PRODUCTIVITY OF SUNFLOWER-SOYBEAN INTERCROPPING SYSTEM AS INFLUENCED BY CANOPY ARCHITECTURE, CO_2 FERTILIZATION, TRIACONTANOL, LIGHT ENRICHMENT, LIME AND ORGANIC AMENDMENTS

H. S. SHIVARAMU

DEPARTMENT OF AGRONOMY
UNIVERSITY OF AGRICULTURAL SCIENCES
BANGALORE

1990

PRODUCTIVITY OF SUNFLOWER-SOYBEAN INTERCROPPING SYSTEM AS INFLUENCED BY CANOPY ARCHITECTURE, CO_2 FERTILIZATION, TRIACONTANOL, LIGHT ENRICHMENT, LIME AND ORGANIC AMENDMENTS

H. S. SHIVARAMU

Thesis Submitted to the
University of Agricultural Sciences, Bangalore
in partial fulfilment of the requirements
for the award of the Degree of

DOCTOR OF PHILOSOPHY (AGRICULTURE)
in
AGRONOMY

BANGALORE NOVEMBER 1990

Dedicated to

My

Late Mother

DEPARTMENT OF AGRONOMY

UNIVERSITY OF AGRUCULTURAL SCIENCES

BANGALORE

CERTIFICATE

This is to certify that the thesis entitled **"PRODUCTIVITY OF SUNFLOWER-SOYBEAN INTERCROPPING SYSTEM AS INFLUENCED BY CANOPY ARCHITECTURE, CO_2 FERTILIZATION, TRIACONTANOL, LIGHT ENRICHMENT, LIME AND ORGANIC AMENDMENTS"**, submitted by **Mr. H.S. SHIVARAMU**, for the degree of **DOCTOR OF PHILOSOPHY (AGRICULTURE) IN AGRONOMY**, of the University of Agricultural Sciences, Bangalore is a record of research work done by him during the period of his study in this University under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

BANGALORE

November, 1990

15-11-1990.

K. Shivashankar
Professor & Head
Department of Agronomy
GKVK, Bangalore - 560 065

APPROVED BY:

Chairman: 27-12-90.
K. Shivashankar

Members: 1. M. Udaya kumar

2. R. Siddaramappa

3. M.K. Jagannath

ACKNOWLEDGEMENT

I place on record my deep sense of gratitude to Dr. K. Shivashankar, B.Sc. (Agri.) (Hons.), M.Sc. (Agri.), M.S., D.Sc. (Leuven), Belgium, Professor and Head of the Department of Agronomy, University of Agricultural Sciences, Bangalore, and Chairman of my Advisory Committee, for his invaluable guidance, helpful suggestions, sustained interest and incessant encouragement rendered during the course of my studies and research.

I am equally grateful to the members of my Advisary Committee, Dr. M. Udaya Kumar, Professor of Crop Physiology, GKVK, UAS, Bangalore; Dr. R. Siddaramappa, Extension Co-ordinator, Hebbal, UAS, Bangalore and Mr. M.K. Jagannath. Statistician, GKVK, UAS, Bangalore for their encouragement during the course of my research and valuable suggestions while preparing the thesis.

I am also grateful to Dr. K.T. Krishnegowda, Agronomist, Dryland Agriculture Project; Mr. O.M. Krishnappa, Field Assistant; Mr. Swamygowda, Lab. Assistant; Mr. Krishnappa, Assistant Professor of Statistics; Mr.C. Manjunath, System Analyst Assistant; Dr. M.A. Shankar, Assistant Professor of Sericulture, Mr. Patric Shivapadam, Lab. Assistant; Mr. Ramalingegowda, Field Assistant; some for their expertise and other for their immense help in providing me the necessary materials and equipments during my study and research.

With great affection, I thank all my friends, for their Sincere and unstinted help in one or the other way during the period of this endeavour. My sisterly love and affection are due to Miss B.N. Poonam Gowda for neat drawing of some of the figures.

The Indian council of Agricultural Research, Senior Fellowship during the period of my study is gratefully acknowledged.

I also acknowledge the sunflower Scheme for providing necessary seed material and the Department of Agricultural Microbiology for supplying Rhizobium culture during the investigations.

To my parents, brothers and Cousin Mr. K.Narayanagowda, whose positive influences on my life are not forgotten; I extend my love and appreciation.

Finally, I thank my God, through whom all things are possible, and without whose blessings of life and health, this investigation would not have bean possible.

Bangalore

November 15th, 1990 (H.S. SHIVARAMU)

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

INTRODUCTION

I. INTRODUCTION

The world's largest oilseed growing country is India and paradoxically, it is India which imports large quantities of edible oils. Till 1965, India was an exporter of oilseeds and oils, and later, consequent to decreased production of oilseeds commensurate with the raise in population levels and hence increased demand for oil, the import of oil kept raising from year to year reaching a maximum of two million tonnes worth rupees 1000 crores during 1987-88. Therefore, currently the urgent task is to intensify oil production, firstly, by spreading the area under oil seed crops in states other than Madhya Pradesh, where soybean is concentrated and Karnataka and Maharastra where sunflower has caught up well, and secondly by increasing the productivity of these crops through sound agronomic practices.

The production of oilseeds and pulses is largely determined by the monsoons. One of the ways to achieve higher yields of oilseeds and pulses in a given season and greater stability in their yields over different seasons is 'intercropping'. Higher productivity and returns in intercropping systems depend on the selection of compatible crops that complement each other in utilising the basic resources of light, nutrients and water. Besides, enhanced productivity is also determined by "Canopy Architecture" of the intercropping system adopted with optimised plant populations and planting geometry. The performance of sunflower and soybean in an intercropping system and the complementarity of these crops at different plant populations and planting patterns needs to be examined as an attempt towards increasing oil yield per unit area.

The potential yields and income of intercropping systems could be further augmented by adopting several agronomic practices. Use of organic manures and amendments is an established practice to improve the physical, chemical and biological properties of soil. Besides, organic amendments such as paddy straw and maize stover, and inorganic amendments like unburnt lime ($CaCO_3$) have the potential to enrich CO_2 of the crop canopy thereby increasing photosynthesis, and these need to be evaluated so that the productivity of the intercropping system is enhanced. Further, organic amendments support and sustain the important biological process of N_2 fixation. However, the time of application of these amendments to make use of the released CO_2 efficiently by the crop and for effective promotion of nodulation has not been studied.

In sunflower, one of the major problems is seed filling. Some of the agronomic practices viz., nutrition especially N, P, K, B, Ca and S, hand pollination, spraying of growth regulators like NAA, GA and auxin transport inhibitor like triiodo benzoic acid (TIBA) to heads have not been found completely successful in achieving seed filling in sunflower. However, other factors influencing the growth and yield of crops like light intensity and CO_2 concentration of the aerial environment and the new growth promoter "Triacontanol" in improving the seed filling in sunflower have not been studied in great details under field conditions. Further, at high density croppings such as intercropping systems, inadequate light at the middle and lower strata of the intercropped canopy greatly affects the productivity and this problem further aggravates during kharif season which is characterised by several cloudy and rainy days.

Therefore, with these points in view, the investigation entitled "Productivity of sunflower-soybean intercropping system as influenced by canopy architecture, CO_2 fertilization, triacontanol, light enrichment, lime and organic amendments" were conducted at Main Research Station of the University of Agricultural Sciences, Hebbal, Bangalore, with the following objectives:

1. To optimize crop canopy architecture through plant population levels and planting patterns of component crops of sunflower-soybean intercropping system;

2. To study the effect of carbon dioxide fertilization, light enrichment and triacontanol application on growth and yield of sunflower and soybean intercrops, and

3. To compare the benefits of organic amendments maize stover and paddy straw and inorganic amendment lime, with that of CO_2 enrichment on the growth and yield of the intercropping system of sunflower and soybean, and to study their effect on physical, chemical and biological properties of soil.

REVIEW OF LITERATURE

II. REVIEW OF LITERATURE

The review of literature pertaining to this investigation entitled "Productivity of sunflower-soybean intercropping system as influenced by canopy architecture, CO_2 fertilization, triacontanol, light enrichment, lime and organic amendments" encomposes intercropping, its advantages and disadvantages, crop density and planting pattern of intercrops, physiological process, the growth and yield of crops as influenced by the carbon dioxide fertilization, light enrichment and triacontanol application, sources and their potentials of field scale CO_2 enrichment, and changes in physical, chemical and biological properties of soil by organic and lime amendments.

2.1 Intercropping, canopy density and architecture of intercrops

Intercropping has been defined by many workers in various ways. According to Tarhalkar and Rao (1975) it is "growing together two or more species with the assumption that two species could exploit the environment better than one".

Intercropping systems have proved beneficial through high biomass and grain production per unit area in a given season, without the use of costly inputs, but by better use of growth resources viz., light

(Lakhani, 1976; Sivakumar and Virmani, 1980), nutrients (Dalal, 1974; Soundararajan, 1978) and moisture (Lakhani, 1976; Shivaramu, 1987). Legumes in the mixture benefit the associated non-legumes as they provide a portion of biologically fixed nitrogen to non-legumes (Tarhalkar and Rao, 1975; Hiremath, 1979; Chandel *et al*., 1988) and the soil nitrogen content is increased thus maintaining soil fertility (Whitehead, 1970). In rainfed farming conditions, intercropping reduces the risk of crop failure and stabilizes the income from the farm (Daniel, 1955; Dayal *et al*. 1967) and it reduces pests and diseases, lodging, soil erosion and damage of high wind velocity (Yagnanarayana Aiyer, 1949; Johnston *et al*. 1978; Rao and Shetty, 1976; Siddoway and Barnett, 1976; Radke and Hagstrom, 1976).

Intercropping poses a problem if there is high degree of mechanization or where the component crops have different requirements for fertilizer, herbicides and pesticides. Thus in rainfed agriculture of the tropics with subsistence farming, the farmer often has a strong inherent preference to it. Hence, a further research on intercropping is helpful for the small farmer of limited means who is most likely to benefit.

2.1.1 Crop density and canopy architecture of intercrops

One of the most important aspects which has emerged from recent studies is that where intercropping gives yield advantage, the total population optimum may be higher than that of either of the sole crops (Shelke 1977; Frayman and Venkateswaralu, 1977; Willey and Rao, 1977).

Robinson (1984) reported that reducing the plant population of sunflower from 52,000 plants per ha in sole cropping to 22,000 plants per ha and introducing a row of soybean in between the two rows did not decrease the yield of sunflower significantly, and an additional yield of soybean was obtained.

Shafshak et al. (1986) observed an increased LAI, LER and relative crowding coefficient with increasing plant density of sunflower+soybean, to higher than either sole crops. The yield of sunflower was in the range of 46 to 66 per cent of sole crop and that of soybean was 51 to 80 per cent, depending on the plant population and planting pattern of intercrop.

Compatibility and complementarity between the two component crops in intercropping depends on the morphological characters, maturity differences, planting pattern, row proportion and spacing adopted altogether influencing the canopy architecture and light interception. In intercropping, better light utilization is one of the factors for yield advantage. In some intercropping systems there will be better distribution of leaf area over time, hence temporal use of light; in other intercropping systems better distribution of leaf area within the canopy profile (vertical distribution of leaves), hence spatial use of light.

Trenbath (1974) reviewed the canopy structure of differrent crop mixtures in relation to light interception and concluded that a taller component with erect leaves and a shorter component with prostate leaves is an ideal combination. In this respect, sunflower was found to be an ideal intercrop with legumes like soybean, groundnut, cowpea, blackgram and greengram because of its non-branching erect stem and shallow root system, whereas legumes are branched, short statured and spreading in habit with deep roots (Narwal and Malik, 1985; Singh and Singh, 1977).

Crookston and Kent (1976) suggested crop mixtures of different inherent response to light intensity like top canopy consisting of a component with high light requirement and bottom of the canopy with low light requirement. In this respect also, sunflower+soybean intercrop is a better combination.

