resources like light, water and nutrients particularly during early crop growth period. However, during advanced crop growth stages, the light use efficiency (LUE) of sole sunflower and its association with redgram under different intrarow spacings was not differed much (Table 9) upto harvest of sunflower. Sivakumar and Virmani (1984), in the analysis of the relationship between dry matter and cumulative intercepted PPFD for different crops observed that maize proved to be superior to sorghum in conversion of intercepted PPFD into dry matter. The results obtained by Willey and Natarajan (1978) and Sivakumar and Virmani (1980) in their study with sorghum:pigeonpea and maize:pigeonpea intercroppings, respectively, were also the same.

After harvest of sunflower, sunflower + redgram association at 30 and 45 cm intrarow sunflower spacings produced somewhat equivalent light use efficiency (LUE) to that of sole redgram, indicating that sunflower + redgram under 30 and 45 cm sunflower intrarow spacings could equally be good for light interception which resulted in higher yields and monetary benefits under rainfed conditions. These findings are similar to those reported by Hughes *et al.* (1987) and Leach and Beech (1988). Srinivas (1991) also observed that the cumulative absorbed PAR of Pearl millet + redgram and sunflower + redgram intercropping in the different row proportions did not differ much indicating that sunflower + redgram intercropping under different row proportions could equally be good for light interception which resulted in higher yields and monetary benefits under dryland farming.

4.4 STUDIES ON SUNFLOWER:

Biometric observations were recorded on the various growth characters, *viz.*, leaf area, leaf area index and dry matter production per plant at a regular interval of 14 days beginning from 28th day after sowing.

4.4.1 Leaf Area:

The data pertaining to mean leaf area per plant as influenced by the various treatments are presented in Table 10 and graphically depicted in Fig. 5.

Table 10. Mean leaf area (cm^2) per plant of sunflower as influenced periodically by different treatments

Treatments	Days after sowing					
	28	42	56	70	84	98
Sole sunflower	946.1	2941.1	4725.5	2729.6	2512.6	853.8
2 SF (45x15 cm): 2RG	841.8	2490.5	3799.8	2514.5	2365.4	735.8
2 SF (45x22.5 cm): 2RG	980.6	2815.9	3810.3	2829.8	2687.6	1001.8
2 SF (45x30 cm):2 RG	1018.3	2920.8	4413.5	6814.9	5616.6	1625.3
2 SF (45x45 cm):2 RG	1145.5	3034.8	5738.4	9487.6	7997.8	2460.7
S.E. ±	14.9	34.5	99.7	114.3	263.4	293.7
C.D. at 5%	41.4	95.8	276.3	316.8	730.3	814.2
General Mean	986.5	2840.6	4497.5	4875.3	4236.0	1333.5

The plant had produced only 986.5 cm^2 of leaf area on the 28th day. It increased rapidly upto the 56th day and reached maximum of 4875.3 cm^2 on 70th day. It declined rapidly thereafter due to senescence of leaves.

The leaf area was the lowest under 2 SF (45 x 15 cm) + 2 RG intercropping because of intrarow competition for natural resources, whereas, it was the

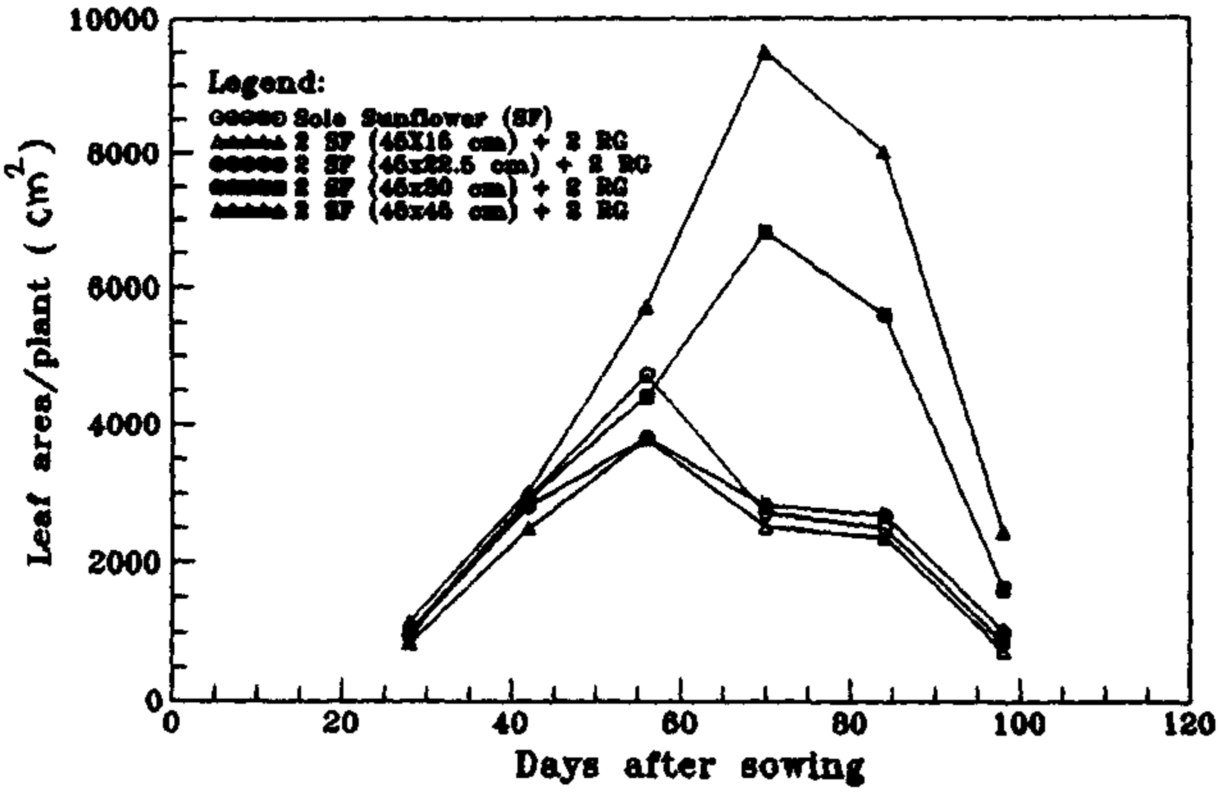

Fig. 5. **Mean leaf area (cm^2) per plant of sunflower as affected periodically by different treatments**

highest under 2 SF (45 x 45 cm) + 2 RG intercropping system at all the growth stages, owing to least intrarow competition for natural resources. Sunflower associated with redgram at wider intrarow spacing of 30 and 45 cm and sole sunflower produced significantly more leaf area than sunflower associated with redgram at closer intrarow spacings (15 and 22.5 cm) on the 42nd and 56th days owing to competition free environment under sole sunflower and least intrarow competition under former intercroppings. Thompson (1982) also reported that as the plant density increased, leaf area per plant decreased. The square planting of sunflower in association with redgram attained significantly the highest leaf area, particularly during the advanced crop growth stages from the 70th day onwards because of increasing leaf size and leaf area duration. It was further observed that 2 SF (45 x 30 cm) + 2 RG intercropping also produced significantly more leaf area than sole sunflower and sunflower associated with redgram at 15 and 22.5 cm intrarow spacing from the 70th day onwards because of early leaf senescence under later cropping systems because of more intrarow competition. Terbea and Stoenescu (1984) also recorded that increasing population density decreased leaf area per plant.

4.4.2 Leaf Area Index (LAI):

The data pertaining to mean leaf area index as influenced by the various treatments are presented in Table 11 and graphically depicted in Fig. 6.

Table 11. Mean leaf area index (LAI) of sunflower as influenced periodically by different treatments

Treatments	Days after sowing					
	28	42	56	70	84	98
Sole sunflower	0.93	2.90	4.66	2.69	2.47	0.83
2 SF (45x15 cm): 2RG	1.24	3.68	5.62	3.72	3.49	1.08
2 SF (45x22.5 cm): 2RG	0.96	2.78	3.75	2.79	2.64	0.98
2 SF (45x30 cm):2 RG	0.75	2.16	3.26	5.04	4.15	1.20
2 SF (45x45 cm):2 RG	0.56	1.49	2.83	4.68	3.94	1.20
S.E. ±	0.01	0.03	0.08	0.07	0.18	0.19
C.D. at 5%	0.03	0.08	0.24	0.21	0.51	-
General Mean	0.89	2.60	4.02	3.78	3.34	1.06

The LAI was only 0.89 on the 28th day because of slow crop growth during initial stages, it rapidly increased and reached maximum of 4.02 on the 56th day. It gradually declined after this period and it was only 1.06 at harvest.

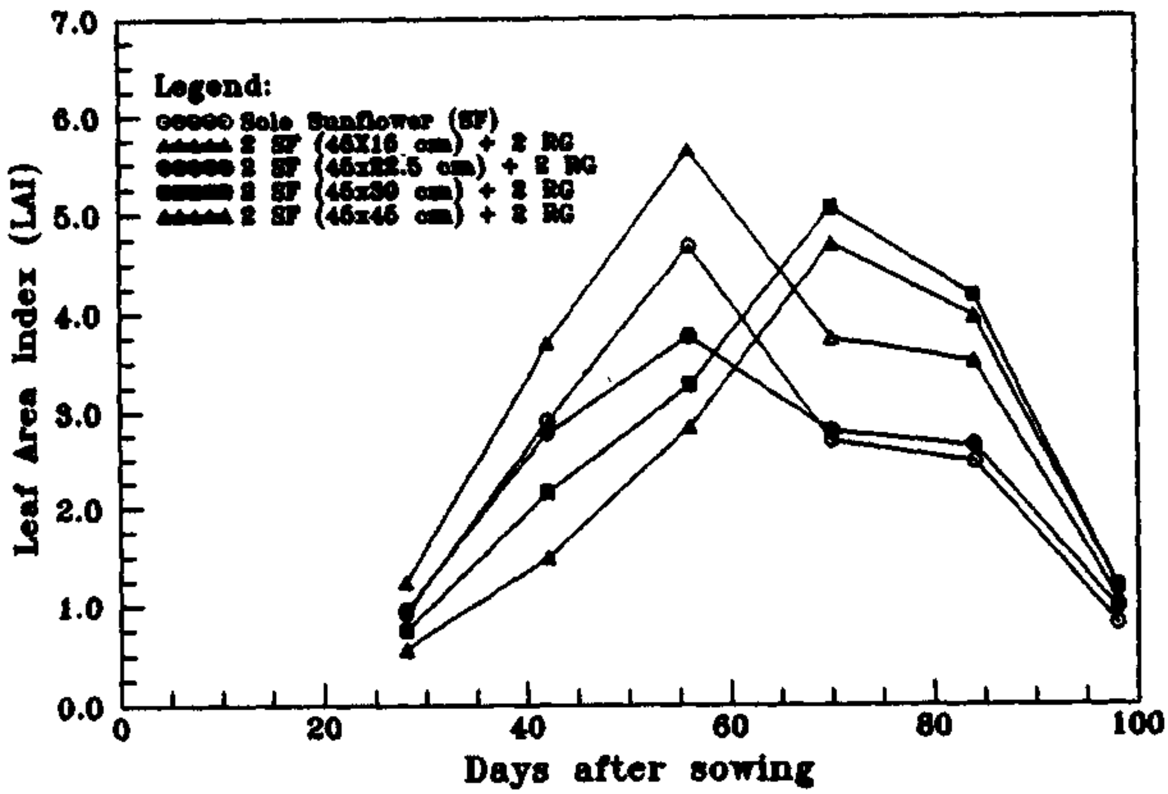

Fig. 6. Mean leaf area index (LAI) per plant of sunflower as affected periodically by different treatments

The sunflower associated with redgram at a closer intrarow spacing of 15 and 22.5 cm produced significantly more leaf area index than its association with redgram at wider intrarow spacing of 30 and 45 cm, because of its faster growth under former intercroppings, which produced more leaf area during early growth period. The LAI is considered as a reliable measure of crop response to available resources. The sunflower associated with redgram at wider intrarow spacings of 30 and 45 cm produced significantly higher LAI values than its association with redgram at closer intrarow spacings and sole sunflower during advanced crop growth period from the 70th day onwards because of higher interception of PAR and lower TPAR which ultimately increased LUE and seed yield under these intercropping systems. These results are in conformity with the findings of Williams *et al.* (1962), Shibles and Weber (1966) and Steiner (1986).

4.4.3 Dry Matter Production:

The data pertaining to mean dry matter production per plant as influenced by the various treatments are presented in Table 12 and graphically depicted in Fig. 7.