Planting geometry plays an important role in modifying the canopy structure and light interception, thus profoundly influencing photosynthesis, the drymatter production and yield of crops. Normally sunflower is planted in solid row spacing of 45 to 60 cm apart and intra row spacing of 20 cm, depending on the genotype, moisture and fertility status of soil. Planting in paired rows without sacrificing the sunflower plant population offers scope for inclusion of compatible crop in between, since pairing of rows opens up the canopy and increases the transmission of light within the canopy. Singh and Singh (1977) found that paired row planting of sunflower and introducing two rows of legume intercrops (groundnut, cowpea or greengram) at Jodhpur was superior than uniform alternate rows of sunflower and legumes. Growing sunflower in 120/30 cm paired rows and three rows of legumes intercrops in between the two pairs gave highest return than 1:1 or 1:4 (Sunflower : legumes) row proportions at Belgaum (Umapathy et al., 1980). At Bangalore, intercropping in alternate rows of 30 cm apart reduced the seed yield of sunflower by 29 per cent and that of soybean by 47 per cent compared to their sole crops, but the total productivity was higher from the system (Shanthamalliah et al., 1978). Chandrasekar and Morachan (1979) adopted the paired row planting of sunflower (60/30 cm x 22.5 cm) and a row of cowpea or two rows of groundnut were introduced in between the two pairs. In the system the yield of sunflower was on par with that of pure sunflower and the yield of cowpea or groundnut was extra. Mohan Kumar (1989) reported that groundnut+soybean intercropping in 4:2 row proportion produced highest total oil yield and gross income compared to either sunflower+soybean or sunflower+groundnut intercropping systems in rice fallows in Bangalore.

Narwal and Malik (1985) reported that intercropping of legumes viz., soybean, greengram cowpea and mothbean with sunflower in alternate rows, had little effect on the growth of sunflower.

Shafshak et al. (1986) reported that among the different planting patterns tried, 1:1 row proportion of sunflower and soybean gave highest number of pods per plant and seed per plant of soybean, whereas 2:4 row proportion gave highest leaf number per plant, 100 seed weight and largest head of sunflower.

Sunflower and soybean intercropped in a strip of 1.66 - 2.32 m wide in ratios of 3:7 or 1:1, gave an average 40 per cent more income and also reduced disease infestation of sunflower with rust, brown spot and blight, considerably (Anon., 1988).

Finlay (1975) observed the yield reduction in soybean and maize to the extent of 61 and 9 per cent, over their respective sole crops when they are grown in separate alternate rows. However, the LER was not much affected (1.30 to 1.31) by planting patterns.

From the review on intercropping, it can be generalized that the yield of soybean is much affected than its associated sunflower or maize. Roquib et al., (1973) reported that the height of companion crop determined the amount of yield reduction in soybean. It was attributed to shading effect of sunflower or any other tall growing companion crops on soybean (Dalal, 1977; Srivastava, et al. 1980).

2.2 Effect of Carbon dioxide fertilization on crops

CO_2 being one of the important inputs in photosynthesis, any change in the ambient CO_2 concentration will have a profound effect on the photosynthetic characteristics of the plants. Currently, green plants grow in an atmosphere of about 335 ppm of CO_2. Many scientists postulated an increase in photosynthesis and plant production by CO_2 enrichment. As early as 1804, De saussure reported that peas exposed to an atmosphere of 8 per cent CO_2 grew better than those in ambient air.

2.2.1 Effect of CO_2 fertilization on physiological processes

Gaastra (1963) showed that CO_2 is a limiting factor and that at full sunlight the photosynthetic carbon fixation rate is not saturated at ambient CO_2 levels. Therefore, CO_2 enrichment was found to increase the photosynthetic rate of many crops viz., soybean (Ackerson, et al., 1984; Huber et al., 1984; Havelka et al., 1984), sunflower (English et al., 1979; Dhawan et al., 1981), Plantago major (Poorter et al., 1988) and in many green house plants (Mortensen, 1984). In these studies, increase in photosynthetic rate was attributed to increase in substrate levels for increase in rubisco activity or due to substantial increase in specific leaf weight. In contrast, a decrease in photosynthetic rate for plants grown at higher CO_2 concentration was reported by Spenser and Bowes (1986) in water hyacinth and in cotton by Sasek et al., (1985) either due to increased mesophyll resistance (Bruggunik, 1984) or stomatal resistance (Peet et al., 1986) or due to starch accumulation (Sasek et al., 1985).

Higher concentration of CO_2 not only increases photosynthesis but also competes with oxygen to bring down photorespiration. Foch et al. (1979) reported a decrease in photorespiration to total photosynthesis ratio with increasing CO_2 concentrations. Hicklenton and Jolliff (1980) found that carbon dioxide enrichment helped to suppress the activity of RuDP oxygenase and reduce the formation of phosphoglycollate and thus reducing photorespiration. Valle et al. (1985) noticed a significant decrease in CO_2 compensation point in soybean leaves adopted to high CO_2 levels indicating a decrease in photorespiration.

Elevated CO_2 increases stomatal resistance and therefore reduces transpiration. Sionit et al. (1981) suggested that increasing CO_2 concentration may induce wheat plants to osmoregulate more effectively and possibly enable them to adopt better to subsequent water stress. Morison and Gifford (1983) noticed that the increase in transpiration efficiency at higher CO_2 level was relatively higher in C_3 plants than C_4 plants. Reduced transpiration was seen in soybean by Huber et al. (1984) from 140 mg H_2O $m^{-2}S^{-1}$ at ambient level to 80 mg m^{-2} S^{-1} at 600 ppm of CO_2. Jones et al. (1985) observed an increase in relationship between CO_2 levels and transpiration rates in soybean plants with instantaneous response to changes in CO_2 concentration.

On the contrary, Valle _et al_. (1985) failed to notice a significant decrese in transpiration rate of soybean plants grown at elevated CO_2 level.

These studies indicate increases in photosynthesis and decreases in transpiration due to CO_2 enrichment . As a consequence WUE generally increases. Rogers _et al_. (1983) reported that CO_2 enrichment behaved as an ideal anti transpirant because of decreased transpiration without affecting the influx of CO_2 through the stomata. Valle (1985) reported a doubling of WUE in soybean leaves at 660 ppm of CO_2, even though there was no significant decrease in transpiration rate. Similar results were also obtained by Jones _et al_. (1985) in soybean leaves. In sunflower, Morison and Gifford (1984) reported that due to doubling of CO_2 concentration in the air increased the WUE by 50.7 per cent. Hence the increase in WUE of plant at elevated CO_2 levels make them more drought resistant. Sionit and Patterson (1985) noticed that under stress conditions, net photosynthesis did not decline as rapidly at high CO_2 as at low CO_2 which could be due to the maintenance of turgor at high CO_2 concentrations. Marks and Strain (1989) worked on asters (C_3) and broomsedge (C_4) and concluded that the C_3 plants would be better competitors during well watered as well as water limited conditions under elevated CO_2 concentrations.

De and Sulaiman (1950) observed higher N fixation in algal cultures aerated with two per cent CO_2 air than the one aerated with ambient air. Richie and Evans (1962) showed that Rhizobium sp require CO_2 for growth and provided a conclusive evidence that Rhizobium japonicum cells from soybean nodules contain very active PEP carboxylase and propionyl-CoA carboxylase enzyme. Hardy and Havelka (1973) found four fold enhancement in N_2 fixation by CO_2 enrichment of soybean due to doubled specific activity of nodules, doubled nodule fresh weight. The source-sink relationship between photosynthesising leaves and nodules was shown by Shivashankar (1976) and obtained higher nitrogenase activity when soybean plants were subjected to 1000 ppm CO_2.

Increase in respiration rate at elevated CO_2 concentration has been reported by Potvin and Strain (1985) in Eleusine indica and Echinocloa crusgalli. Hrubec et al. (1985) found that dark respiration was enhanced in young leaves of soybean and not in mature ones indicating the differential effect of CO_2 enrichment in different plant parts. Gifford et al. (1985) studied the response of three species of plants and found that the root respiration of CO_2 enriched wheat plants was some times reduced. In sunflower, respiration was enhanced and in mungbean no significant difference was found.

Varying reports of effect of high CO_2 on senescence have been given. Sionit et al. (1981) noticed that leaves of wheat plants grown in higher CO_2 senesce four days earlier. Whereas, Hardy and Havelka (1975) reported delayed senescence in soybean, probably because, the high CO_2 enabled nodules to fix nitrogen faster, delaying extraction of nitrogen from the leaves.

2.2.2 Effect of CO_2 fertilization on growth and yield

There is a large body of information regarding the effect of CO_2 concentration on dry matter (DM) accumulation in plants. CO_2 enrichment increased DM production in C_3 cereal crops like wheat (Gifford, 1979), oil seed crops like soybean and sunflower (Shivashankar et al., 1976; Havelka et al. 1984), vegetable crops like cucumber and cabbage (Slack and Hand, 1985; Heij et al., 1984) fruit crops like oranges and tomatoes (Downton et al., 1987; Calvert and Slack 1975), root crops like casava and potato (Imai, et al., 1984; Ku and Edward, 1977). Faster vegetative growth of forest nurseries (Zimmerman et al., 1970). In addition to food crops and crops of commercial importance, which would gain advantage out of enriched CO_2 concentrations, the weeds like water hyacinth and wild rice have been reported to accelarate their growth rates and produce greater DM (Poorter _et al_., 1988; Potvin and Strain, 1985).

In soybean, the growth analysis was done to reason out the increased DM at higher CO_2 concentrations and observed that it was due to increased leaf area, leaf area duration and net assimilation rate (Patterson and Flint, 1980; Rogers _et al_., 1983) and due to decreased leaf area ratio and specific leaf area (Patterson and Flint, 1980).

In sunflower, Mauney _et al_. (1978) analysed the effect of CO_2 on growth, at vegetative, reproductive and maturity stages and observed that at vegetative stage the NAR and RGR were higher in CO_2 enriched treatment thereby the DM was increased. At reproductive stage also the DM production and NAR were higher due to CO_2 fertilization. Whereas, at maturity stage the total DM was almost same in CO_2 enriched and in control due to the fact that the duration of sunflower was reduced by ten days by CO_2 enrichment. They further reported that the reduction in duration due to CO_2 fertilization is common in determinate types where the entire stem apex is ended with an inflorescence. On contrary, Morison and Gifford (1984) reported an increase in dry weight (61.5%) and specific leaf weight (11.3%) due to CO_2 enrichment.

The higher DM yield due to CO_2 fertilization usually leads to increase in seed yield. But the extent of increase in seed yield depends on the growth stage and duration of enrichment. Cooper and Brun (1967) recorded an increased seed yield from 24.7 g to 38.9 g per plant due to CO_2 enrichment throughout the crop growth stage. Whereas, Hardman and Brun (1971) studied the CO_2 enrichment effects at different stages of crop growth and obtained an increase in seed yield by 20 per cent when enrichment is made during flowering, 37 per cent when enrichment is made from 50 per cent flowering to harvest and 50 per cent increase through continous enrichment. Similarly, Havelka _et al_. (1984) obtained 56 to 81 per cent increase in seed yield of soybean varieties by CO_2 fertilization due to increase in the number of seeds per unit area and harvest index. Ackerson _et al_. (1980) reported that soybeans continously exposed to higher CO_2 exhibited an 80 per cent increase in seed yield over control.

An extensive review by Kimball and Idso (1983) revealed that due to doubling of the present CO_2 level which is expected by 2025 AD the yield of agricultural crops, on an average will increase by 36 per cent. But on the climate point of view, several theoretical models have predicted that the doubling of atmospheric CO_2 concentration will increase the earths temperature by 2-3^{0}C which could seriously upset the ecological balance. However, recent empirical evidence (Dahlman, et al., 1985) suggests that the warming may only be about 0.25^{0}C due to doubling of CO_2. If this is the case, the effect of CO_2 on agricultural crops is beneficial because of increased crop yields and decreased water use efficiency. Hence according to Dahlman et al. (1985) the elevated CO_2 is regarded as a resource rather than a conventional air pollutant.