Table 12. Mean dry matter (g) per plant of sunflower as influenced periodically by different treatments

Treatments	Days after sowing					
	28	42	56	70	84	98
Sole sunflower	5.50	22.37	58.37	76.62	110.62	127.30
2 SF (45x15 cm): 2RG	3.87	16.75	45.06	81.25	128.37	142.70
2 SF (45x22.5 cm): 2RG	4.25	19.75	54.62	86.25	162.00	175.22
2 SF (45x30 cm):2 RG	5.62	22.87	57.43	161.62	230.75	243.60
2 SF (45x45 cm):2 RG	6.87	24.87	79.50	208.25	294.62	308.07
S.E. ±	0.25	1.91	3.34	8.55	13.49	7.73
C.D. at 5%	0.71	5.30	9.28	23.72	37.41	21.44
General Mean	5.22	21.32	59.00	122.80	185.27	199.38

The plant had hardly accumulated 5.22 g of dry matter per plant on the 28th day. The dry matter production rapidly increased with advancement in crop age upto the 84th day. The rate of dry matter production was observed to decline 84 DAS and plant had accumulated maximum dry matter of 199.38 g per plant at harvest.

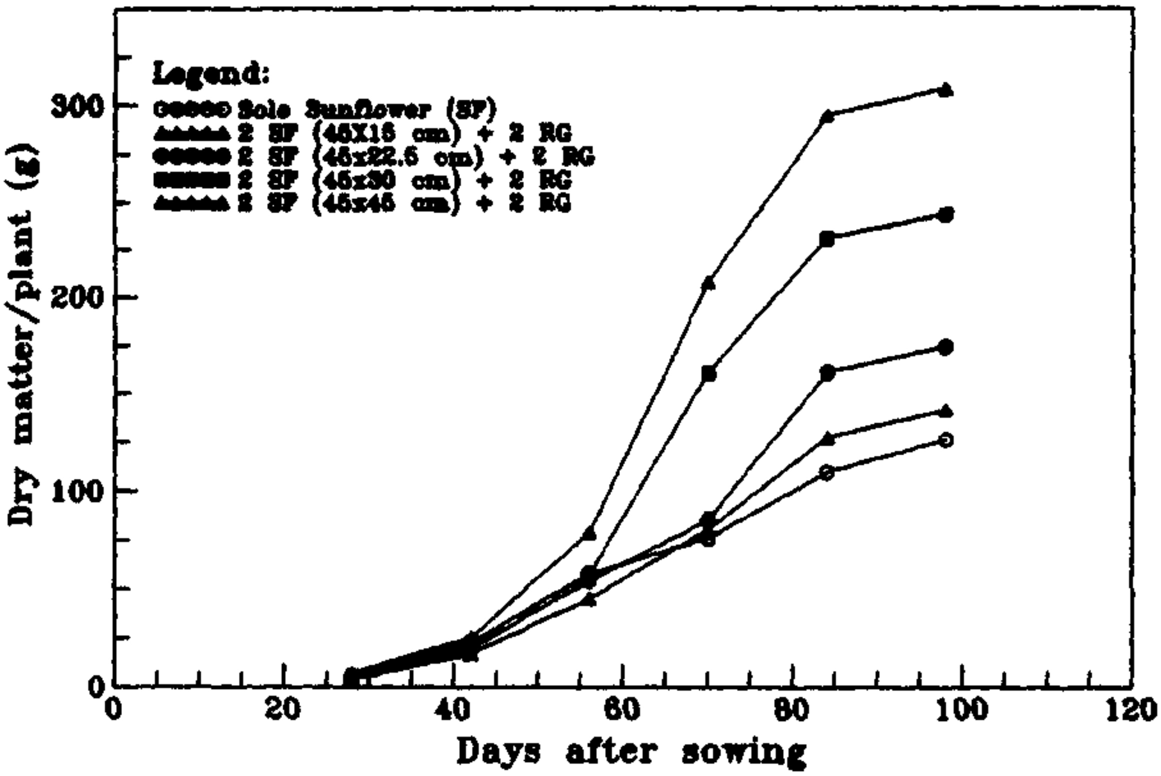

Fig. 7. Mean dry matter (g) per plant of sunflower as affected periodically by different treatments

The dry matter production per plant was the lowest under intercropping of 2 SF (45 x 15 cm) + 2 RG throughout the crop growth period due to more competition for natural resources like light, moisture and nutrients owing to less intrarow spacing. Sole sunflower and 2 SF (45 x 30 cm) + 2 RG intercropping accumulated more dry matter per plant than 2 SF (45 x 22.5 cm) + 2 RG intercropping during the early crop growth period of 28^{th} and 42^{nd} day because of competition free environment under sole sunflower and less competition under former intercropping due to wider intrarow spacing. The dry matter accumulated per plant was the highest under the intercropping of 2 SF (45 x 45 cm) + 2 RG at all the crop growth stages because of wider intrarow spacing of sunflower which offered least competition for natural resources like intercepted PAR, soil moisture and nutrients which ultimately increased dry matter production. It was also observed that 2 SF (45 x 30 cm) + 2 RG intercropping accumulated significantly more dry matter per plant than sunflower associated with redgram at narrow intrarow spacing of 15 and 22.5 cm and sole sunflower from the 70^{th} day onwards because of more LAI, which helped for interception of more PAR and improving LUE and thus, helped in accumulation of more dry matter. Number of workers have reported higher dry matter production per plant under lower plant population (Shibles and Weber, 1965; Kostrej and Repka, 1972; Itnal *et al.*, 1977; Tollenaar and Bruulsema, 1988).

4.4.4 Yield Components and Yield:

The data in respect of yield contributing characters and yield of sunflower as influenced by different cropping systems are presented in Table 13 and yield contributing characters and biological, seed and stalk yield are depicted in Fig. 8 and Fig. 9, respectively.

Table 13. Mean values of yield components and yields of sunflower as influenced by different treatments

Treatments	Yield components			Yield (kg ha^{-1})			Harvest index (%)
	No.of seeds/plant	Wt. of seeds/plant (g)	Thousand seed weight (g)	Biological	Seed	Stalk	
Sole sunflower	729	33.30	44.75	6682	1869	4813	28.38
2 SF (45x15 cm): 2 RG	810	37.95	45.00	5312	1751	3561	33.38
2 SF (45x22.5 cm): 2 RG	899	47.22	51.50	4628	1724	2904	37.64
S SF (45x30 cm): 2 RG	1066	61.22	55.50	4477	1715	2762	38.74
2 SF (45x45 cm): 2 RG	1363	95.65	67.75	3805	1670	2135	44.05
S.E. ±	66	4.74	2.49	419	084	374	2.04
C.D at 5%	182	13.14	6.92	1162	-	1036	5.67
General Mean	973	55.06	52.90	4981	1746	3235	36.44

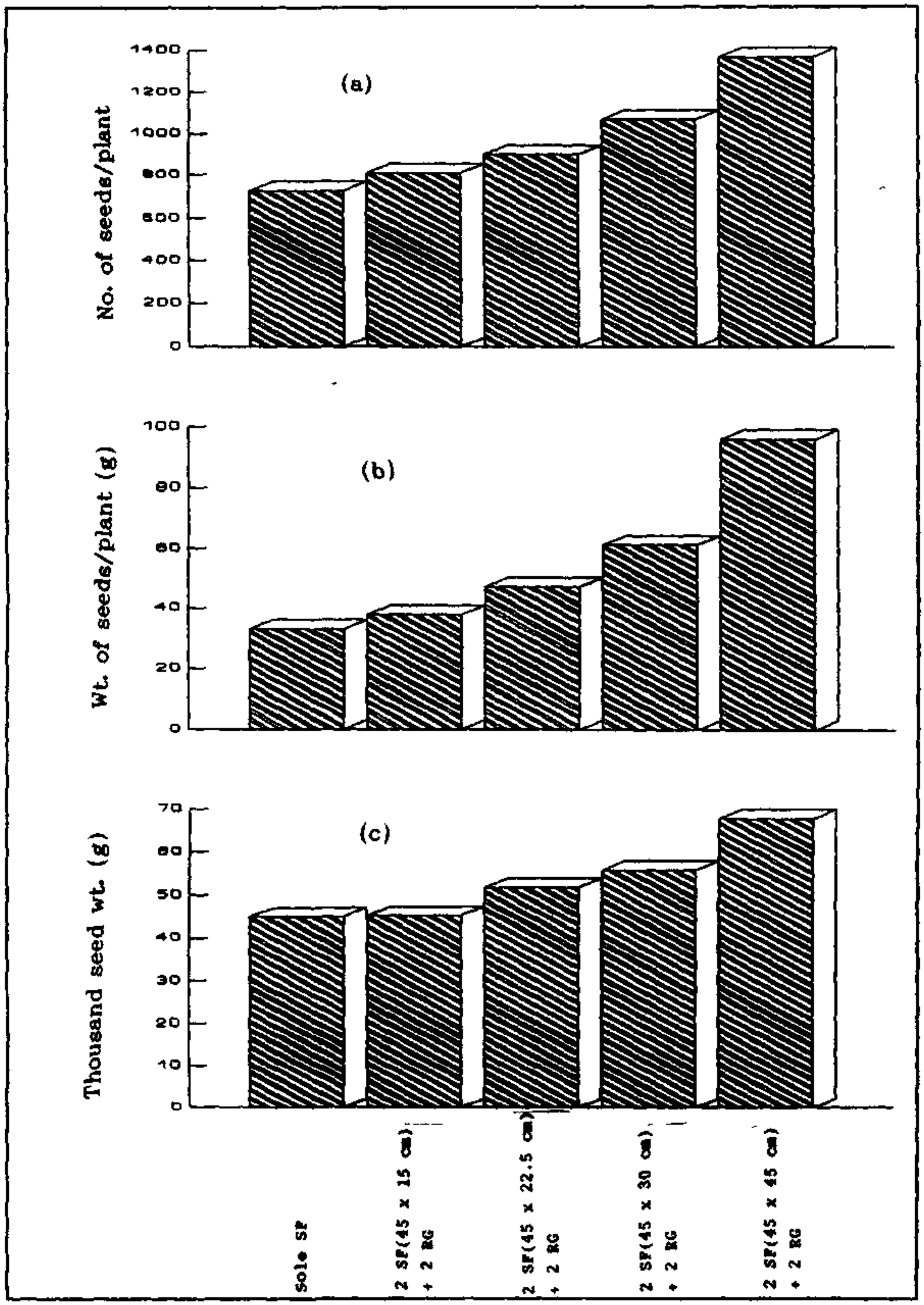

Fig. 8. Mean number of seeds (a) and their weight/plant (b) and thousand seed weight (c) of sunflower as influenced by different treatments