2.2.3 Response of C_3 and C_4 plants to CO_2 fertilization

Two common types of crop plants (C_3 and C_4) respond some what differently to changes in CO_2 concentration. Wong (1979) reported that C_3 crop (cotton) would respond better than C_4 crop (maize) to elevated CO_2 levels. Carlson and Bazzas (1982) observed that C_4 (amaranthus) does not respond to higher CO_2 than C_3 plants which have responded very well upto 1200 ppm of CO_2. Several biochemical and morphological differences exist between these plants, but one of the main reasons is that C_4 plants fix CO_2

first through ribulose 1, 5-diphosphate carboxylase, whereas C_3 plants fix CO_2 first through phosphoenol pyruvate (PEP) carboxylase (Slack and Hatch, 1967). Another reason is that C_4 plants appear to close their stomata in response to increasing CO_2 concentration to a greater extent than C_3 plants. Gifford (1970) found that stomata of maize close above a concentration of 400 ppm CO_2 at a rate proportional to the increase of CO_2, thus counterbalancing the effects of increased CO_2 levels in the ambient air.

Hence, leaves of C_3 plants do have a better potential for response to increased CO_2 than those of C_4 plants because their stomata do not close readily with increasing CO_2. Besides, increasing CO_2 may inhibit photorespiration in C_3 plants and photosynthetic enzymes in these plants may be more responsive to higher internal concentration of CO_2.

2.2.4 Sources of CO_2 and their feasibility of field scale enrichment

For CO_2 enrichment, a source that is free of contaminants, readily available at economically cheaper rate and effectively dispensable to the crop is needed.

2.2.4.1 Pure CO_2

The CO_2 enrichment method has the fewest side effects but yet it poses problems in injection of pure CO_2 from pressurized tanks of liquid CO_2 directly in to the required site besides being costly. It can be used to raise high value crops in green house.

2.2.4.2 Non traditional sources of CO_2

The CO_2 produced as byproducts of various industries can be used. But CO_2 gas may be contaminated with pollutants like ethylene, SO_2, NO_2, CO etc.

2.2.4.3 Combustion of fossil fuels

The CO_2 produced by combustion of fossil fuels is another source. But major problems can arise with combustion process and the water vapour generated during combustion can complicate humidity control inside a green house.

2.2.4.4 Acid treatment of unburnt lime

The CO_2 released during acid treatment of unburnt lime ($CaCO_3$) can be used for CO_2 enrichment, but to monitor the reaction process to supply CO_2 at a correct dose continuously for certain period during the day is difficult.

2.2.4.5 Biologically derived CO_2

The major degradatory product of organic matter decomposition is CO_2. Utilizing this biologically derived CO_2 is another way of CO_2 enrichment (Shivashankar et al., 1976). It was observed by Shivashankar et al. (1976) that incorporation of straw increased CO_2 content of soil air and improved the growth and yield of crops, hence they concluded straw incorporation as a partial substitution to the expensive CO_2 enrichment.

Katyal (1977) and Geetha Kumari (1989) in their studies observed an increase in CO_2 evolution with the addition of organic amendments. Evolution of CO_2 was highest in maize stalk compared to peat and compost when applied to a sandy loam soil (Benedetti et al., 1982). Maize yield was favourably influenced by evolution of CO_2 from incorporated FYM, straw mulch and chopped straw (Suri and Goswamy, 1982). Gupta and Tripathi (1986) observed a linear relationship between rate of carbon dioxide evolution and organic carbon content of soil; CO_2 production was found more in poultry manure treated plots. A pot culture on CO_2 evolution pattern as influenced by straw and azolla incorporation showed an increase in CO_2 concentration at the soil surface (0-5 cm) ranging from 73 to 120 ppm at 31 days after incorporation of azolla (10 t/ha) and /or straw (2 t/ha) (Shivashankar and Krishnaiah, 1986). Carbon dioxide concentration measured at 45 days after planting inside the canopy (15 cm above the soil surface) of ragi and soybean pure and intercrops showed 27 to 55 ppm higher CO_2 in treatments where organic amendment (4 t/ha) was applied at sowing over control (Geetha Kumari, 1989).

The evolution of CO_2 depends on many soil factors like aeration, moisture content, type of organic matter and its content, C:N ratio, pH etc., which altogether affect the microbial activity in the soil. One of the early workers who used CO_2 evolution rates to study organic matter decomposition was Wollny (1888) who found CO_2 release to be in proportion with the organic matter content in soil. According to Tenney and Waksman (1930) under anaerobic condition decomposition of all organic material is slower and it is much slower if the plant material consist of more resistant components (Hemicellulose and Lignin); hence CO_2 production is less. Moisture content also plays an important role in the rate of decomposition as the decrease in soil moisture content also decreases the CO_2 evolution. Raymond *et al*. (1977) reported a moisture status of 60 to 80 per cent of field capacity as favourable for optimum rate of decomposition.

Prasanna Kumar (1983) obtained more CO_2 evolution in soil amended with straw compared to control in ~~his~~ laboratory incubation studies. He reported that though mineralization was more with 1.0 per cent carbon than with 0.5 per cent, the rate of mineralization was not proportional to the level of carbon added. Application of organic residues like maize stover or ragi husk brought remarkable improvement in the biological activity in terms of the activity of dehydrogenase enzyme and thus the CO_2 evolution (Venugopal, 1988; Geetha Kumari, 1989).

Type of organic residues greatly influence the rate of CO_2 evolution. Gaur et al. (1970) reported higher CO_2 production rates in maize stover as compared to cowpea straw and dung. Evolution of CO_2 was highest in maize stalk compared to peat and compost when applied to a sandy loam and incubated for 130 days at 30^0C under optimum water content (Benendetti et al., 1982). Reinertsen et al. (1984) reported that microbial biomass production and wheat straw decomposition rates in the early stages were largely dependant on the size of the water soluble carbon pool and the extent of nitrogen immobilization was directly related to the available carbon in the straw residue.

2.2.4.6 Trapping of dark respiration CO_2

A new technique to elevate the CO_2 levels using the CO_2 released during dark respiration of plants and soil respiration. Sudha (1990) studied the response of seven tree species to elevated CO_2 by adopting this technique in which the CO_2 released during night time was trapped by covering the dug out trenches with polythene structure. The forest seedlings inside were observed to have faster growth with increased plant height, leaf number, leaf area and drymatter accumulation.

2.3 Effect of organic amendments on physical, chemical and biological properties of soil

The CO_2 supply to the crop canopy by organic matter during its decomposition process is one among many beneficial effects like on soil fertility and crop yield. Application of farm yard manure or straw increased the total nitrogen, potash and organic carbon content of soils (Biswas _et al_., 1971; Chaudhary _et al_., 1981; Kuduk, 1978; Shivashankar, 1986; Venugopal and Shivashankar, 1989) and it is an important source of secondary and micronutrients (Katyal and Sharma, 1979; Parsa _et al_., 1979; Prasad and Singh, 1981). Increase in hydraulic conductivity (Biswas _et al_., 1970), Soil aggregation (Balasubramanian _et al_., 1972;

Gattani *et al*., 1976; Laddha *et al*., 1984 and Dormaar and Summerfeldt, 1986), cation exchange capacity (Kapland and Ester, 1985), water holding capacity (Anon., 1979; Anon., 1986), lowering the bulk density (Havangi and Mann, 1979), crust strength (Anon., 1986) were observed by the application of organic amendments.

Thus, organic amendment improves soil fertility and productivity, thereby having positive influence on growth and yield of crops. Favourable effect of application of paddy straw on soybean yield was reported as early as 1929 by Thortan. Shivashankar *et al*. (1975) reported a reduction in plant height of soybean by straw incorporation but grain yield increased progressively from 1.00 t in control to 1.96 t and 2.29 t ha^{-1} with 2 and 4 t ha^{-1} of wheat straw, respectively. An increase in leaflet number, dry weight, chlorophyll content and dry matter production per plant and increase in per cent N, protein content of seeds with a concurrent increase in soybean yield was observed with 3 and 6 t ha^{-1} of straw by Shivashankar *et al*. (1976). Shivashankar and Shantaram (1980) obtained higher yield of soybean with 3 t ha^{-1} of paddy straw incorporation both under rainfed and irrigated conditions. In fingermillet, water hyacinth incorporation at the rate of 6 t ha^{-1} at 2 to 4 weeks prior to transplanting increased the grain yield from

23 q to 34.5 q ha^{-1} (Shivashankar, 1986). On contrary, Norman and Krampitze (1946) observed a reduction in dry matter production and N content of soybean plants by straw incorporation.

Promotion of N_2 fixation is another favourable effect of addition of organic amendment. Shivashankar et al. (1976), Shivashankar and Vlassak (1978), Shivashankar and Shantharam (1980) reported that straw application to soybean improved the nodulation and nitrogenase activity and thus improving the growth and yield.

To sum up, organic matter application was observed to improve physical, chemical and biological properties of soil, release CO_2 to the crop canopy during its decomposition, enhance N_2 fixation by increasing the nitrogenase activity and promote growth and yield of crops.

2.4 Effect of light enrichment on crops

Unlike other resources viz., nutrients and water, light is 'instantaneously avaialble' and has to be instantaneously intercepted by the crop, if it is to be used for photosynthesis. Whereas, nutrients and water can be stored in 'reservoirs' from which demands could be made as and when required (Donald, 1961).

Light is one of the important growth factors affecting the yield of crops. Hence, there is a direct correlation between total incoming solar radiation and total biological yield (Nichiporvich, 1962) and grain yield (Hayashi, 1972). Light availability to the crop canopoy can be increased (light enrichment) by three ways viz. (1) increasing the leaf area index so that the interception is increased (Shibles and Weber, 1965); (2) manipulation of the canopy architecture to an ideal type for better light interception and light distribution (Watson and Witts, 1959; Kriedeman et al., 1964; Pearce et al., 1967) and (3) artificial light enrichment either by lamps or reflectors (Johnston et al., 1969; Schou et al., 1978).

Donald (1963) observed that competition for light occurred when one plant casts shadow on another or within a plant when one leaf shades another leaf. He also indicated that competition for light was affected by plant height.

At high productivity levels, the primary ecological factor limiting the grain yield of many crops is inadequate light at the middle and lower strata of the crop canopy. Johnston et al., (1969) enriched the soybean canopy with artificial light by placing fluorescent lamp in the canopy throughout the crop growth period and observed an increased yield by

17 per cent. Whereas, Schou _et al_., (1978) used reflectors for light enrichment for 15 days period at different growth stages of soybean and obtained 57 per cent more seed weight per plant when enrichment was made during late flowering to mid pod formation stage. The increased seed weight was attributed to enhanced photosynthesis and delayed senescence of lower leaves. Similarly, Streeter and Jeffers (1979) recorded 35 per cent increase in seed yield when additional light was given to the lower canopy at reproductive phase, mainly due to increase in the number of pods at the lower nodes, but the vegetative growth was not influenced by light enrichment.

Soybean flowers profusely, but only a small fraction of the flowers develop into mature pods and others abscise either as flowers or as immature pods. A prevalent hypothesis is that pod set is regulated by the supply of photoassimilates to developing flowers and pods. Hence, Heindle and Brun (1983) studied the effect of short-term supplmental white and red light in the lower portion of the canopy, on abscission of flowers and pods and obseved that the light treatment reduced the flower abscission (from 35% to 31%) and pod abscission (from 80% to 72%) and increased the seed yield per node (0.119 to 0.220 g). Myers _et al_. (1987) studied the pod set percentage by changing the quality of light assuming that the light quality may also affect the pod setting, in addition to the light quantity. They found that red supplemental light caused a significant increase in fruit set compared to far-red and control, which lead to the conclusion that the soybean recemes contain a photoreceptor which detects the quality of light and regulate the abscission of reproductive structures. They further elaborated that the decreased red/far-red ratio at the lower canopy by supplemental red light increased the sucrose movement into the reproductive structures and decreased the abscission of flowers and pods. Hence, it can be concluded that the light intensity at the lower canopy affects the photosynthetic efficiency of lower leaves, whereas the light quality regulates the translocation of sucrose into the recemes of lower nodes.