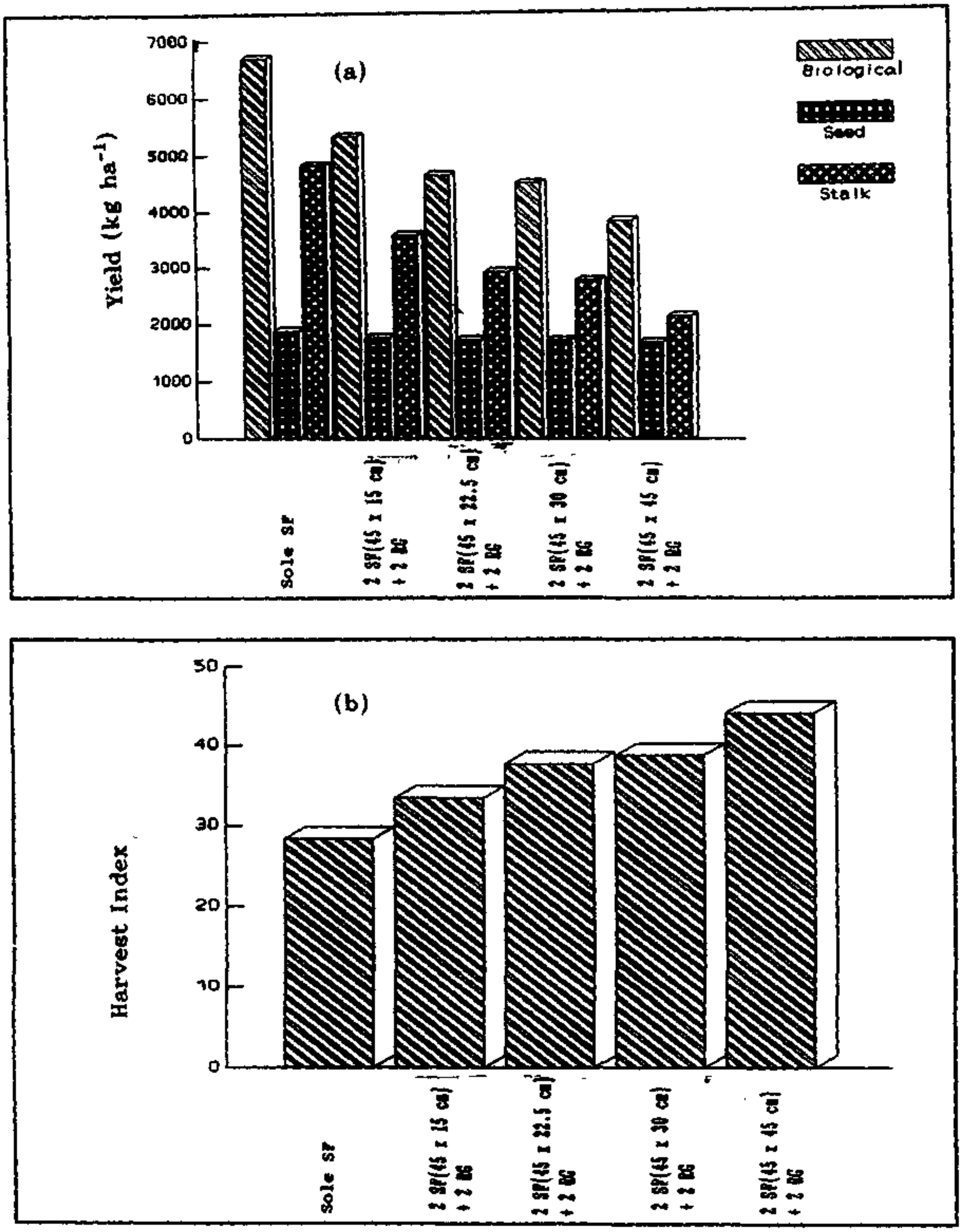

Fig. 9. Mean biological, seed and stalk yields (a) and Harvest Index (%) of sunflower (b) as influenced by different treatments

The mean values of the number of seeds and their weight per plant were 973 and 55.06 g, respectively. The mean 1000 seed weight was 52.90 g. The mean biological, seed and stalk yields were 4981, 1746 and 3235 kg ha^{-1}, respectively. The mean harvest index was 36.44.

The values of important yield components, *viz.*, number of seeds and their weight per plant and 1000 seed weight were significantly the highest under 2 SF (45 x 45 cm) + 2 RG intercropping system. These results are similar to those recorded by Stickler and Wearden (1965) and Lutz *et al.* (1971). Whereas, these values were the lowest under the sole sunflower because of more intrarow competition under sole sunflower due to closer intrarow spacing and less intrarow competition under intercropping system. The part of nitrogen fixed by associated redgram might have been made available to sunflower under intercropping system and helped for its vigorous growth and consequently increased values of these yield components. The intercropping of 2 SF (45 x 30 cm) + 2 RG produced significantly more number of seeds and their weight per plant and 1000 seed weight as compared to intercropping of 2 SF (45 x 15 cm) + 2 RG owing to wider intrarow spacing under former intercropping which helped in harvesting the natural resources more efficiently resulting in increased values of these yield components. These results are similar to those recorded by Rao and Reddy (1982), Leon and Moreno (1982), Terbea and Stoenescu (1984), Narwal and Malik (1985) and Cardinali (1985).

The biological and stalk yields were significantly the highest under sole sunflower because of more plant population and taller plants. The intercropping of 2 SF (45 x 15 cm) + 2 RG produced significantly more biological and stalk yield than 2 SF (45 x 45 cm) + 2 RG intercropping system because of more number of plants per unit area and more plant height owing to closer intrarow spacing under former intercropping system. These results corroborates the finding of Pawar and Sarnaik (1975), Upadhayay and Srinivas (1976) and Steiner (1986). However, seed yield was not significantly influenced in sole and intercropping systems because of the lower values of the yield components under sole sunflower. This might have been compensated by more number of plants per unit area on one hand and higher values of yield components under 2 SF (45 x 45 cm) + 2 RG intercropping on the other hand. Therefore, advantages could not be reflected in final seed yield because of more than 50% decrease in plant population under this intercropping system. These results are similar to those reported by Bond *et al.*, (1964) and Steiner, (1986).

4.5 STUDIES ON REDGRAM:

Biometric observations were recorded on the various growth characters, *viz.*, leaf area, leaf area index and dry matter production per plant at a regular interval of 14 days beginning from the 28th day onwards.

4.5.1 Leaf Area:

The data regarding mean leaf area per plant as influenced by the various treatments are presented in Table 14 and graphically depicted in Fig. 10.

The leaf area development was slow during the initial stages and plant had hardly produced 174.6 cm^2 of leaf area on the 28th day. It increased rapidly from the 42nd day to the 126th day. There was steep increase in leaf area from the 70th day onwards and it reached maximum of 5020.7 cm^2 on the 126th day because of beginning of grand growth period of redgram. The leaf area declined after 126th day and it was 2274.7 cm^2 at the harvest.

The leaf area was significantly more under sole redgram throughout the crop growth period than intercroppings, except on the 56th day because of competition free environment under sole redgram which helped for harvesting

Table 14. **Mean leaf area (cm^2) per plant of redgram as influenced periodically by different treatments**

Treatments	Days after sowing										
	28	42	56	70	84	98	112	126	140	154	160
Sole redgram	200.2	468.1	993.8	1445.0	3496.2	5172.7	6862.9	6915.5	6082.8	3172.8	2623.6
2 SF (45x15cm):2 RG	165.2	404.0	1144.9	1201.2	2498.5	3120.4	3734.0	3823.3	3405.3	2017.8	1600.4
2 SF (45x22.5 cm):2 RG	169.1	407.5	1172.3	1227.0	2686.0	3552.6	4087.8	4342.8	3645.3	2317.8	2120.5
2 SF (45x30 cm)· 2 RG	166.9	409.7	1100.6	1304.0	2885.9	3927.7	4650.5	4756.7	4298.0	2647.7	2461.1
2 SF (45x45 cm):2 RG	171.6	414.4	1120.3	1386.6	3008.4	4097.7	5152.6	5265.3	4965.3	2865.4	2567.6
S.E. ±	2.1	11.2	62.4	40.6	289.9	282.1	346.0	280.1	333.4	265.8	136.3
C.D. at 5%	5.9	31.1	-	112.7	803.8	781.9	959.3	776.4	924.2	737.0	378.0
General Mean	174.6	420.7	1106.4	1312.8	2915.0	3974.2	4897.5	5020.7	4479.3	2604.3	2274.7

the natural resources more efficiently. The intercropping of 2SF (45 x 45 cm) + 2 RG produced significantly more leaf area on the 28th day as compared to 2 SF (45 x 15 cm) + 2 RG intercropping system. Further, it was observed that sunflower planted in square geometry of 45 x 45 cm under intercropping system significantly increased leaf area as compared to sunflower associated with redgram at closer intrarow spacing of 15 and 22.5 cm from the 70th day onwards except on 84th day owing to wider intrarow space available for redgram under square geometry of sunflower which helped for intercepting more PAR and extracting of moisture and nutrients more efficiently. Gardiner and Craker

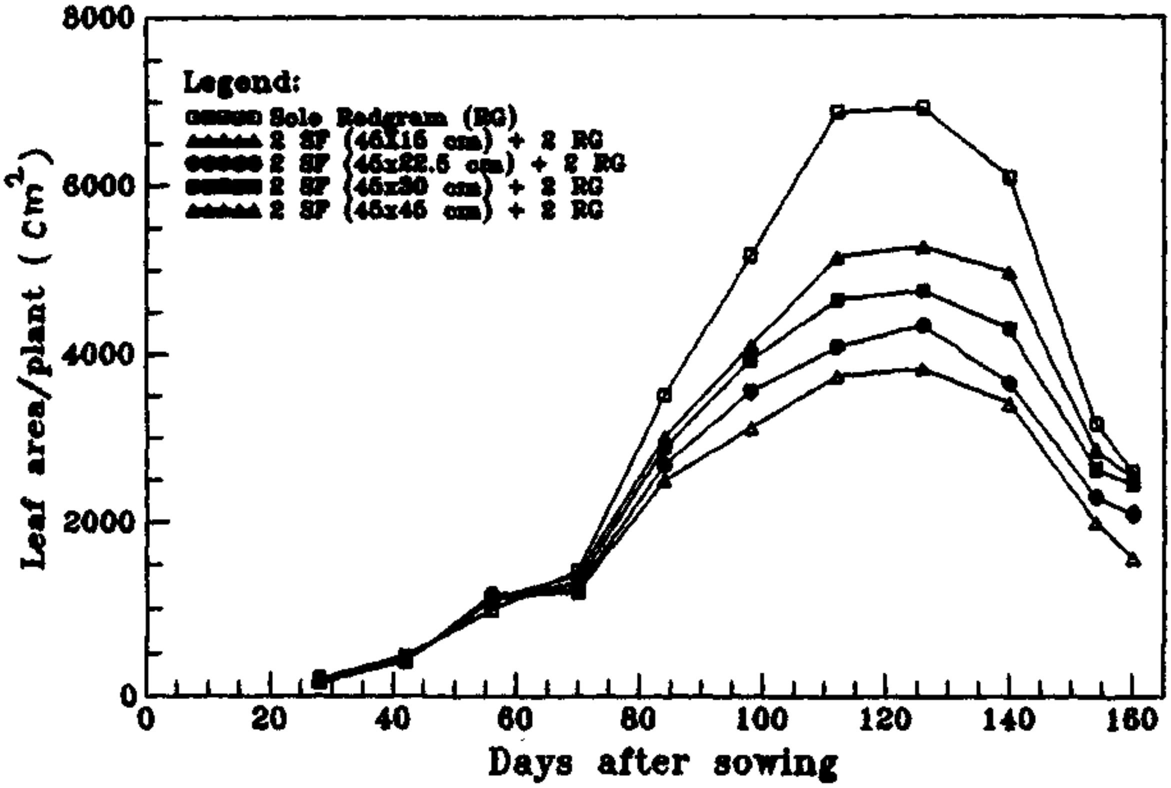

Fig. 10. Mean leaf area (cm^2) per plant of redgram as affected periodically by different treatments

(1979), Deshpande (1980) and Nikam *et al.* (1984) observed that with decrease in plant density of main crop, leaf area of intercrop increased. The intercropping of 2 SF (45 x 30 cm) + 2 RG produced significantly more leaf area than 2 SF (45 x 15cm) + 2 RG intercropping on the 98th and 112th day. The former intercropping also proved significantly superior to leaf area production per plant than sunflower associated with redgram intercropping at closer row spacing of 15 and 22.5 cm from the 126th day onwards because of more space available for redgram under former intercropping system. Leaf area was the lowest under 2 SF (45 x 15 cm) + 2 RG intercropping system at the harvest. These results are in conformity with the findings of Gardiner and Craker (1979).

4.5.2 Leaf Area Index (LAI):

The data pertaining to mean leaf area index as influenced by the various treatments are presented in Table 15 and graphically depicted in Fig. 11.

Table 15. Mean leaf area index (LAI) of redgram as influenced periodically by different treatments

Treat-ments	Days after sowing										
	28	42	56	70	84	98	112	126	140	154	160
Sole redgram	0.10	0.25	0.54	0.79	1.94	2.87	3.80	3.84	3.38	1.76	1.45
2 SF (45x15cm):2 RG	0.23	0.59	1.69	1.77	3.69	4.61	5.53	5.66	5.04	2.98	2.37
2 SF (45x22.5 cm):2 RG	0.24	0.60	1.73	1.81	3.97	5.26	6.05	6.43	5.40	3.43	3.14
2 SF (45x30 cm):2 RG	0.24	0.60	1.62	1.92	4.27	5.81	6.88	7.04	6.36	3.92	3.64
2 SF (45x45 cm):2 RG	0.25	0.60	1.65	2.04	4.45	6.06	7.63	7.80	7.35	4.24	3.80
S.E. ±	0.02	0.02	0.08	0.06	0.40	0.28	0.35	0.36	0.26	0.37	0.19
C.D. at 5%	0.07	0.04	0.21	0.16	1.12	0.77	0.98	1.02	0.73	1.03	0.55
General Mean	0.21	0.53	1.45	1.67	3.66	4.92	5.97	6.15	5.50	3.26	2.88

The redgram attained hardly 0.21 LAI at 28th day after sowing. Thereafter, it increased gradually and reached maximum of 6.15 at the 126th day after sowing. The LAI declined thereafter because of leaf senescence and attained the minimum value of 2.88 at the 160th day after sowing.

The LAI was significantly lower under sole redgram than different intercropping systems throughout the crop growth period because of wider row to row spacing. It was significantly decreased under 2 SF (45 x 15 cm) + 2 RG intercropping system as compared to sunflower associated with redgram in wider

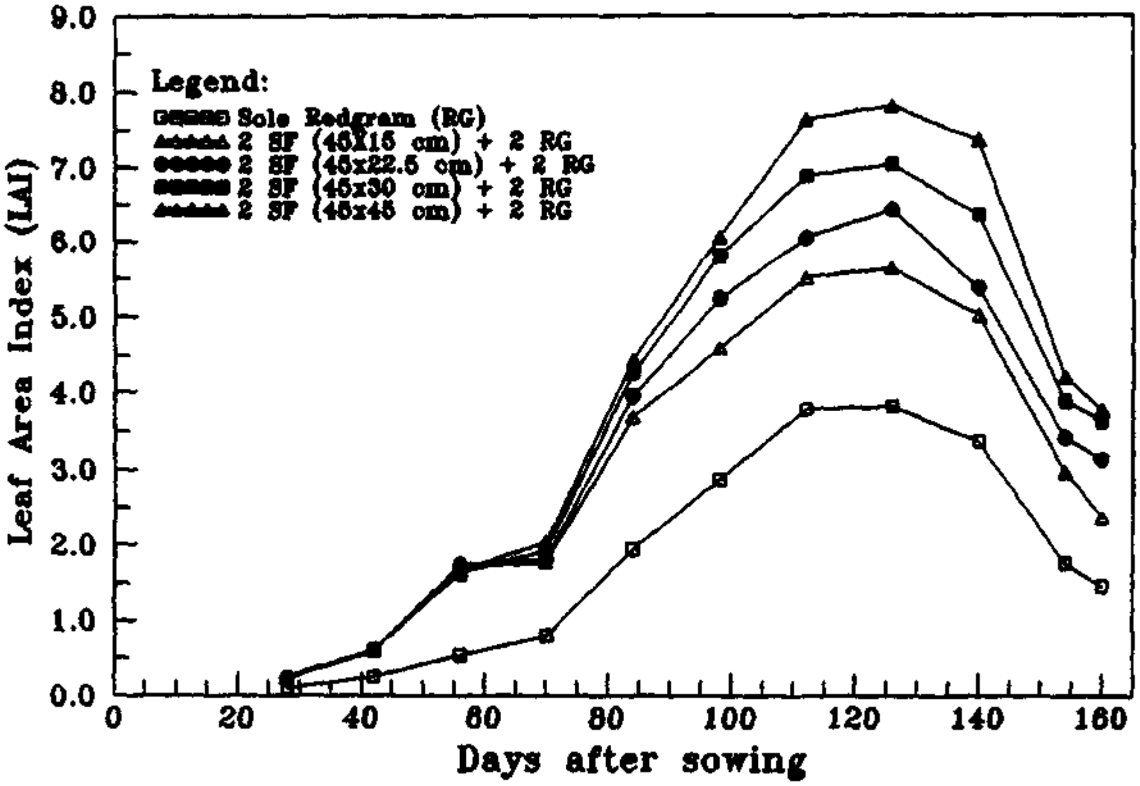

Fig. 11. Mean leaf area index (LAI) of redgram as affected periodically by different treatments

intrarow spacings of 30 and 45 cm during advanced crop growth period, *viz.*, 98 days onwards owing to higher leaf area production under later cropping systems. Fischer and Wilson (1975) and Gardiner and craker (1979) also observed that the maximum LAI occured in low density planting at later stages. It was further observed that 2 SF (45 x 45 cm) + 2 RG intercropping attained significantly more LAI values than 2 SF (45 x 22.5 cm) + 2 RG intercropping from the 98th day onwards showing complimentary interaction for natural resources under former intercropping system.

4.5.3 Dry Matter Production:

The data regarding mean dry matter production per plant as influenced by the various treatments are presented in Table 16 and graphically depicted in Fig. 12.

Table 16. Mean dry matter (g) per plant of redgram as influenced periodically by different treatments

Treat-ments	Days after sowing										
	28	42	56	70	84	98	112	126	140	154	160
Sole redgram	1.00	1.68	4.68	14.12	29.62	66.37	83.12	106.25	148.00	157.12	166.20
2 SF (45x15cm):2 RG	0.56	1.68	5.68	10.37	20.62	29.50	39.25	42.25	59.87	67.50	77.40
2 SF (45x22.5 cm):2 RG	0.56	1.93	5.87	11.87	22.62	35.50	45.37	55.12	70.12	79.87	90.75
2 SF (45x30 cm):2 RG	0.62	1.87	5.62	12.37	24.37	40.37	49.12	70.12	99.50	116.25	125.70
2 SF (45x45 cm):2 RG	0.62	1.87	5.62	13.87	26.25	54.87	65.12	80.50	129.00	132.25	140.85
S.E. ±	0.06	0.10	0.32	0.57	2.87	6.29	5.99	5.63	12.23	10.89	4.22
C.D. at 5%	0.17	-	0.90	1.58	7.97	17.45	16.62	15.61	33.91	30.20	11.70
General Mean	0.67	1.81	5.50	12.52	24.70	45.32	56.40	70.85	101.30	110.60	120.18

The rate of dry matter production was slow during the early crop growth period and plant had hardly accumulated 1.81 g of dry matter on the 42nd day. It increased gradually from the 42nd day and plant had produced 70.85 g of dry matter on the 126th day. The rapid increase in dry matter accumulation was observed during advanced crop growth period from 126th day onwards and maximum dry matter of 120.18 g per plant was recorded at the harvest.

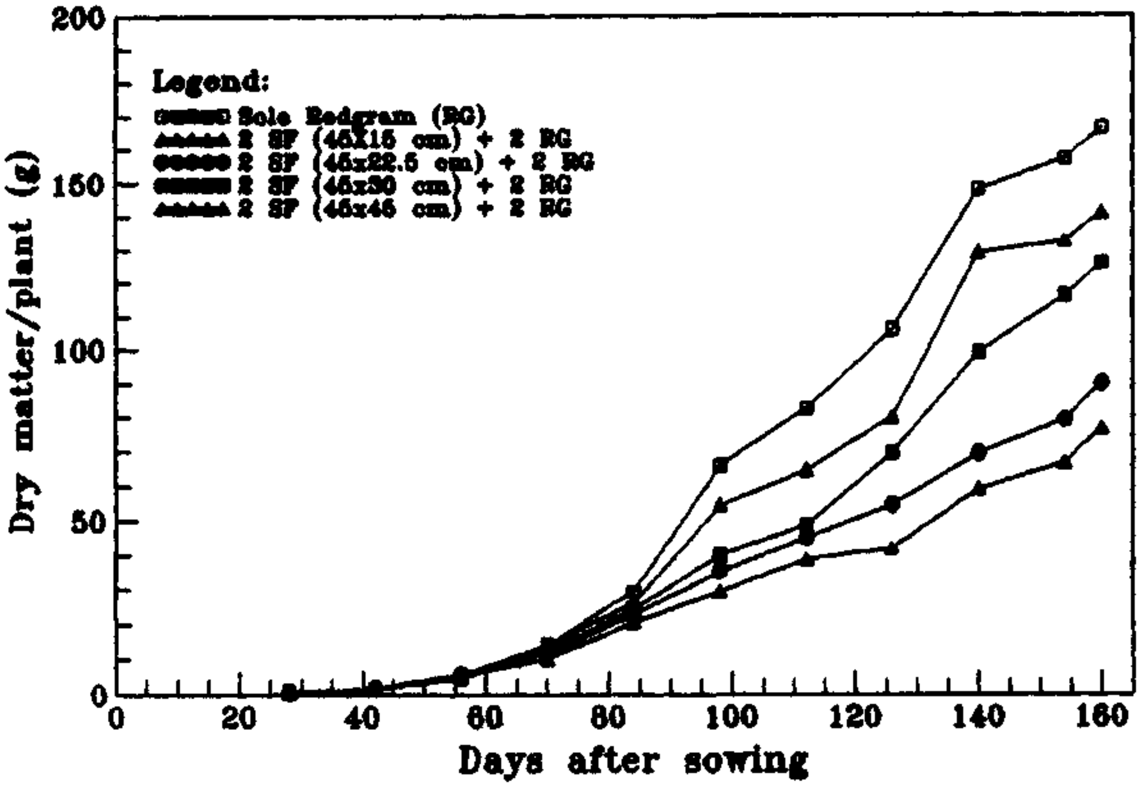

Fig. 12. Mean dry matter (g) per plant of redgram as affected periodically by different treatments

Dry matter production was the highest on the 28th day and the lowest on the 56th day under sole redgram showing no definite trend during early crop growth period. However, the dry matter per plant was significantly more under sole redgram and its association with sunflower in square geometry than redgram associated with sunflower at closer intrarow spacings of 15 and 22.5 cm on the 70th day and 112th day onwards because of competition free environment under sole redgram and wider intrarow spacing of sunflower under square geometry which helped for harvesting of natural resources like solar radiation, soil moisture and nutrients more efficiently. The economic yields are the results of leaf area production and dry matter accumulation in the plant which were thus significantly improved under sole redgram and 2 SF (45 x 45 cm) + 2 RG intercropping system, particularly during the advanced crop growth period resulting in more seed yield. These results corroborate the findings of Williams *et al.*, (1965), Monteith (1977), Biscoe and Gallagher (1977), Steiner (1986), Hunsal and Malik (1987) and Tollenaar and Bruulsema (1988).

4.5.4 Yield Components and Yield:

The data in respect of yield contributing characters and yields of redgram are presented in Table 17. Yield contributing characters and the yields are depicted in Fig. 13 and Fig. 14, respectively.

The mean number of seeds and their weight was 223 and 22.12 g per plant, respectively. The mean 1000 seed weight was 92.80 g. The mean biological, seed and stalk yields were 4431, 1085 and 3346 kg ha^{-1}, respectively. The mean harvest index was 23.62.

Table 17. Mean values of yield components and yields of redgram as influenced by different treatments

Treatments	Yield components			Yield (kg ha^{-1})			Harvest index (%)
	No. of seeds/ plant	Wt. of seeds/ plant (g)	Thousand seed wt. (g)	Biological	Seed	Stalk	
Sole redgram	431	38.95	99.75	6064	2166	3898	35.75
2 SF (45x15 cm):2 RG	119	12.25	84.50	2181	510	1671	22.96
2 SF (45x22.5 cm):2 RG	168	18.40	88.37	3845	831	3014	21.47
2 SF (45x30 cm):2 RG	184	19.35	94.62	4262	852	3410	20.02
2 SF (45x45 cm):2 RG	215	21.65	96.75	5804	1066	4738	17.92
S.E. ±	28	2.75	0.75	251	119	169	1.91
C.D. at 5%	78	7.63	2.10	697	332	468	5.31
General Mean	223	22.12	92.80	4431	1085	3346	23.62