In sunflower, summer crop yielded higher than the kharif crop in South India (Chhabra et al., 1982; krishnegowda, 1983) mainly because of higher light intensity (540 cal/cm^2/day) and higher sunshine hrs (8.56) in summer as against kharif season (365 cal/cm^2/day and 6.4 hrs) (Veeraraja Urs, 1977; Habeebullah et al., 1983). Kharif season is characterized by several cloudy, partial cloudy, overcast and rainy days; as a result the light intensity is approximately 40-50 per cent than that in summer (Anon., 1973; Murthy et al., 1975).

Rawson and Hindmarsh (1983) observed a significant reduction in total biomass production and seed yield due to shading and also the harvest index, whereas the oil content was incresed by shading.

A field experiment on sunflower was taken in Australia both in winter and summer with an average light intensity of 9.5 and 25.5 MJ/day, respectively (Rawson et al., 1984). The results revealed that all the growth and yield parameters were superior in summer compared to winter, the linear rate of leaf area increased with time was almost twice as fast under summer than in winter, the final leaf area index was 5 in summer against 3 in winter and a very high correlation of total biomass, total seed number and filled seed number with the total radiation intercepted between sowing to anthesis.

2.5 Interaction effect of CO_2 and light on crops

Incident light intensity influences the rate of CO_2 fixation in plants, thus the response of crops to CO_2 enrichment increases with increase in light intensity. The net photosynthesis in soybean leaves has been estimated to be from 8 to 65 mg $CO_2/dm^2/hr$ with light saturation occuring between 20 and 160 K.lux (Bohning and Burnside, 1956 and Beuerlein and Pendleton, 1971). The positive interactions were observed in soybean (Copper and Brun, 1967; Sionit et al., 1982) and in sunflower (English et al., 1979) as like in other crops. Generally, C_3 plants reach their peak carbon dioxide assimilation at relatively low light intensity when compared to C_4 plants. The maximum fixation of CO_2 by a single leaf was observed only at 40 to 50 K.lux in soybean, potato and other C_3 plants (Chapman and Loomis, 1953; Burnside and Bohning, 1957 and Mahendra Singh et al., 1974). But the canopy photosynthesis or the photosynthesis of a C_3 crop community responded upto 90 K. lux (Yoshida, 1972), indicating that light intensity is the limiting factor for photosynthesis of crop community of C_3 plants also, hence affecting the productivity.

2.6 Effect of triacontanol application on crops

A number of organic compounds which when introduced into a plant in relatively small quantiity induce developmental changes. This has led to the discovery of plant hormones, as agents controlling growth and development, and attempts to modify the growth of crop plants by applying these compounds in agriculture and horticulture, are being done extensively.

A long chain alcohol 1-Triacontanol a saturated straight chain, primary alcohol with 30 carbon (first identified by Chibnall et al., 1933) has been shown experimentlly to increase seedling growth and crop yield when applied to different crops. It is a naturally occurring wax component of many plant species and is present in the environment wherever there is organic matter. At present, triacontanol would be considered by most, to be secondary plant growth substance and not a plant harmone. Literature pertaining to the effect of triacontanol on photosynthesis, photorespiration, flowering, growth and yield and also environmental factors which inhibit the triacontanol effects are reviewed here.

Ries and Wert (1977) working with alfalfa meal and chloroform extracts of the meal observed the increase in growth and yield of several plant species. A crystalline substance isolated from the active fraction of alfalfa meal increased the dry weight and water uptake of rice seedlings when sprayed on the foliage or applied in nutrient culture. The substance was identified as triacontanol by mass spectrometry. Sprays containing this compound also increased the growth of corn and barley. The report by Crizaldo et al. (1979) on Albizia falcataria where 15 days old seedlings were sprayed weekly with 12 treatments of triacontanol (0.05 to 0.60 ppm) for 5 weeks indicated that 0.10 ppm and 0.15 ppm treatments produced the most vigorous seedling growth and root development; but above 0.15 ppm, toxicity symptoms appeared. Ge et al. (1984) obtained an increase in the total length of the root system by 62-88 per cent and plant height by 23 per cent, when the seedlings of Poncirus trifoliate were cultured in distilled water containing 0.3 ppm triacontanol.

Rao (1985) reported that treatment of 0.5 ppm triacontanol to rice at booting stage increased heat resistance and photosynthetic rate of the leaves, while leaf chlorophyll content was unaffected. Chen et al. (1982) showed that 0.1 ppm triacontanol treatment to cotton accelerated photophosphorylation in the chloroplast and increased storage of ATP, leading to increased dry matter accumulation in reproductive organs, while delayed bud shedding and abscission of young bolls. Debata and Murthy (1981) showed that foliar spray of triacontanol at 10 ppm, 10 days after anthesis in rice increased the chlorophyll content, retention of green leaf area and mobilization of ^{14}C photosynthates. Haugstad et al. (1983) observed that Chlamydomonas reinhardtii (C_3 species) when cultured in an aqueous solution containing triacontanol, the photorespiration was significantly reduced, whereas the photosynthesis, was unaffected.

Ries et al., (1978) reported that foliar sprays of triacontanol ranging from 5 to 500 mg/ha significantly incresed marketable yield of 7 crops tested. However, the seed or soil treatment with triacontanol did not show any response. In maize - soybean intercropping, triacontanol (Grinit as trade name) application increased the grain yield of maize from 33 to 55 q per ha with one spray and to 57.3 q per ha with two sprays. In intercropped soybean also, the increase in yield was from 3.9 q per ha over to 4.66 and 5.5 q per ha with one and two sprays (Shivashankar, 1986). In another study, Patil and Bangal (1985) showed application of foliar spray of 0.5 per cent triacontanol to pigeonpea significantly increased the number and weight of seeds per plant. Jadhav et al., (1987) also observed an increase in yield by 156 per cent in mustard and 13 per cent in lablab bean by foliar spray of triacontanol at 0.5 ppm concentration. The higher yield was attributed to increase in the partitioning of assimilates towards the sink leading to higher filled fruits per plant and harvest index.

There are many reports also, indicating no positive effect of triacontanol on growth and yield of crops. Steffens and Worley (1980) under green house conditions did not find any significant increase in growth of soybean by soaking seeds with or by foliar spray of triacontanol at 3-5 trifoliate leaf stage. Similarly, Jourdan and Oplinger (1983) in field trials observed no response to foliar application of triacontanol at early reproductive stage and neither did soaking the seeds. Bosland _et al_. (1979) obtained no positive effect of triacontanol, appplied at 0.01, 1.0 and 10.0 ppm as a foliar spray at 8 to 10 leaf stage of muskmelons. Bouwkamp and Mc Ardle (1980) reported that triacontanol applied at 100 ppb to sweet potato increased per cent dry weight and per cent nitrogen of leaves soon after treatment but had no measurable effect on root yields, root protein or percentage dry matter of the roots. Prasanna (1987) reported a significant increase in photosynthetic rate upto 96 to 120 hrs after application of triacontanol in redgram and sunflower at 10 ppm concentration and in groundnut at 1 ppm concentration, but did not find any effect on yield and yield parameters; he further reported that repeated foliar application at least four times during the crop growth period may significantly affect the yield as it was observed in redgram.

The effectivity of triacontanol is affected by many factors. Ries _et al_. (1983) observed that it is a more effective plant growth stimulator when formulated as a colloidal dispersion than as a suspension in chloroform and Tween-20 or acetone, napthalene acetic acid (NAA) and $CaCl_2$. It is more effective when applied by low volume sprayers. McKeown (1983) observed that the pH of the spray of $\geq$ 8 was most effective when applied to maize, rice or soybean.

The foregoing reviews on triacontanol shown to increase photosynthesis, chlorophyll content, translocation of photosynthates, thus the growth and yield of crop. Howerver, many have reported no or poor response of crops to application of triacontanol.

MATERIAL AND METHODS

III. MATERIAL AND METHODS

The investigations entitled "Productivity of sunflower-soybean intercropping system as influenced by canopy architecture, CO_2 fertilization, tria-contanol, light enrichment, lime and organic amendments" were taken during kharif (August to November) 1988 and 1989, and summer (January to May 1989 and 1990). The details of the material used and techniques adopted during the course of this investigation are described in this chapter.

3.1 Location

The experiments were conducted at the Main Research Station, Hebbal, University of Agricultural Sciences, Bangalore located at 13^{O}N latitude, $77^{O}37'$ E longitude and at an altitude of 899 m above mean sea level.

3.2 Soil properties

Prior to laying out of the experiments, composite samples of soil were drawn from a depth of 0-15 cm and analysed for physico-chemical characteristics. The values obtained along with the methods of determination are given in Table 1. Soil of the experimental site was sandy loam. The field capacity of the soil was 15.5 per cent with a permanent

Table 3.1 Soil properties of experimental site

Particulars	Mean values			Methods followed
I Physical properties				
Mechanical composition(%)	**Depth (0-15)**			
Coarse sand	52.25			International **pipette** method (Piper, 1966)
Fine sand	24.60			
Silt	9.25			
Clay	8.30			
Textural class	Sandy loam			
II Physico-chemical properties				
1. Field capacity (%)	15.50			Field method (Piper, 1960)
2. Permanent wilting point (%)	6.71			Pressure plate method (Richard, 1954)
3. Bulk density (g cc^{-1})	1.59			Core sampler method (Piper, 1966)
4. Pore space (%)	51.02			Keenrazkaski measurements
	Experiments			
	I	II	III	
5. Soil reaction (pH)	6.70	6.90	6.70	Potentiometry (Jackson, 1973)
6. Electrical conductivity at 25^0C (mmhos cm^{-1})	0.20	0.20	0.20	Conductometry (Jackson, 1973)
7. Cation exchange capacity (meq/100 g)	7.62	7.65	7.68	Neutral normal ammonium acetate method (Jackson, 1973)
III Chemical properties				
1. Organic carbon (%)	0.61	0.70	0.59	Walkley and Black method (Jackson, 1973)
2. Available N (Kg ha^{-1})	360.20	371.60	359.50	Alkaline permanganate method (Subbiah and Asija, 1956)
3. Available P_2O_5 (kg ha^{-1})	48.91	50.02	47.60	Olsen's extractant method (Jackson, 1973)
4. Available K_2O (kg ha^{-1})	290.51	305.10	310.20	Flame Photometry (Jackson, 1973)

wilting point of 6.71 per cent. Bulk density of the soil was 1.59 and pore space was 51.02 per cent. The pH (6.7 to 6.9) was almost neutral and the Electric conductivity (0.2 m mhos/cm at 25^{0}C) was normal. The cation exchange capacity ranging from 7.62 to 7.68 meq per 100 g was low. The organic carbon (0.59 to 0.70%), the available nitrogen (359.50 to 371.60 kg/ha), the available P_2O_5 (47.6 to 50.02 kg/ha) and available K_2O (290.50 to 310.20 kg/ha) contents were medium in all the experimental sites. On the whole, the fertility status of these three experimental sites was medium.

3.3 Climate

The normal as well as actual weather data on rainfall, maximum and minimum temperature, relative humidity, evaporation and bright sunshine hours that prevailed during crop growth period are presented in Appendix 1 and Fig 3.1, 3.2 and 3.3.

3.3.1 Normal climatic conditions

The normal annual rainfall of Hebbal is 804.8 mm. Premonsoon thunder showers are received right from the month of April and the rainy season terminates in November with two peaks, one occurring during the month of May (105 mm) and the second in September (199 mm). The maximum temperature ranges from 26.2^{0}C to 34.0^{0}C and minimum temperature varying from 13.9^{0}C to 21.2^{0}C.

The hottest month is April and coldest, December. The relative humidity is lowest in March (53.1%) and high from June to November (71.3 to 76.2%). Maximum evaporation is recorded in the months of March and April while the lowest in November. Maximum daily bright sunshine hours are recorded from January to April (9.4 to 9.9 hrs).

3.3.2 Climatic conditions during crop growing period

The meteorological data of the crop growing period (August to November 1988 and 1989, January to May of 1989 and 1990) are presented in Appendix 1 and depicted in Fig. 3.1, 3.2 and 3.3. The rainfall during 1988 <u>kharif</u> season was heavy and more than the normal in July (276.9 mm), August (278.3 mm) and September (442.4 mm) and less than normal in October (69.6 mm) and November (10 mm) months. Whereas in 1989 <u>kharif</u>, the July (182.2 mm), September (215.6 mm) and October (199.6 mm) months received more than the normal and other months received less than normal. The daily rainfall data during the cropping seasons are given in Appendix 2 and graphically illustrated in Fig. 3.3. There were 32 rainy days of > 2.5 mm rainfall in 1988 cropping season as against 21 in 1989.

Maximum temperature was almost normal during 1988 and 1989, whereas summer season of 1990 was warmer

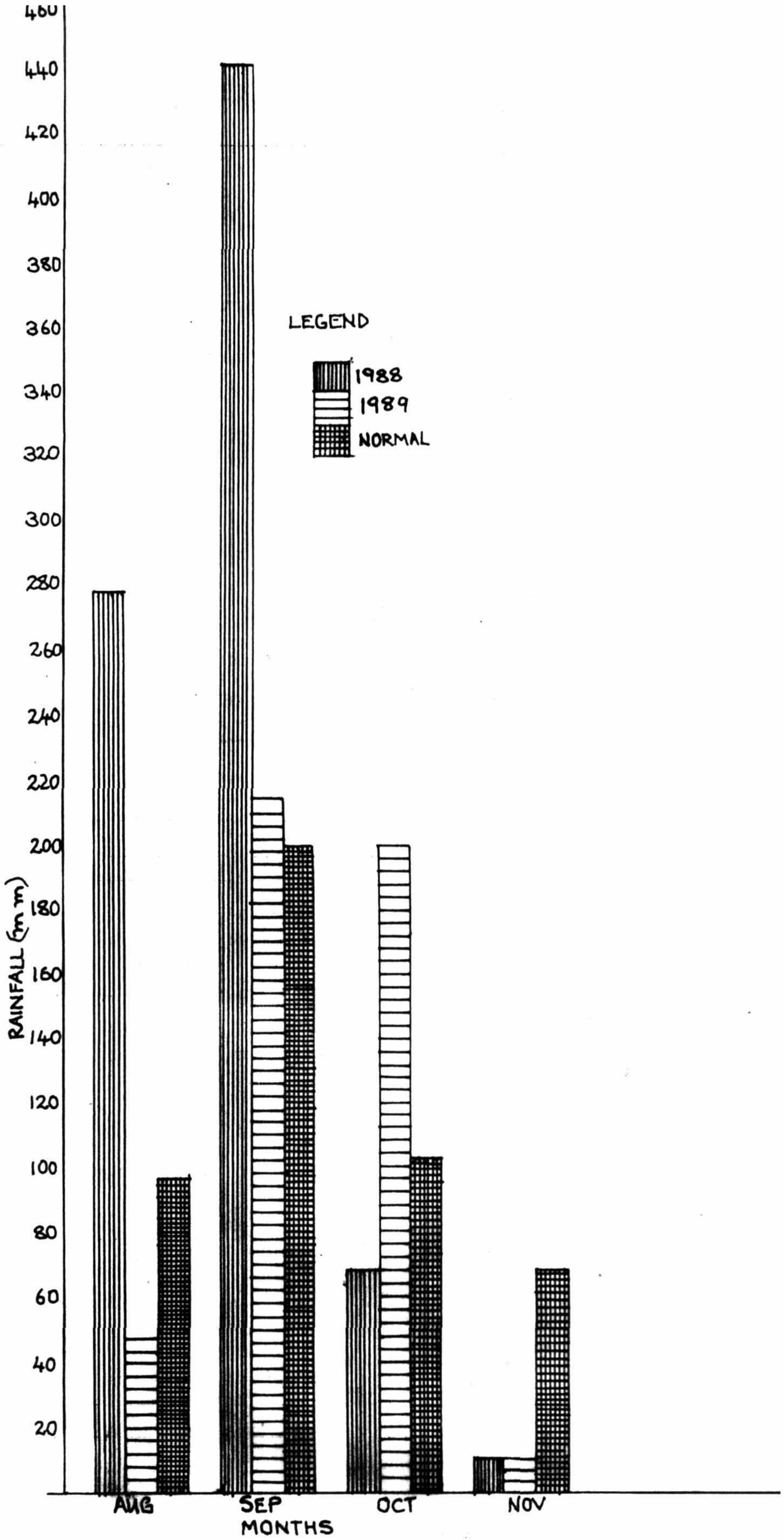


Fig 3.1 Actual and normal monthly rainfall during crop growth period at Hebbal

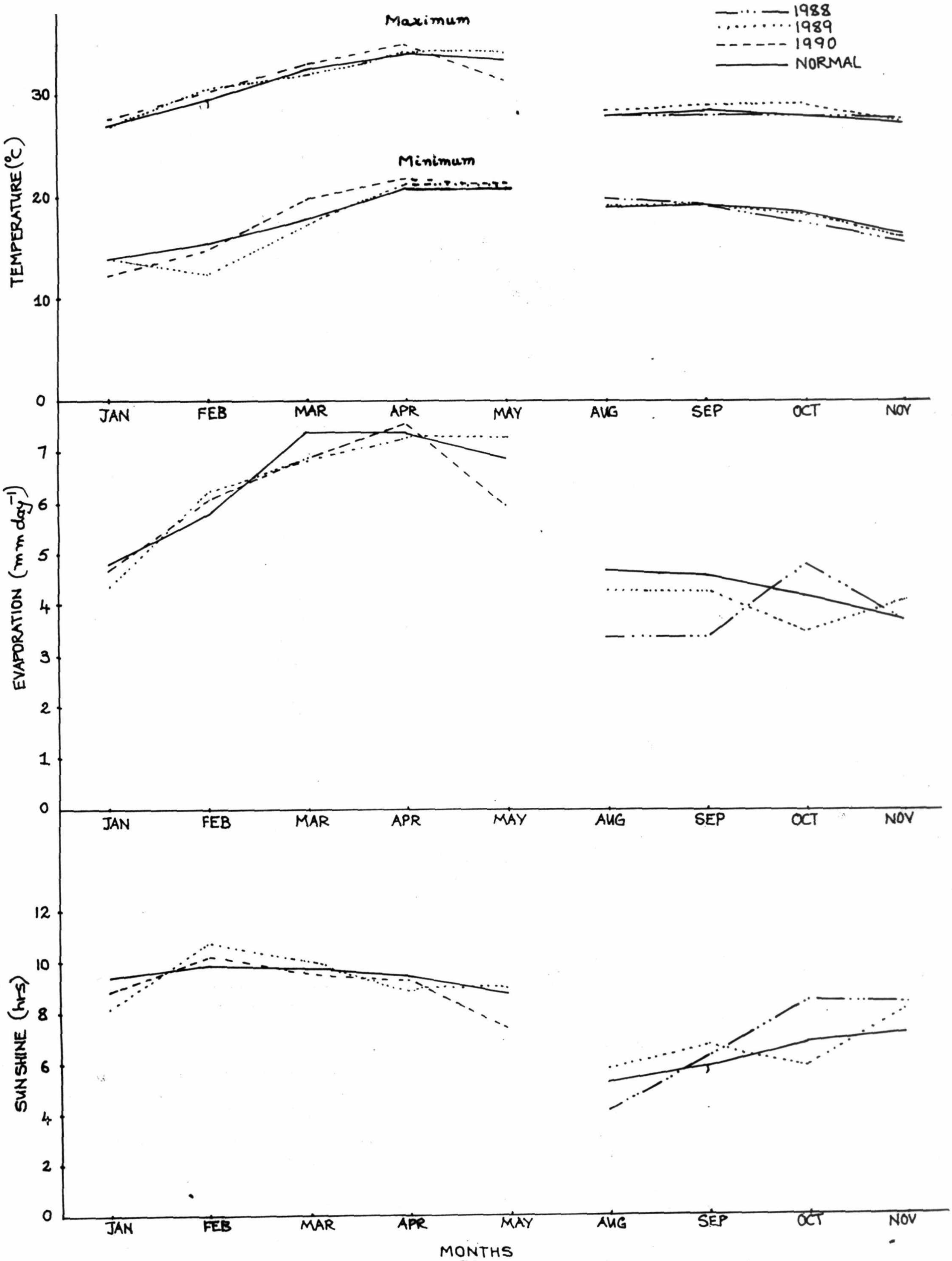


Fig 3.2 Actual and normal monthly weather data prevailed during the crop growth period (January to May 1989, 1990 and August to November 1988, 1989) at Hebbal

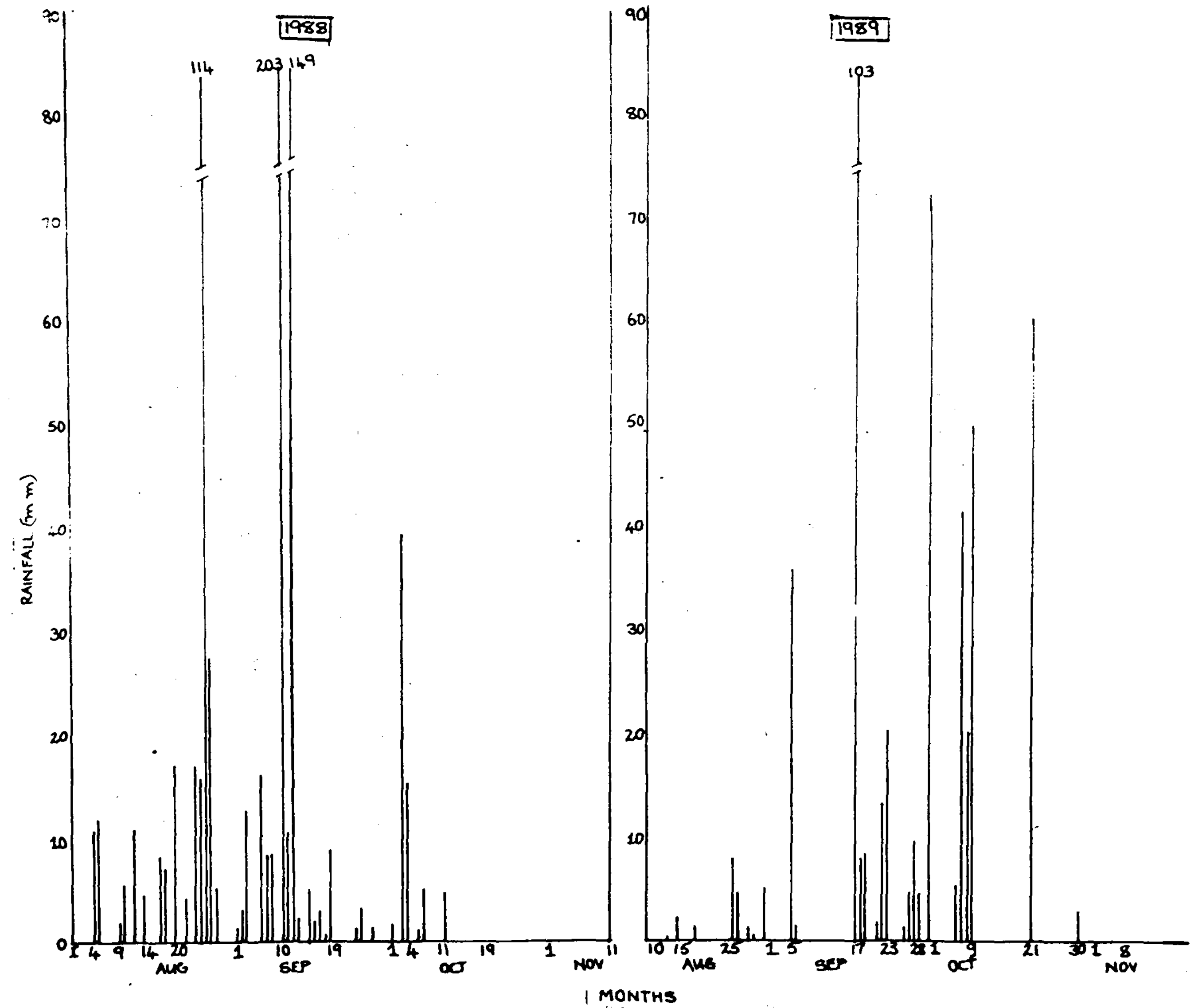


Fig 3.3 Daily rainfall during cropping seasons of experiment I
(1-8-88 to 11-11-88 and 10-8-89 to 17-11-89) at Hebbal

by 0.3 to 1.1 ^{0}C. Minimum temperature was considerably below normal in October (-0.9) and November (-1.1) 1988) and January 1990 (-1.15), while it was more than the normal in August 1988 (0.8), March (2.2) and April (1.4) 1990, and normal in other months. Open pan evaporation was by and large normal in all the seasons. The daily duration of sunshine hours that prevailed during October and November 1988, and February, September and November 1989 were above normal by 0.8 to 1.6 hrs, whereas it was less than normal in August 1988, January and October 1989 and May 1990 by 0.9 to 1.4 hrs.