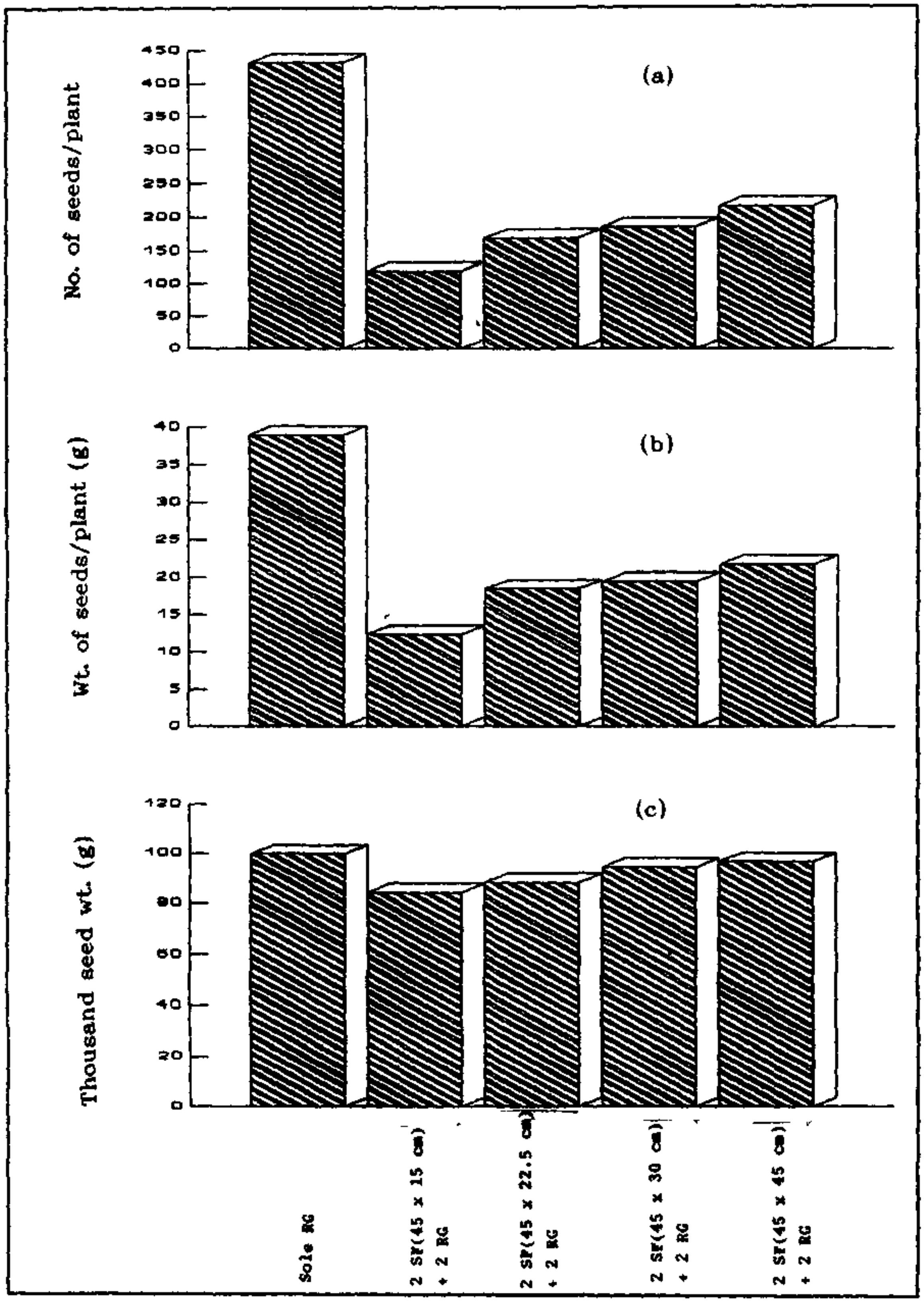

Fig. 13. **Mean number of seeds (a) and their weight/plant (b) and thousand seed weight (c) of redgram as influenced by different treatments**

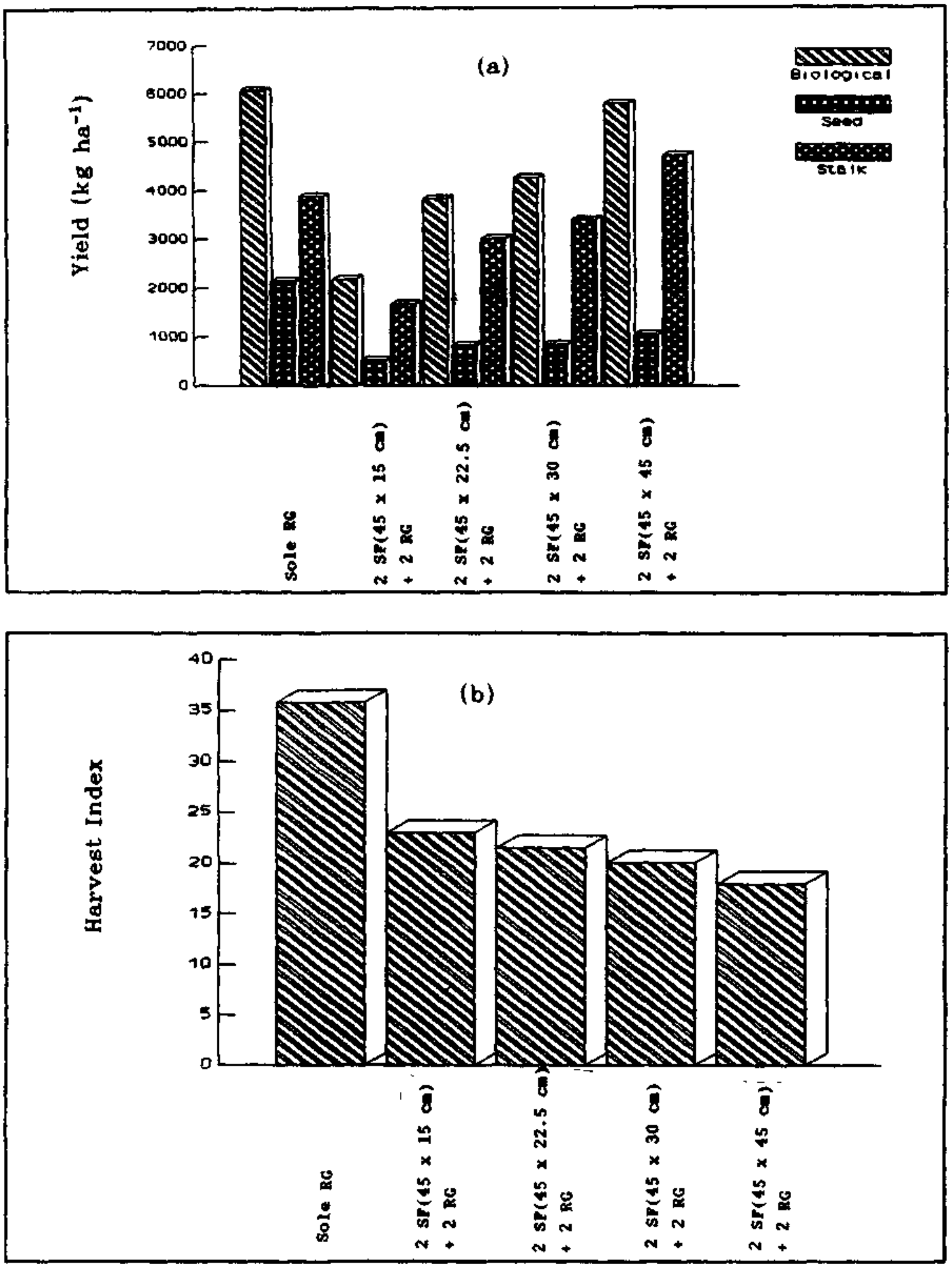

Fig. 14. **Mean biological, seed and stalk yields (a) and Harvest Index (%) of redgram (b) as influenced by different treatments**

The number of seeds and their weight per plant and 1000 seed weight were significantly the highest under sole redgram because of availability of more sunlight throughout the crop growth period. The number of seeds and their weight per plant was significantly more under 2 SF (45 x 45 cm) + 2 RG intercropping than that of 2 SF (45 x 15 cm) + 2 RG intercropping system due to wider intrarow spacing of sunflower which helped in better development of individual plant of redgram under former intercropping system. It was also observed that 1000 seed weight of redgram was significantly higher with increasing intrarow spacing of sunflower under intercropping system owing to more space for redgram development which might have harvested natural resources like solar radiation, moisture and nutrients efficiently and consequently increased 1000 seed weight. These results corroborate the findings of the Stickler and Wearden (1965), Soundarajan and Palaniappan (1979) and Hefni *et al.* (1985).

The biological yield was the lowest under 2 SF (45 x 15 cm) + 2 RG intercropping. Sole redgram and its association with sunflower in square geometry of 45 x 45 cm produced more biological yield than other intercropping systems.

The seed yield was significantly the highest under sole redgram because of higher values of all the yield contributing characters, *viz.*, leaf area, dry matter, number of seeds and their weight per plant and 1000 seed weight. The shade free environment under sole redgram also intercepted more PAR and extracted more moisture and nutrients resulting in more seed yield. Rafey *et al.* (1986), Dandwate (1987) and Jadhav *et al.* (1991) observed that redgram yield in intercropping systems was appreciably lower than its pure stand.

It was also observed that intercropping of 2 SF (45 x 15 cm) + 2 RG produced significantly the lowest seed yield because of more competition for natural resources, particularly, light due to closer intrarow spacings of sunflower. These results corroborate the findings of Willey and Osiru (1972) and Umrani (1981).

The stalk yield was significantly more under 2 SF (45 x 45 cm) + 2 RG intercropping and significantly lower under 2 SF (45 x 15 cm) + 2 RG intercropping owing to wider intrarow spacing of sunflower under former intercropping. It helped in vigorous vegetative growth of redgram, whereas, closer intrarow spacing of sunflower under later intercropping suppressed the growth of redgram. It was also noticed that sole redgram produced significantly more stalk yield than its association with sunflower at 22.5 and 30 cm intrarow spacings because of free availability of sunlight under sole redgram. These results corroborate the findings of Nnko and Doto, (1978), Choudhari and Misangu (1979), Edje (1980) and Deshpande (1980).

The harvest index was significantly more under sole redgram than its association with sunflower with different intrarow spacings indicating better source:sink relationship under sole redgram due to harvesting of natural resources more efficiently. It was also interesting to note that the harvest index decreased with increasing intrarow spacing of sunflower though differences were not significant indicating that the conversion efficiency of vegetative dry matter into reproductive parts decreased with increasing intrarow sunflower spacing under intercropping system. These results corroborate the findings of Leach and Beech, (1988).

4.6 STUDIES ON CROPPING SYSTEM:

4.6.1 Leaf Area:

The data pertaining to combined leaf area of the cropping systems as influenced periodically by different treatments are presented in Table 18 and depicted in Fig. 15.

Table 18. Mean leaf area (cm^2) of the cropping system as influenced periodically by different treatments

Treatments	Days after sowing										
	28	42	56	70	84	98	112	126	140	154	160
Sole sunflower	946.1	2941.1	4725.5	2729.6	2512.6	853.8	-	-	-	-	-
Sole redgram	200.2	468.1	993.8	1445.0	3496.2	5172.7	6862.9	6915.5	6082.8	3172.8	2623.6
2 SF (45x15cm):2 RG	1007.1	2894.5	4944.7	3715.7	4864.0	3856.2	3734.0	3823.2	3405.3	2017.8	1600.4
2 SF (45x22.5 cm):2 RG	1149.7	3223.5	4982.6	4056.8	5373.6	4554.4	4087.8	4342.8	3645.3	2317.8	2120.5
2 SF (45x30 cm)· 2 RG	1185.2	3330.5	5514.2	8119.0	8502.6	5553.1	4650.5	4756.7	4298.0	2647.7	2461.1
2 SF (45x45 cm):2 RG	1317.1	3449.2	6858.8	10874.3	11006.3	6548.4	5152.5	5265.3	4965.3	2865.4	2567.6
S.E. ±	14.6	34.3	92.2	119.3	353.3	454.2	346.0	280.1	333.4	265.8	136.3
C.D. at 5%	40.7	95.1	255.8	330.8	979.3	1259.2	959.2	776.4	924.2	737.0	378.0
General Mean	967.6	2717.8	4669.9	5156.7	5959.2	4423.1	4897.5	5020.7	4479.3	2604.3	2274.7

The leaf area development was slow during initial stages and plant had produced 2717.8 cm^2 of leaf area on the 42^{nd} day. It rapidly increased from the 42^{nd} day onwards and reached maximum of 5959.2 cm^2 on the 84^{th} day. It declined (4423.1 cm^2) on the 98^{th} day because of harvesting of sunflower and again increased 5020.7 cm^2 on the 126^{th} day due to full vegetative growth of the

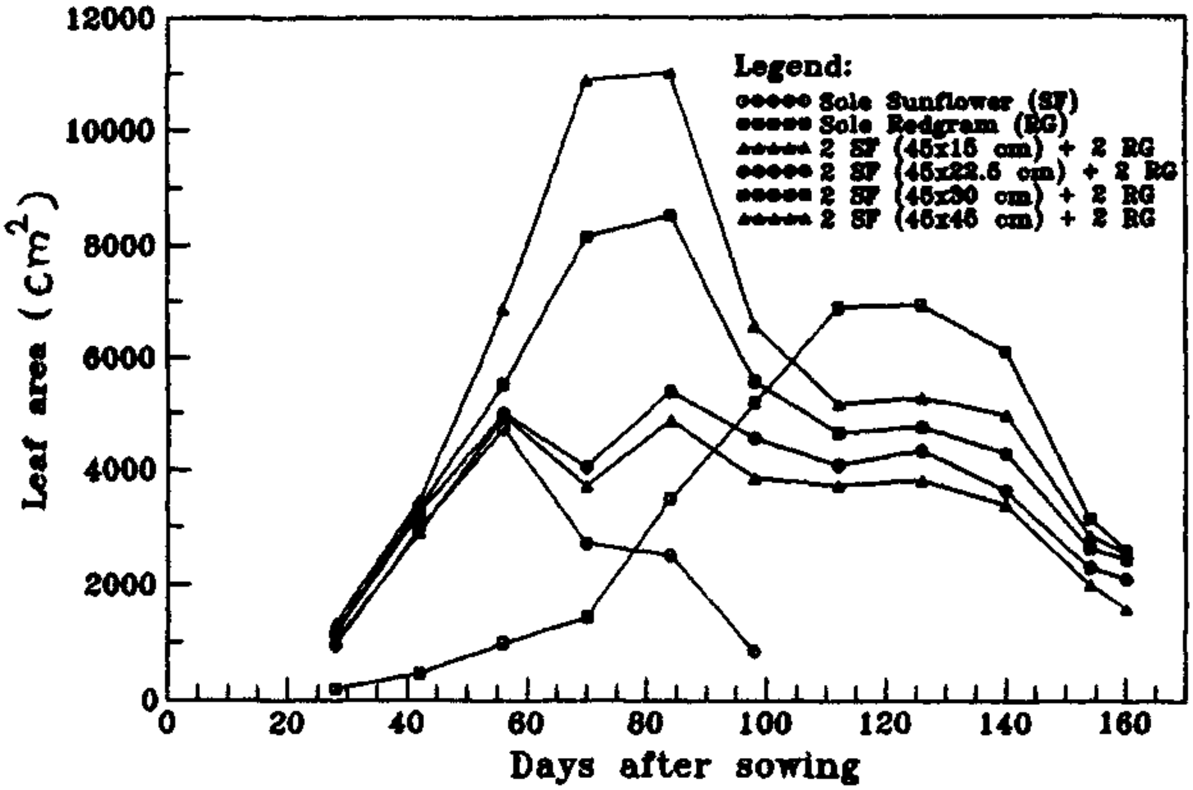

Fig. 15. Mean leaf area (cm^2) of cropping system as affected periodically by different treatments

redgram and decreased thereafter owing to leaf senescence of redgram. The distribution of leaf area showed bimodal distribution expressing temporal complementarity of component crops. The leaf area of 2274.7 cm^2 per plant was recorded at harvest.

The leaf area of sole redgram was significantly the lowest upto the 70th day because of slow growth of the redgram during the early growth period.

The leaf area of sole sunflower was significantly lower than its association with redgram in different intrarow spacings throughout the crop growth period. Similar results were recorded by Srinivas (1991). It was also interesting to note that the leaf area of the cropping systems significantly increased with increase in intrarow spacing of the sunflower during early crop growth period upto the

42nd day showing complementary interactions. The sunflower associated with redgram at wider intrarow spacings of 30 and 45 cm produced significantly higher leaf area than its association with redgram at closer intrarow spacings of 15 and 22.5 cm upto the 84th day because of harvesting of natural resources, *viz.*, solar radiation, moisture and nutrients by the component crops more efficiently which resulted in increased leaf area. The leaf area was significantly more under 2 SF (45 x 45 cm) + 2 RG intercropping than sole component crops and association of redgram with sunflower at closer intrarow spacings of 15 and 22.5 cm on the 98th day showing complementary interactions for growth resources. Further, it was observed that 2 SF (45 x 15 cm) + 2RG intercropping* decreased leaf area significantly as compared to sole redgram and its association with sunflower at wider intrarow spacings of 30 cm showing competitive interaction under closer intrarow spacing of sunflower.

After harvest of sunflower (98th day onwards), sole redgram produced significantly more leaf area than its association with sunflower under different intrarow spacings upto the 140th day because of competition free environment and its full blooming period. The sole redgram attained more leaf area than its association with sunflower at closer intrarow spacings of 15 and 22.5 cm on the 154th and the 160th day. The association of sunflower (45 x 15 cm) with redgram produced less leaf area than 2 SF (45 x 45 cm) + 2 RG intercropping from the 112th day onwards and 2 SF (45 x 30 cm) + 2 RG intercropping on the 126th and 160th day owing to competitive interactions between the component crops under former intercropping. These results corroborate the findings of Gardiner and Craker (1979).

4.6.2 Leaf Area Index (LAI):

The data pertaining to combined leaf area index of the system as influenced periodically by different treatments are presented in Table 19 and depicted in Fig. 16.

Table 19. Mean leaf area index (LAI) of cropping system as influenced periodically by different treatments

Treatments	Days after sowing										
	28	42	56	70	84	98	112	126	140	154	160
Sole sunflower	0.93	2.90	4.66	2.69	2.47	0.83	-	-	-	-	-
Sole redgram	0.10	0.25	0.54	0.79	1.94	2.87	3.80	3.84	3.38	1.76	1.45
2 SF (45x15cm):2 RG	1.48	4.27	7.31	5.49	7.19	5.70	5.53	5.66	5.04	2.98	2.37
2 SF (45x22.5 cm):2 RG	1.21	3.39	5.49	4.60	6.62	6.24	6.05	6.43	5.40	3.43	3.14
2 SF (45x30 cm): 2 RG	0.99	2.76	4.89	6.97	8.42	7.01	6.88	7.04	6.36	3.92	3.64
2 SF (45x45 cm):2 RG	0.81	2.10	4.48	6.72	8.39	7.26	7.63	7.80	7.35	4.24	3.80
S.E. ±	0.01	0.03	0.09	0.09	0.40	0.38	0.35	0.36	0.26	0.37	0.19
C.D. at 5%	0.03	0.09	0.27	0.26	1.13	1.05	0.98	1.02	0.73	1.03	0.55
General Mean	0.92	2.61	4.56	4.54	5.84	4.98	5.97	6.15	5.50	3.26	2.88

The LAI production was slow during the initial stages and cropping systems attained only 0.92 LAI on the 28th day. It was increased gradually and reached the values of 5.84 on the 84th day, and it was slightly decreased to 4.98 on the 98th day because of harvesting of sunflower and again increased to 6.15 on the 126th day owing to maximum leaf area production by redgram. The LAI values declined thereafter and it was 2.88 on the 160th day.

2 SF (45X15 cm) + 2 RG

2 SF (45X30 cm) + 2 RG

Plate 3. Difference between treatments at flowering.

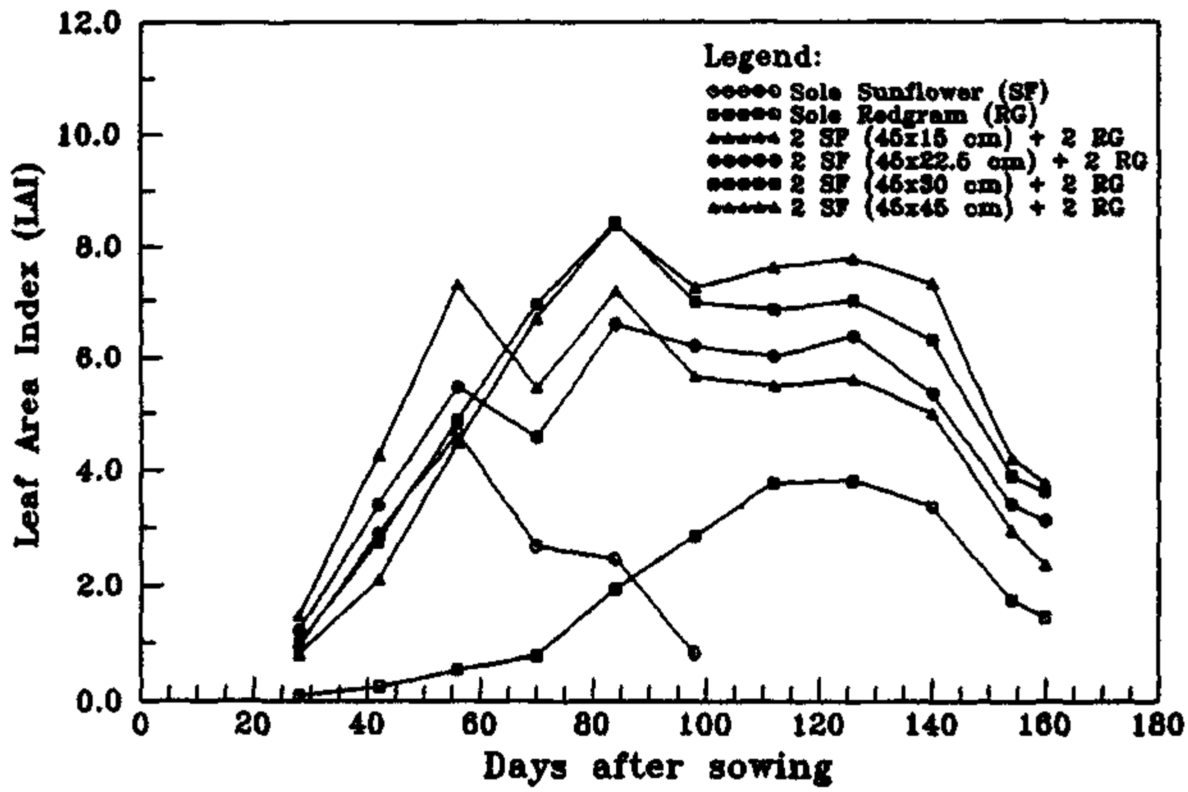

Fig. 16. Mean leaf area index (LAI) of cropping system as affected periodically by different treatments

The LAI was significantly the lowest under sole redgram throughout the crop growth period because of wider row to row spacing. The intercropping of 2 SF (45 x 15 cm) + 2 RG attained significantly the highest LAI on the 42nd and 56th day owing to narrow sunflower intrarow spacings resulted in more competition for natural resources and produced faster growth of the component crops. Similar trend was noticed under the intercropping of 2 SF (45 x 22.5 cm) + 2 RG on these days. The LAI of sole sunflower was significantly less than its association with redgram in different intrarow spacings from the 70th DAS onwards indicating complementary interactions for growth resources under intercropping systems. These results are in conformity with the findings of Srinivas (1991). The sunflower + redgram association under the wider intrarow spacings of 30 and 45 cm produced more LAI than sunflower + redgram association at closer sunflower intrarow spacings of 15 and 22.5 cm on the 70th and 84th day showing complementary interactions between component crops for natural resources under former intercropping systems.

After harvest of sunflower (98th day), the LAI values were significantly less under intercropping system of 2 SF (45 x 15 cm) + 2 RG than sunflower associated with redgram at wider intrarow spacings of 30 and 45 cm. This was attributed to the competitive nature of component crops for growth resources under former intercropping owing to less intrarow sunflower spacing. The competition free environment and complimentary interactions for growth resources under later intercroppings owing to wider intrarow sunflower spacings increased LAI values. These results corroborates the findings of Gardiner and Craker (1979), Deshpande (1980) and Srinivas (1991). It was further observed that 2 SF (45 x 45 cm) + 2 RG intercropping attained significantly more LAI values than 2 SF (45 x 22.5 cm) + 2 RG intercropping from the 98th day onwards showing complimentary interactions for natural resources under former intercropping system.

4.6.3 Dry Matter Production:

The data pertaining to combined dry matter production by the different treatments are presented in Table 20 and graphically depicted in Fig. 17.

The rate of dry matter production was slow during the initial crop growth period and plant had hardly produced 27.49 gm^{-2} of dry matter. The rate of dry matter production increased rapidly from 28th day onwards and maximum combined dry matter of 1066.39 gm^{-2} was recorded on the 98th day. It declined (386.99 gm^{-2}) on the 112th day due to harvest of sunflower and increased thereafter. The maximum dry matter of redgram (828.67 gm^{-2}) was recorded at harvest on 160th day.