3.4 Previous history of the experimental site

Three field experiments were taken in PG Experimental Block of Main Research Station and each experiment was repeated once in the succeeding year. The preceding summer crop was ragi on the experimental site where experiments-I and II were taken in kharif 1988 whereas, on the site where Experiment II was taken in summer 1989, the earlier crop was cowpea in kharif 1988. And in the period between first and second years of field investigations, the plots were left fallow.

3.5 Crops and genotypes

The sunflower hybrid KBSH-1 and Soybean variety Hardee were used in these investigations.

KBSH-1: The sunflower hybrid matures in 95 to 100 days and yields 26 and 30 per cent more than the seed and oil yield of BSH-1, respectively. Plant height is 120-150 cm, stem diameter is 1.75-2.25 cm and head diameter is 15-17 cm. Thousand grain weight is 41.42 g and oil per cent is 42-44. It yields around 20 q/ha under irrigated conditions.

Hardee: This variety of soybean was introduced from USA. It matures in about 100-105 days. Plants are determinate in habit, flowers are white, pod pubescence is grey, seeds are bold, light yellow in colour with rosy hilum. Thousand seed weight is 167 g; oil and portein contents are about 19.5 and 34 per cent, respectively. Fairly tolerant to bacterial pastules but susceptible to yellow mosaic virus.

3.6 Details of manures and fertilizers

Urea, super phosphate and muriate of potash were used as source of N, P and K, respectively. Chopped paddy straw and maize stover were used as organic amendments in Experiment II.

3.7 Seeds and Seed treatment

Sunflower hybrid KBSH-1 seed was procured from All India Co-ordinate Research Project on Sunflower, GKVK and Soybean variety, Hardee was obtained from Main Research Station, Hebbal. Soybean seeds were treated with UAS culture of Rhizobium japonicum.

3.8 Experimental details

3.8.1 Experiment I: Performance of sunflower and soybean in intercropping with varied plant populations and planting patterns

The field experiment was conducted for two years with 14 treatments including two pure crops and 12 intercrop combinations from out of three factors. The treatments were superimposed in the second year in the same location plotwise.

Treatments:Sole crops

SF = Sunflower pure crop (60 cm x 20 cm) with 83,333 plants per ha (100%).

SB = Soybean pure crop (30 cm x 10 cm) with 3,33,333 plants/ha (100%).

Intercrops: Sunflower-soybean intercropping involved 12 treatments with all possible combinations of three factors viz., population levels of sunflower (A_1 = 75% and A_2 = 100%), population levels of soybean (B_1 = 50%, B_2 = 75% and B_3 = 100%) and planting patterns of sunflower (C_1 = uniform rows and C_2 = paired rows).

$A_1B_1C_1$ = Sunflower in uniform rows (80 cm x 20 cm) with 62,500 plants per ha (75%) and a row of soybean (1,66,666 plants/ha, 50%, 7.5 cm between plants) in between the two rows.

$A_1B_1C_2$ = Sunflower in paired rows (105/55 cm x 20 cm) with 62,500 plants per ha (75%) and two rows of soybean (1,66,666 plants/ha, 50%, 7.5 cm between plants) in between the two pairs.

$A_1B_2C_1$ = Sunflower in uniform rows (90 cm x 17.78 cm) with 62,500 plants per ha (75%) and two rows of soybean (2,50,000 plants/ha, 75%, 8.89 cm between plants) in between the two rows.

$A_1B_2C_2$ = Sunflower in paired rows (135/45 cm x 17.78 cm) with 62,500 plants per ha (75%) and four rows of soybean (2,50,000 plants per ha, 75%, 8.89 cm between plants) in between the two pairs.

$A_1B_3C_1$ = Sunflower in uniform rows (100 cm x 16 cm) with 62,500 plants per ha (75%) and three rows of soybean (3,33,33 plants/ha, 100%, 9 cm between plants) in between the two rows.

$A_1B_3C_2$ = Sunflower in paired rows (150/50 cm x 16 cm) with 62,500 plants per ha (75%) and five rows of soybean (3,33,333 plants/ha, 100%, 7.5 cm between plants) in between the two pairs.

$A_2B_1C_1$ = Sunflower in uniform rows (60 cm x 20 cm) with 83,333 plants per ha (100%) and row of soybean (1,66,666 plants/ha, 50%, 10 cm between plants) in between the two rows.

$A_2B_1C_2$ = Sunflower in paired rows (75/45 cm x 20 cm) with 83,333 plants per ha (100%) and two rows of soybean (1,66,666 plants/ha, 50%, 10 cm between plants) in between the two pairs.

$A_2B_2C_1$ = Sunflower in uniform rows (75 cm x 20 cm) with 83,333 plants per ha (100%) and two rows of soybean (2,50,000 plants/ha, 75%, 10.66 cm between plants) in between the two rows.

$A_2B_2C_2$ = Sunflower in paired rows (120/30 cm x 10 cm) with 83,333 plants per ha (100%) and four rows of soybean (2,50,00 plants/ha, 75%, 10.8 cm between the plants) in between the two pairs.

$A_2B_3C_1$ = Sunflower in uniform rows (90 cm x 13.35 cm) with 83,333 plants per ha (100%) and three rows of soybean (3,33,333 plants/ha, 100%, 10 cm between plants) in between the two rows.

$A_2B_3C_2$ = Sunflower in paired rows (135/45 cm x 13.35 cm) with 83,333 plants per ha (100%) and five rows of soybean (3,33,333 plants/ha, 100%, 8.33 cm between plants) in between the two pairs.

Design and layout

The experiment was laid out in RBD design with three replications. The plan of layout is presented in Fig. 3.4.

Plot size: 5 m x 3 m

Spacing and plant population: As per the treatment details.

3.8.2 Experiment II: Effect of carbon dioxide fertilization, light enrichment and triacontanol sprays in sunflower-soybean intercropping

This field experiment was conducted for two years (kharif 1988 and 1989) with eight treatment combinations from out of three factors. The treatments were superimposed in the second year in the same location plotwise.

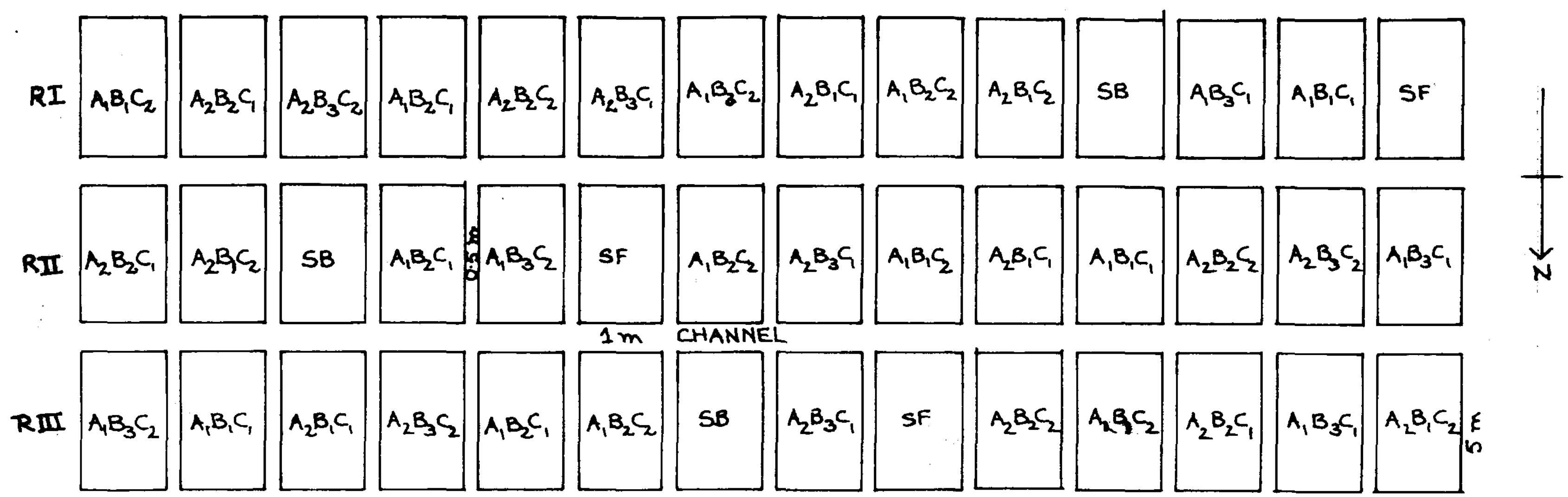


Fig 3.4 Plan of layout of experiment

Treatment details

1. **Sole crops: SF = Sunflower, SB = Soybean**
2. **Interorops:**

A = Sunflower population levels

A_1 = 62,500 plants ha^{-1} (75% of sole)

A_2 = 83,333 plants ha^{-1} (100% of sole)

B = Soybean population levels

B_1 = 1,66,666 plants ha^{-1} (50% of sole)

B_2 = 2,50,000 plants ha^{-1} (75% of sole)

B_3 = 3,33,333 plants ha^{-1} (100% of sole)

O = Planting pattern of sunflower

C_1 = Uniform rows

C_2 = Paired rows

Treatments

T_1 : Pure control

T_2 : CO_2 fertilization

T_3 : Light enrichment

T_4 : Triacontanol spray

T_5 : CO_2 fertilization + Light enrichment

T_6 : CO_2 fertilization + Triacontanol spray

T_7 : Light enrichment + Triacontanol spray

T_8 : CO_2 fertilization + Light enrichment
Triacontanol spray

In the treatments receiving CO_2 enrichment, transparent polythene open top chambers were constructed around each plot of 2.25m x 1.75 m (3.94 m^2) size with 1.75 m height (Plates 1 and 2). The carbon dioxide gas was supplied through an overhead distribution system of PVC tubes in a closed circuit from carbon dioxide cylinders fitted with regulators. Approximately 800 ppm of CO_2 was maintained in the chamber during sunshine hours generally from 8.30 AM to 5 PM. The CO_2 enrichment was made for 60 days between 30 days to 90 days after sowing. CO_2 concentration was measured by using a CO_2 Analyser (ADC, LCA2-10009).

Light enrichment to respective plots was made through reflection of sunlight by aluminium sheets

Plate 1. CO_2 and light enrichment to sunflower-soybean intercrop treatments

Plate 2. A close view of CO_2 and light enriched treatment

Plate 1

Plate 2

measuring 3 m length and 1.25 m width, inclined at 30^0 to the vertical plane (Plates 1 and 2). The sheets were placed at northern side of the plots, since the sun was inclined towards south of around 23^0 with respect to vertical (due to migration of sun towards southern hemisphere) during August to December months at Bangalore of 13^0N latitude (Subbiah Mudaliar, 1979). Thus, the sheets were angled at approximately 53^0 to the sun rays. The sheets were kept parallel to the crop rows (i.e. in East-west direction). The light enrichment was done during the same period of CO_2 fertilization. The light intensity was measured using tube solarimeter and it was around 25 per cent higher in light enriched plots than control.

Triacontanol was sprayed to respective treatments three times viz, Button stage (40 days after sowing), at mid flowering (55 days after sowing) and at mid seed filling (75 days after sowing) stages of sunflower, which coincided with vegetative, mid flowering and early pod filling stages, respectively in soybean. Triacontanol in liquid formulation obtained in the trade name of 'Grinit' manufactured by Saklaspur Organics Pvt. Ltd., Bangalore was used at 0.05 ppm concentration. Around 500 l of spray mixture was used per ha.

Design and Layout

The factorial Experiment with a Randomized Block Design consisted of eight treatments and three replications. The plan of layout is presented in Fig. 3.5.

Plot size

Gross plot size: 4 m x 3.70m

Net plot size : 3 m x 2.25 m

Spacing and plant population

Sunflower was grown in uniform rows of 75 cm x 16 cm with 83,333 plants per ha (100%) and two rows of soybean having 2,66,666 plants per ha (80%) at 10 cm between the plants was introduced in between the two sunflower rows.

3.8.3 Studies on CO_2 evolution rate and changes in physical, chemical and biological properties of soil by organic and lime amendments

The rate and duration of CO_2 evolution was studied during 1990 summer season incorporating two types of organic residues and lime ($CaCO_3$) at two levels each (4 and 8 t/ha) with one control, in lysimeter containers measuring 1.5 m x 1.15 m. The lysimeter plots were irrigated at six days interval as

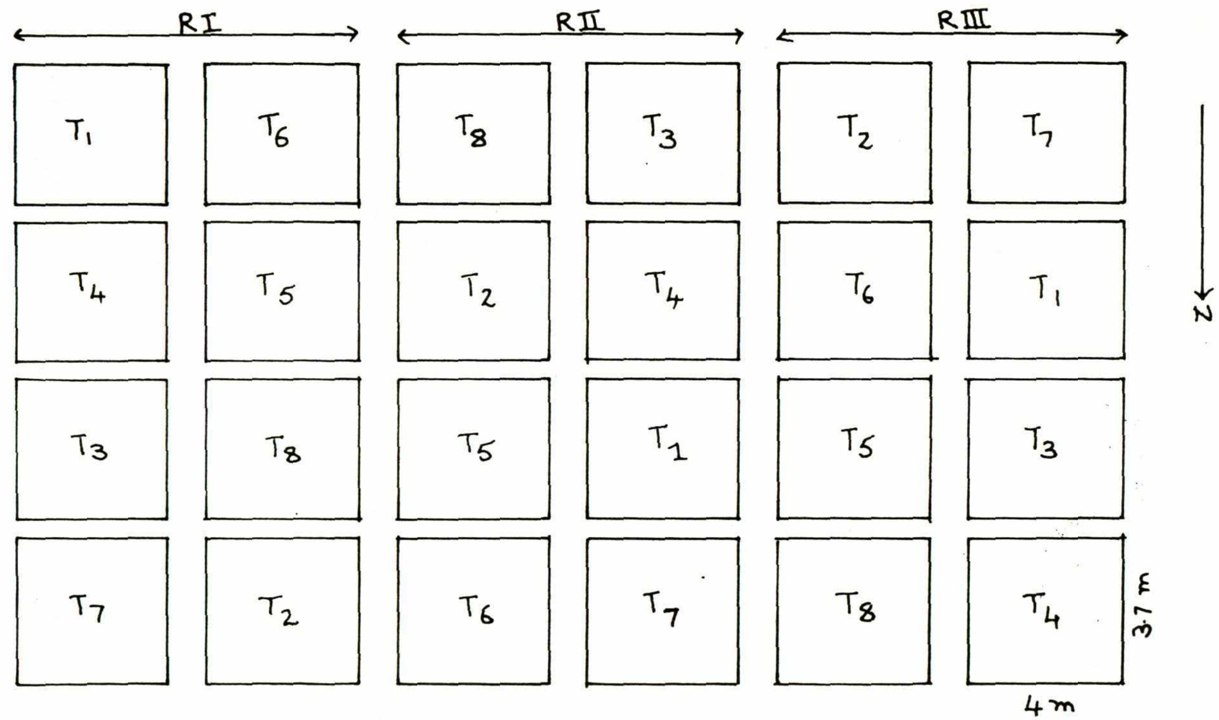


Fig 3.5 Plan of layout experiment II

Plate 3. CO_2 evolution studies in lysimeter containers using a portable Infra-Red Gas Analyser (IRGA)

Plate 3

in the field experiment. The rate of CO_2 evolution from each treatment was estimated at two days interval by trapping the released carbon dioxide for 15 minutes and measuring its concentration (ppm) using the instrument (ADC, LCA2-10009), a portable IRGA (Plate 3). The transparent polythene sheet was used to trap the releasd CO_2 by covering it over the lysimeter plots. Simultaneously, the changing nutrient status of the soil in each treatment along with pH was studied by estimating the soil N, P_2O_5, K_2O and organic carbon at 20 days interval. The microbial activity in each treatment was also studied at ten days interval by determining the dehydrogenase activity of the soil whose methodology is described later. The study was conducted upto 60 days.

3.8.4 Experiment III: Studies on CO_2 fertilization and time of application of organic and lime amendments in sunflower-soybean intercropping

This field study was taken up with 14 treatments for two years (Summer 1989 and 1990). The treatments were superimposed in the second year in the same location plotwise.

Treatments

T_1 : Control

T_2 : CO_2 fertilization

T_3 : Maize stover incorporation @ 4 t per ha at 20 days before sowing

T_4 : Maize stover incorporation @ 4 t per ha at the time of sowing

T_5 : Maize stover incorporation @ 4 t per ha at 20 days after sowing

T_6 : Maize stover incorporation @ 4 t per ha at 40 days after sowing

T_7 : Paddy straw incorporation @ 4 t per ha at 20 days before sowing

T_8 : Paddy straw incorporation @ 4 t per ha at the time of sowing

T_9 : Paddy straw incorporation @ 4 t per ha at 20 days after sowing

T_{10} : Paddy straw incorporation @ 4 t per ha at 40 days after sowing

T_{11} : Lime (unburnt i.e. $CaCO_3$) application @ 4 t per ha at 20 days before sowing

T_{12} : Lime (unburnt i.e. $CaCO_3$) @ 4 t per ha at the time of sowing

T_{13} : Lime (unburnt i.e. $CaCO_3$) application @ 4 t per ha at 20 days after sowing

T_{14} : Lime (unburnt i.e. $CaCO_3$) @ 4 t per ha at 40 days after sowing

Maize stover, paddy straw and unburnt lime ($CaCO_3$) were analysed for carbon content. Maize stover and paddy straw contained 42 and 39 per cent organic carbon, respectively and unburnt lime contained 24 per cent CO_2 or 6.6 per cent carbon. The details of C:N and C:P ratios of organic amendments are given in Appendix 3.

Design and Layout

The experiment was laid out in RBD design with three replications. The plan of layout is presented in Fig. 3.6.

Plot size: Same as Expt. II.

Spacing and plant population: Same as Expt. II.

3.9. Cultural operations

3.9.1 Preparation of the land

The land was ploughed once with tractor disc plough and followed by passing cultivator thrice. After harrowing, the land was smoothened with a wooden planks and weeds were picked. Further, after the formation of layout, all the individual plots were dug manually and weeds were removed. After levelling, the plots were made ready for sowing. Channels were also formed between each block either to serve for irrigation or to dispose the excess rain water.

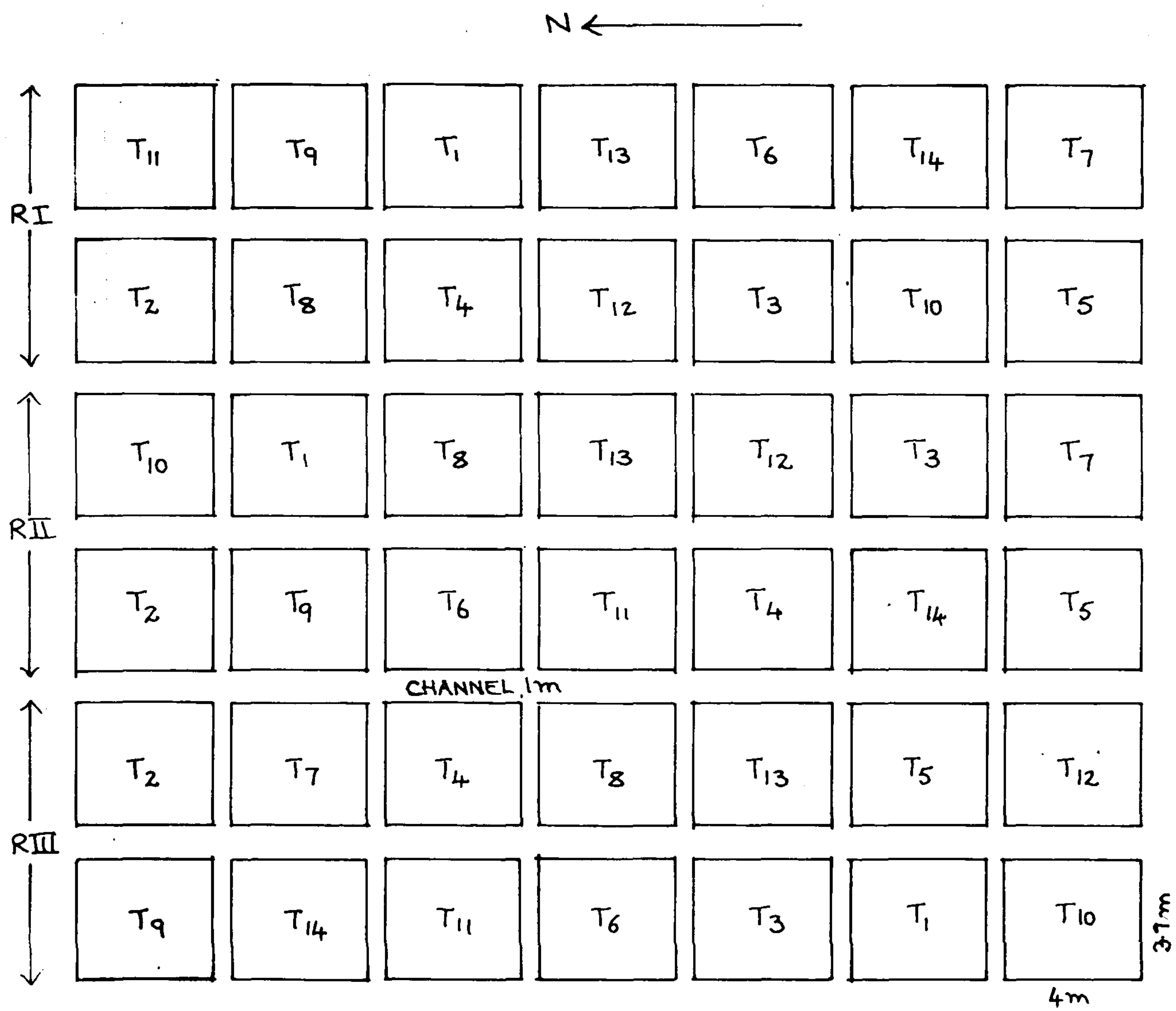


Fig 3.6 Plan of layout of experiment III

3.9.2 Fertilizer application

Recommended dose of fertilizer (Appendix 4) was applied in the seed furrows opened manually. It was mixed thoroughly into the soil before sowing. The fertilizer dosage was reduced proportionately to the plant population of component crops in different intercropping treatments. Experiment I was rainfed and so received the entire dose of N, P_2O_5 and K_2O of both sunflower and soybean at the time of sowing in their respective crop rows. Whereas, Experiment II and III, which were irrigated, the nitrogen dose of only sunflower component was given in splits as recommended (75% of N as basal and 25% at button stage) while the entire P_2O_5 and K_2O as single basal application. For soybean component, the full dose of N, P_2O_5 and K_2O were given at the time of sowing. While top dressing to sunflower, the nitrogen was band placed near its rows.

3.9.3 Sowing

The crops were sown in the furrows already opened. In the respective rows of sunflower and soybean, two seeds per hill were placed and moist soil was covered immediately. In Experiments I and II laid out in kharif season, sowing was on 1-8-1988 in the first year and 10-8-1989, in the second year. In

Experiment III, sowing was taken in summer on 13-1-1989 in the first year and 17-1-1990 in the second year. Wherever there were some gaps, resowing was done immediately after one week.