Table 20. Mean dry matter (gm^{-2}) of cropping system as influenced periodically by different treatments

Treatments	Days after sowing										
	28	42	56	70	84	98	112	126	140	154	168
Sole sunflower	54.32	220.99	576.54	756.79	1092.59	1257.29	-	-	-	-	-
Sole redgram	5.55	12.49	26.04	78.47	164.58	368.75	461.81	590.28	822.22	872.92	923.34
2 SF (45x15cm):2 RG	32.87	136.58	375.93	678.71	1103.71	1275.56	290.74	312.96	443.52	499.99	573.33
2 SF (45x22.5 cm):2 RG	25.15	111.88	313.27	513.89	967.59	1128.27	336.11	408.34	519.44	591.67	672.22
2 SF (45x30 cm): 2 RG	25.46	98.61	254.39	690.28	1035.19	1201.29	363.89	544.45	737.04	861.11	931.11
2 SF (45x45 cm):2 RG	21.61	75.31	237.96	616.98	921.92	1167.16	482.41	596.29	955.56	979.63	1043.33
S.E. ±	1.47	8.97	20.32	39.31	46.70	62.02	38.63	39.19	74.30	65.38	28.74
C.D. at 5%	4.09	24.86	56.33	108.97	129.46	171.91	107.09	108.65	205.95	181.23	79.67
General Mean	27.49	109.31	297.36	555.85	880.93	1066.39	386.99	490.46	695.56	761.07	828.67

The dry matter production was significantly the lowest under sole redgram upto the harvest of sunflower (98^{th} day) because of slower growth of redgram during early part of the growth period owing to its longer duration. The sole sunflower accumulated significantly the highest dry matter upto the 70^{th} day because of competition free environment and faster growth of sunflower owing to its shorter life span. The intercropping of 2 SF (45 x 15 cm) + 2 RG produced significantly more dry matter than sunflower + redgram association at wider intrarow spacings of 30 and 45 cm upto the 56^{th} day because of faster growth of the component crops due to competitive interaction for natural resources under former intercropping system.

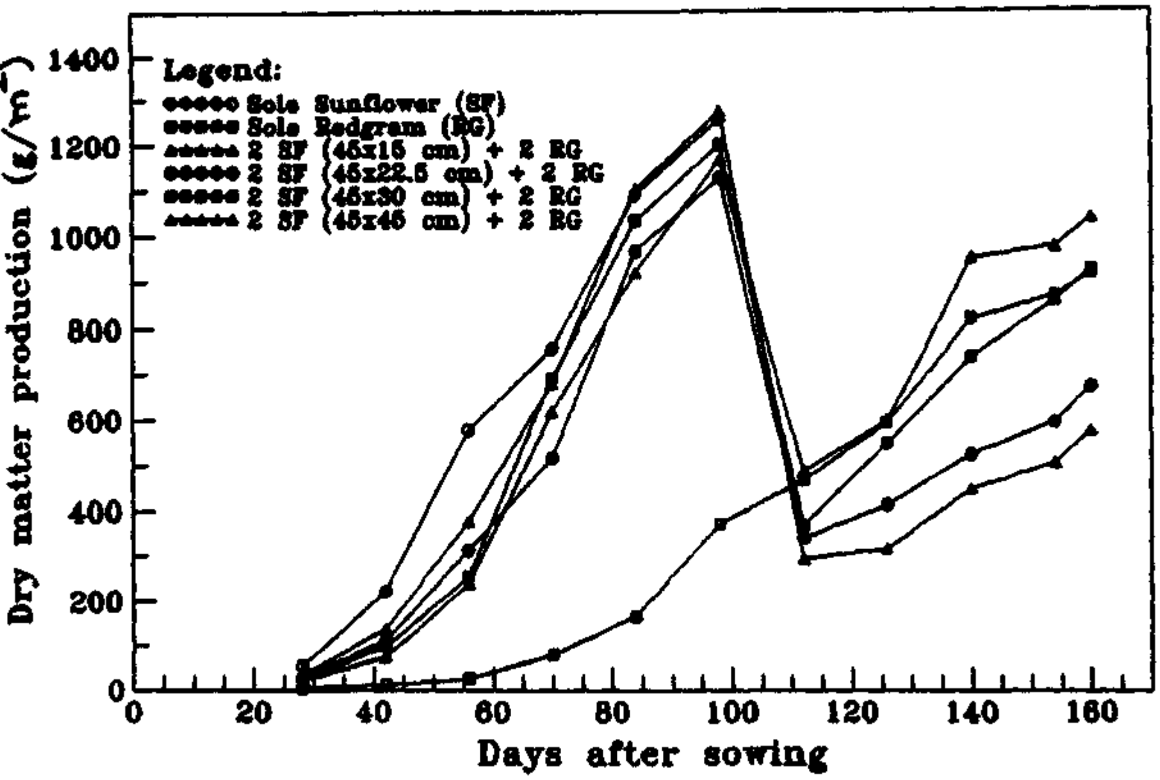

Fig. 17. Mean dry matter (g m^{-2}) of cropping system as affected periodically by different treatments

The intercropping of 2 SF (45 x 22.5 cm) + 2 RG produced significantly less dry matter than the sole sunflower and its association with redgram at 15 and 30 cm on the 70th day. Sole sunflower also had significantly higher dry matter production over 2 SF (45 x 45 cm) + 2 RG intercropping on the same day. The association of sunflower with redgram in different intrarow spacings produced as much combined dry matter as that of sole sunflower on the 84th day showing complementary interaction between component crops for harvesting the natural resources like solar radiation, moisture and nutrients more efficiently.

After harvest of the sunflower (98th day), sole redgram and its association with sunflower in square geometry of 45 x 45 cm produced significantly more dry matter than sunflower + redgram association at sunflower intrarow spacings of 15 and 22.5 cm because of competition free environment under sole redgram and wider intrarow spacing of sunflower under former intercropping system helped for better growth and development of redgram and produced more dry matter. It was also noticed that 2 SF (45 x 30 cm) + 2 RG intercropping accumulated significantly more dry matter m^{-2} than 2 SF (45 x 15 cm) + 2 RG intercropping after harvest of sunflower from the 98th day onwards showing complementary interactions. These results corroborate the findings of Nnko and Doto (1978), Choudhari and Misangu (1979), Edje (1980) and Deshpande (1980).

4.6.4 Sunflower Seed Yield Equivalent:

The data regarding yields, sunflower seed yield equivalent, net monetary returns, benefit:cost ratio and LER are presented in Table 21 and sunflower seed yield equivalent and net monetary returns are depicted in Fig. 18.

Table 21. Mean yield, sunflower seed yield equivalent, net monetary returns, benefit:cost ratio and LER as influenced by different treatments

Treatments	Seed yield ($kg\ ha^{-1}$)		Stalk yield ($kg\ ha^{-1}$)		sunflower seed yield equivalent	Net monetary returns	Benefit: cost ratio	LER
	Base crop	Inter-crop	Base crop	Inter crop	($kg\ ha^{-1}$)	($Rs.\ ha^{-1}$)		
Sole sunflower	1869	-	4813	-	1869	14869	3.60	1.00
Sole redgram	-	2166	-	3898	1773	16539	4.50	1.00
2 SF (45x15 cm):2 RG	1751	510	3561	1671	2169	19357	4.68	1.18
2 SF (45x22.5 cm):2 RG	1724	831	2904	3014	2405	22578	5.31	1.31
2 SF (45x30 cm):2 RG	1715	852	2762	3410	2413	22870	5.38	1.32
2 SF (45x45 cm):2 RG	1670	1066	2135	4738	2543	24920	5.80	1.40
S.E. ±	84	120	374	169	121	1366	0.25	0.06
C.D. at 5%	-	332	1036	468	335	3785	0.71	0.18
General Mean	1746	1085	3235	3346	2195	20189	4.88	1.20

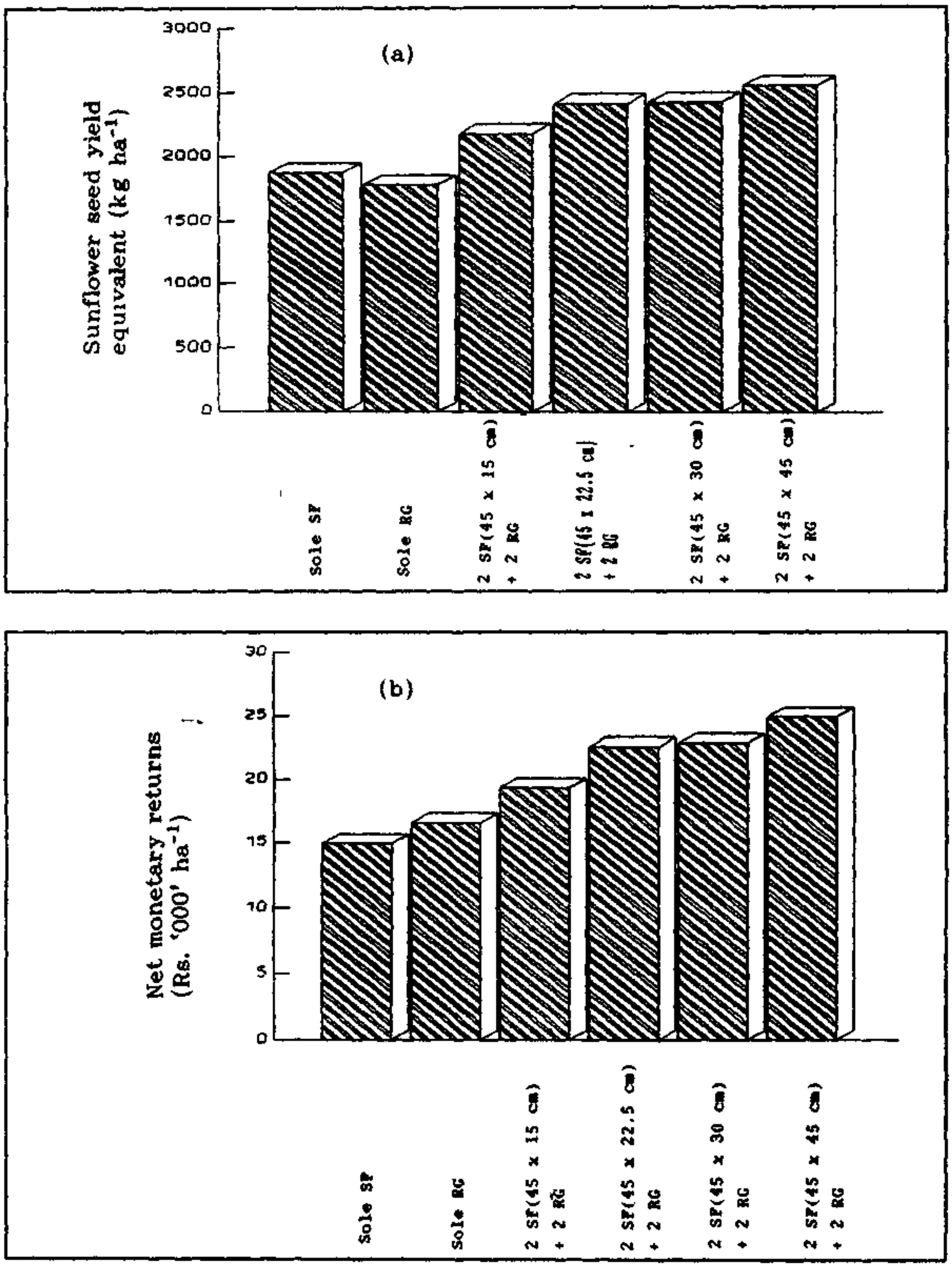

Fig. 18. Sunflower seed yield equivalent (a) and net monetary returns (b) of cropping systems as affected by different treatments

The mean sunflower seed yield equivalent was 2195 kg ha^{-1}.

The sunflower + redgram association in different intrarow sunflower spacings significantly increased sunflower seed yield equivalent as compared to their sole crops indicating complementary interactions for natural resources like solar radiation, moisture and nutrients. The sunflower seed yield equivalent was significantly lower under 2 SF (45 x 15 cm) + 2 RG intercropping as compared to 2 SF (45 x 45 cm) + 2 RG intercropping which inturn was found to be on par with sunflower + redgram association at 22.5 and 30 cm intrarow sunflower spacings. It would be, therefore, advisable to adopt sunflower + redgram association at 22.5, 30 and 45 cm intrarow spacings of sunflower. Biradar *et al.* (1988), Jadhav *et al.* (1991) and Jadhav *et al.* (1992) observed that base crop grain yield equivalent was more under intercroppings than sole crops.

4.6.5 Net Monetary Returns and Benefit:Cost Ratio:

The mean net monetary returns were Rs. 20189 ha^{-1} and benefit:cost ratio was 4.88.

The sunflower + redgram intercroppings at 22.5, 30 and 45 cm intrarow spacings produced significantly higher net monetary returns and benefit:cost ratio than sole crop of either sunflower or redgram. This was attributed to the harvesting of natural resources like solar radiation, moisture and nutrients more efficiently under intercropping systems than their component crops. Thus, monetary benefits were more under intercropping system than either of their component crops. It would, therefore, be beneficial to adopt sunflower + redgram association at any of the 22.5, 30 and 45 cm intrarow spacings of sunflower. These results corroborate the findings of Biradar *et al.* (1988), Salomibina *et al.* (1992) and Jadhav *et al.* (1992). The sunflower + redgram association under square geometry of sunflower (45 x 45 cm) significantly increased the net monetary returns and benefit:cost ratio than the sunflower + redgram association at 15 cm intrarow spacing of sunflower because of wider intrarow sunflower spacing under former intercropping helped for harvesting the natural resources more efficiently.

4.6.6 Land Equivalent Ratio (LER):

The mean LER was 1.20.

The sunflower + redgram association under square geometry of sunflower produced significantly more LER than their component sole crops and 2 SF (45 x 15 cm) + 2 RG intercropping system. However, former intercropping was on par with sunflower + redgram intercropping where sunflower was planted at 22.5 and 30 cm intrarow spacings. The yield advantage under sunflower + redgram intercroppings at 22.5, 30 and 45 cm intrarow spacings of sunflower was 31, 32 and 40 per cent, respectively. The higher yield advantage under these intercropping systems was mainly attributed to the efficient utilization of natural resources like solar radiation, soil moisture and nutrients because of complementary interactions between component crops. It would be, therefore, advisable to adopt sunflower + redgram intercropping at any of these intrarow spacing ranging from 22.5 to 45 cm to obtain the maximum yield advantage. Similar results were reported by Natarajan and Willey (1980a)and Salomibina *et al.* (1992).

5. SUMMARY AND CONCLUSIONS

5. SUMMARY AND CONCLUSIONS

5.1 SUMMARY:

The present investigation "Effect of planting density of sunflower intercropped with redgram on light use efficiency of intercropping system under rainfed conditions", the results of which have been reported and discussed in the preceding chapter was planned with a view to find out the light use efficiency (LUE) of sunflower + redgram intercropping system. The present investigation was conducted at the Agricultural College Farm, Pune-5 during *kharif* season of 1991.

The soil of the experimental field was vertisol (deep black) in nature with an uniform depth of 100 cm. It was clayey in texture, low in available nitrogen and phosphorus and fairly rich in potash. It was neutral to slightly alkaline in reaction. The soil moisture content of 0-30 cm soil layer at field capacity and permanent wilting point was 34.62 and 18.30%, respectively, with a bulk density of 1.24 g cm^{-3}.

The experiment was laid out in a randomized block design with four replications. Six cropping systems, *viz.*, sole sunflower, sole redgram, intercroppings of 2 SF (45 x 15 cm) + 2 RG, 2 SF (45 x 22.5 cm) + 2 RG, 2 SF (45 x 30 cm) + 2 RG, 2 SF (45 x 45 cm) + 2 RG were under study. The gross and net plot size was 5.4 x 5.4 m and 3.6 x 3.6 m, respectively. The sunflower and intercropped redgram was dibbled on June 27, 1991 at a distance as per treatments. The sole sunflower and its association with redgram was fertilized with 50 kg N + 25 kg P_2O_5 ha^{-1}, whereas, sole redgram was fertilized with 12.5 kg N + 25 kg P_2O_5 ha^{-1} at the time of dibbling. The sunflower variety Morden and redgram variety BDN-2 were under study.

The season was fairly good for the different crops and satisfactory yields were obtained. Besides yield data, periodical observations on leaf area, leaf area index (LAI) and dry matter production per plant were recorded at an interval of 14 days from the 28^{th} day onwards. The micrometeorological observations included incident PAR and transmitted PAR (TPAR) which were recorded at an interval of 7 days from the 20^{th} day onwards. The difference between incident PAR and transmitted PAR was considered as intercepted PAR (IPAR)

The important findings of the investigation are summarized below.

5.1.1 Micrometeorological Observations:

The intercepted photosynthetically active radiation (IPAR) was significantly the lowest under sole redgram during growing period of sunflower, whereas, it was significantly the highest under the sole sunflower upto the 62^{nd} day. Wider intrarow spacings of sunflower (30 and 45 cm) intercepted slightly more PAR than narrow intrarow sunflower spacings (15 and 22.5 cm) during flowering and grain filling period. After harvest of the sunflower, the sole redgram intercepted more PAR than its association with sunflower in different plant densities. The intercepted PAR (IPAR) under sunflower + redgram intercroppings was improved with increase in the intrarow spacings after harvest of sunflower.

The intercropping of 2 SF (45 x 15 cm) + 2 RG was equally efficient to that of sole sunflower not only in interception of PAR but also in conversion of intercepted PAR to dry matter due to complementary interaction. During advanced crop growth period, the light use efficiency (LUE) of sole sunflower and its association with redgram under different intrarow spacings did not differ much upto harvest of sunflower. After harvest of sunflower, the association ofsunflower + redgram at 30 and 45 cm intrarow sunflower spacings produced somewhat equivalent light use efficiency (LUE) to that of sole redgram indicating that sunflower + redgram under 30 and 45 cm intrarow sunflower spacings could equally be good for light interception resulting in higher yields and monetary benefits.

5.1.2 Studies on Sunflower:

The leaf area per plant of sunflower was the lowest under 2 SF (45 x 15 cm) + 2 RG intercropping system and was the highest under 2 SF (45 x 45 cm) + 2 RG intercropping system. However, reverse trend was observed in case of LAI. The dry matter production per plant was the lowest under 2 SF (45 x 15 cm) + 2 RG intercropping system and was the highest under 2 SF (45 x 45 cm) + 2 RG intercropping system.

The values of yield components, *viz.*, number of seeds and their weight per plant and thousand seed weight were the highest under intercropping of 2 SF (45 x 45 cm) + 2 RG and the lowest under sole sunflower. The intercropping of 2 SF (45 x 30 cm) + 2 RG also produced significantly more values of these yield components than 2 SF (45 x 15 cm) + 2 RG intercropping. The biological and stalk yields were significantly the highest under the sole sunflower. The intercropping of 2 SF (45 x 15 cm) + 2 RG also produced significantly more biological and stalk yields than 2 SF (45 x 45 cm) + 2 RG intercropping. However, seed yield was not influenced due to sole and intercropping systems.

5.1.3 Studies on Redgram:

The leaf area production was significantly more under sole redgram throughout the crop growth period than intercropping systems. The intercropping of 2 SF (45 x 45 cm) + 2 RG significantly increased leaf area as compared to sunflower associated with redgram at closer intrarow spacings.

However, LAI was significantly lower under sole redgram than different intercropping systems upto the 98th day. After this period, it was significantly decreased under 2 SF (45 x 15 cm) + 2 RG intercropping system as compared to sole redgram and its association with sunflower at wider intrarow spacings of 30 and 45 cm. Dry matter production was significantly more under sole redgram and its association with sunflower in square geometry than redgram associated with sunflower at closer intrarow spacings of 15 and 22.5 cm during advanced crop growth period resulting in more seed yield.

The number of seeds and their weight per plant and thousand seed weight were significantly the highest under sole redgram. The values of these yield components were significantly more under 2 SF (45 x 45 cm) + 2 RG intercropping than 2 SF (45 x 15 cm) + 2 RG intercropping system. The biological yield was the lowest under 2 SF (45 x 15 cm) + 2 RG intercropping. Sole redgram and its association with sunflower in square geometry of 45 x 45 cm significantly increased biological yield as compared to other intercropping systems. The seed yield and harvest index was significantly the highest under sole redgram and the seed yield was the lowest under the intercropping of 2 SF (45 x 15 cm) + 2 RG. The stalk yield was significantly more under 2 SF (45 x 45 cm) + 2 RG intercropping and significantly lower under 2 SF (45 x 15 cm) + 2 RG intercropping. The sole redgram produced significantly more stalk yield than its association with sunflower at 22.5 and 30 cm intrarow spacings.

5.1.4 Studies on Cropping Systems:

The leaf area of sole redgram was significantly the lowest upto the 70th day. The leaf area of sole sunflower was significantly less than its association with redgram in different intrarow spacings. After harvest of sunflower, sole redgram produced significantly more leaf area than its association with sunflower. The LAI was significantly the lowest under sole redgram upto the 84^{th} day. The LAI of sole sunflower was significantly less than its association with redgram from the 70^{th} day onwards showing complementary interaction. After harvest of sunflower, the LAI values significantly decreased under intercropping systems at 22.5 and 45 cm intrarow spacings of sunflower as compared to sole redgram and other intercropping systems. The dry matter production was significantly the lowest under sole redgram upto harvest of sunflower. The sole sunflower accumulated significantly the highest dry matter upto the 70^{th} day. After harvest of sunflower, sole redgram and its association with sunflower in square row geometry of 45 x 45 cm produced significantly more dry matter than sunflower + redgram association at 15 and 22.5 cm intrarow spacings.

The sunflower + redgram intercroppings at 22.5, 30 and 45 cm intrarow sunflower spacings significantly increased sunflower seed yield equivalent, net monetary returns and benefit:cost ratio as compared to sole croppings of either sunflower or redgram showing complementary interaction under intercropping systems. It would, therefore, be advisable to adopt sunflower + redgram association at any of the 22.5, 30 and 45 cm intrarow spacings of sunflower.

The yield advantage in terms of LER under sunflower + redgram intercroppings at 22.5, 30 and 45 cm intrarow spacings of sunflower was 31, 32 and 40 per cent, respectively, owing to efficient utilization of natural resources under intercropping systems. Therefore, it would be suggested to adopt sunflower + redgram intercroppings at any of the 22.5, 30 and 45 cm intrarow sunflower spacings.

5.2 CONCLUSIONS:

The broad conclusions are as follows:

1. Sole sunflower intercepted significantly the highest PAR upto the 62nd day. The intercepted PAR was significantly the lowest under the sole redgram during growing period of sunflower and the highest after harvest of sunflower. The IPAR under intercropping systems was improved with increase in intrarow spacings after harvest of sunflower.

2. The LUE of sole sunflower and its association with redgram under different intrarow spacings did not differ much during growth period of sunflower. After harvest of sunflower, the association of sunflower + redgram at 30 and 45 cm intrarow sunflower spacings produced equivalent LUE to that of sole redgram indicating that intercropping under these intrarow sunflower spacings could equally be good for light interception resulting in higher yields and monetary benefits.

3. The sunflower + redgram intercropping at sunflower plant population of 49,382 (22.5 cm), 37,037 (30 cm) and 24,691 (45 cm) plants/ha significantly increased sunflower seed yield equivalent, net monetary returns and benefit:cost ratio compared to sole cropping of either sunflower or redgram showing complementary interactions. It would, therefore, be advisable to adopt sunflower + redgram intercroppings at any of plant population of sunflower at 49,382, 37,037 and 24,691 plants/ha.

4. The yield advantages under sunflower + redgram association at sunflower plant population of 49,382 (22.5 cm), 37,037 (30 cm) and 24,691 (45 cm) plants/ha was 31, 32 and 40 per cent, respectively, suggesting adoption of sunflower + redgram intercroppings at these plant population.

These results are, however, based on one year's experimentation, therefore, for the confirmation of these results investigations needs to be repeated with studies on soil, canopy and air temperature and periodical fluctuations in soil moisture.

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APPENDIX

APPENDIX

The following prices were considered for calculating cost of cultivation.

Sr. No.	Particulars	Rates (Rs.)
1	a) Man and woman	20 day^{-1}
	b) Tractor charges	300 ha^{-1}
2	Bullock pair	50 day^{-1}
3	a) Sunflower seeds	11 kg^{-1}
	b) Redgram seeds	9 kg^{-1}
4.	Rhizobium culture	5/250 g (bag)
5.	Urea	2500 ton^{-1}
6.	Single super phosphate	920 ton^{-1}
7.	BHC 10%	4.50 kg^{-1}
8.	Supervision charges	@ 10% on production cost
9.	Interest on capital	@ 13% for half life period of the crop
10.	Land revenue	200 ha^{-1}
11.	Rental values on land	@ 1/6 value of gross receipts
12.	Hire charges on Implements	150/crop/year

VITA

VITA

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of

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in

AGRICULTURAL METEOROLOGY

1992

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