3.9.4 After care

Thinning: After twenty days of sowing, thinning of sunflower and soybean was done retaining one healthy seedling per hill.

Weeding: Hand weeding was given twice, first at 20 days after sowing and the second at 35 days after sowing with the help of weeding hook.

Earthing up: Earthing of sunflower and soybean was done by using hand guddali at 40 days after sowing coinciding with the button stage of sunflower. Top dressing of nitrogen to sunflower was also carried along with this operation in irrigated experiments.

Plant protection: Soybean crop was given two plant portection sprays at 25 and 40 days after sowing with Monocrotophos during both the years against leaf minor. In sunflower, to control the head borer attack Endosulfan was sprayed at full bud formation stages in both first and second years.

Hand pollination: It was taken up in sunflower by gently touching the open flowers by palm covered with soft white cloth, in the morning hours between 8 AM and 11 AM. It was continued for 8 to 10 days during the flowering period.

Irrigation: Irrigations were given for <u>kharif</u> irrigated experiment at 10 days interval during dry spells and at every 6 days interval for summer experiment.

3.9.5 Harvesting:

Net plots were harvested separately after leaving border rows. Heads of sunflower plants were first harvested when the back of the head turned lemon yellow in colour and then stalks were cut with sickles. In the case of soybean full plants were cut at the base when most of the leaves turned yellow. The heads of sunflower and pods of soybean were dried and the seeds were separated by gently beating with sticks, then they were dried again and cleaned.

3.10 Crop growth studies

3.10.1 Sunflower

Leaf area index (LAI): Leaves of three randomly selected plants were separated and the total leaf area was estimated by leaf disc method. Leaf area per plant was calculated and later divided by land area to get LAI. In intercropping, the land area provided between the sunflower rows irrespective of the space occupied by the soybean component, was taken for calculation of LAI.

Total dry matter production per plant: Three randomly selected plants were cut at the base and dried in the hot air oven at $70^{0}C$ till constant weight were obtained. The dry weight of sample plants were totalled and mean worked out to get dry matter production per plant.

Leaf area duration (LAD): It is the cumulated LAI over the growing season, calculated as per the formula suggested by Power et al. (1967) and is expressed in days.

$$LAD = \frac{[L_i + L_{(i+1)}]}{2} (t_2 - t_1)$$

Where, L_i = Leaf area index at ith stage

$L(i+1)$ = Leaf area index at (i+1) stage

$t_2 - t_1$ = Time interval between (L_i + 1) and L_i

Stem girth: The girth of the stem at the base was measured at physiological maturity stage.

Plant height/stem girth ratio: The ratio was calculated as in index of sturdyness of the plant by using plant height and stem girth measured at physiological maturity.

Other ancillary growth characters viz., plant height and days to physiological maturity were also noted.

3.10.2 Soybean

Plant height: Height of three randomly selected plants was measured from the base to growing bud in cm and mean plant height was calculated.

Number of primary branches: The branches from the mainstem were counted from these three randomly selected plants and averaged to get mean primary branches per plant.

Leaf area index (LAI): Leaves of three randomly selected plants were separated and the total leaf area was estimated by leaf disc method. Leaf area per plant was calculated and divided by land area to obtain LAI values. In intercropping as like in sunflower, the land area presented between soybean rows irrespective of the space occupied by sunflower was taken for calculation of LAI.

Total dry matter production per plant: Three plants were uprooted from each treatments; dried in the oven at 70^{0}C till constant weights were obtained and mean values were worked out and expressed in g.

Nodule count per plant: At flowering stages, three plants were uprooted for recording this observation. Plants were dug out along with the root system carefully. Roots were washed to remove the adhering soil and nodules were separated and the number of effective nodules were recorded. Then mean number of nodules was calculated.

LAD: By using the leaf area per plant, LAD was calculated as described in the case of sunflower.

Ancillary growth characters like plant height and days to physiological maturity were also noted.

3.11 Combined growth parameters of sunflower-soybean intercropping system

The parameters like total LAI, total LAD (days) and total biomass yield (q/ha) of the intercropping system as a whole were calculated by adding the respective parameters of individual components.

3.12 Studies on light transmission and Canopy architecture in intercropping

The leaf area and the canopy spread at every 10 cm vertical interval of the crop canopy from top to ground level was measured at peak flowering stage of sunflower, which coincided with early pod filling phase of soybean in sunflower-soybean intercrop. For measuring the vertical leaf area distribution, whatever the leaves present within every 10 cm canopy heights of sunflower and soybean were picked separately and the leaf area was calculated by leaf disc method. For this study, two spots were fixed randomly in the net plot area and the adjacent sunflower and soybean plants were used.

Before picking the leaves for leaf area estimation, the light intensities at the top of sunflower, at the top of soybean and at ground level was measured using tube solarimeter instrument, in the same spot at every 10 cm horizantal interval till a complete strip of a given planting pattern was covered. From the light intensity readings of microvolts obtained from tube solarimeter, the per cent transmitted light at the top of soybean canopy and at ground level was calculated. Further, the canopy surface exposed to the sun in different intercrop treatments was calculated as described by Rajendra Prasad and Reddy (1973).

3.13 Yield and yield components

3.13.1 Sunflower

Seed yield: The heads were harvested from the net plot area and the seeds were separated by gently beating with sticks. Seeds were sundried for 2 to 3 days. After drying, the weight was recorded and the kg per plot values were converted into q per ha for presentation of results.

Stalk + empty head yield: Stalks and empty heads after separating the seeds were sun dried, weighed and converted to q per ha for presentation of results.

Diameter of the matured head: The distance between the two diagonally opposite edges of the head was recorded as head diameter from three randomly selected heads from each plot.

Seed yield per plant: Seeds were separated from the randomly selected heads from each plot and dried thoroughly and cleaned. Weight of the seeds was recorded as seed yield per plant.

Number of filled seeds: The well filled seeds of the same heads were counted and averaged out to get the number of seeds per head.

Number of unfilled seeds: After separating the well filled seeds, the remaining unfilled seeds were counted.

Per cent filling: Percentage of filled seeds per head was worked out by taking the number of filled seeds per head to that of total number of seeds per head.

1000 seed weight: A random sample was taken from the seed yield per plant and 1000 seeds were counted and weighed.

Harvest index: It is the proportion of total dry matter represented by economic yield as suggested by Donald (1962). It was calculated as follows:

$$HI = \frac{\text{Seed yield}}{\text{(Seed + Stalk) Yield}}$$

Oil content and oil yield: Oil content in seeds was determined by Nuclear Magnetic Resonance Spectrometer (NMR, model Minispec 20Pi). Oil yield was calculated using oil per cent in seed and seed yield obtained per ha.

3.13.2 Soybean

Seed yield: Yield per plot was recorded by taking the weight of seeds obtained from net plot and then yield per hectare was computed.

Stover yield: After soybean plants from net plot area were dried and threshed to separate the seeds, the remaining stem and pod husks were weighed and converted into q per ha and taken as stover yield.

Number of pods per plant: The number of filled pods were counted from three randomly selected plants and averaged to get mean pods per plant.

Number of seeds per pod: Pods from the randomly selected plants were threshed, seeds separated, counted and mean values were caculated.

Seed yield per plant: Seeds of same three plants were separated, dried and cleaned. Weight of the seeds was recorded and mean values were calculated.

100 seed weight: Hundred seeds were counted from the total seed yield of three plants, weighed and expressed in g.

Harvest index: It was calculated as explained in sunflower.

3.14 Total oil yield

The oil yield of individual components of intercropping obtained in q per ha were added to get the total oil yield of the intercropping system as a whole.

3.15 Chemical analysis

3.15.1 Plant analysis

The plant samples of sunflower and soybean collected for dry matter production studied at harvest were analysed for nitrogen, phosphorus and potassium contents after having dried in hot air oven at 70^{0}C and powdered in micro willey mill. Nitrogen content by Micro-Kjeldahl's method, phosphorus by Vanadomolybdate phosphoric yellow colour method and potassium by Flame Photometer method were used for determination as described by Jackson (1973).

Nutrient uptake studies

The uptake of nitrogen, phosphorus and potassium per plant was calculated by multiplying the oven dry weight of the whole plant with their corresponding percentage of nitrogen, phosphorus and potassium. From this the total uptake per hectare was computed.

Chlorophyll content

Chlorophyll from the weighed green leaf tissues of sunflower and soybean collected at flowering stage was extracted by DMSO (Hiscox and Isrealstam, 1979) and optical density of the extract was taken at 645, 652 and 663 nm in a double beam spectrophotometer. Total chlorophyll, chlorophyll 'a' and chylorophyll 'b' were calculated using the following formulae.

$$\text{Chlorophyll a (mg g}^{-1}\text{)} = 12.7 \ (D_{663}) - 2.69 \ (D_{645}) \ X \ \frac{V}{W x 1000}$$

$$\text{Chlorophyll b (mg g}^{-1}\text{)} = 22.9 \ (D_{645}) - 4.68 \ (D_{663}) \ X \ \frac{V}{W x 1000}$$

$$\text{Total chlorophyll (mg g}^{-1}\text{)} = \text{Chlorophyll a (mg g}^{-1}\text{)} + \text{Chlorophyll b (mg g}^{-1}\text{)}$$

Total D = Optical density of the extract

V = Final volume of the extract

W = Fresh weight of the leaf discs

Crude protein content of the seeds : This was calculated by multiplying the nitrogen percentage of seeds by a factor 6.25 (Jackson, 1973).

3.15.2 Soil analysis:

The composite soil samples collected prior to the experiment and soil samples collected from individual plots in the middle and after the experiment were analysed for soil pH, organic carbon, available nitrogen, available P_2O_5 and available K_2O and are presented in Table 3.1 and Table 4.32 to 4.36. Soil pH was determined by potentiometry (Jackson, 1973) and organic carbon was estimated by Walkley and Black method (Jackson, 1973). Available nitrogen was estimated by Alkaline permanganate method (Subbiah and Asija, 1956), available phosphorus by Olsen's Extractant method (Jackson, 1973) and available potassium by Flame Photometry with neutral normal ammonium acetate extractant (Jackson, 1973).

Dehydrogenase activity: Procedure given by Casida et al. (1964) was used for estimating the activity of dehydrogenase. Weighed soil sample (5 g) was treated with $CaCO_3$, distilled water and 2, 3, 5 triphenyl tetrazolim chloride (TTC) and incubated in B.O.D. at 37^{0}C. The triphenyl formazon (TPF) formed was extracted with methanol or acetone and intensity of pink colour was determined by referring to a standard graph and expressed as mg TPF formed g^{-1} soil hr^{-1} at 37^{0}C.

3.16 Economic analysis

Gross income from each treatment was worked out with the prevailing produce cost viz., sunflower seed: Rs. 400 q^{-1}, stalk Rs. 20 q^{-1}, soybean seed Rs. 300 q^{-1} and soybean stover Rs. 10 q^{-1}.

3.17 Statistical analysis

The data relating to different characters of three experiments were analysed statistically by analysis of variance of factorial R.C.B.D. and by developing suitable contrasts (Snedecor and Cochran, 1967). The 'F' test, standard error of mean (S.Em.±) critical difference (C.D.) and coefficient of variability (C.V.) are provided for the data presented. The interpretation of data is based on probability level of 0.05.

The contrasts were developed for Experiment I and III while analysing the data, and some times more than one S.Em.± and CD values were calculated (depending on the type of observations) for such contrasts of unequal number of observations. Interaction values between the factors are presented and interpreted only where ever they were significant or found important.

3.18 Competition functions

3.18.1 Land equivalent ratio (LER)

It is defined as "the relative land area under sole crops that is required to produce the yields achieved in intercropping at the same level of management (Willey, 1979). It is calcualted as follows:

$$LER = \frac{\text{Mixture yield of species `a'}}{\text{Pure stand yield of species `a'}} + \frac{\text{Mixture yield of species `b'}}{\text{Pure stand yield of species `b'}}$$

3.18.2 Competitive ratio (CR)

Competitive ratio is a measure of intercrop competition to indicate the number of times by which one component crop is more competitive than other (Willey and Rao, 1980).

$$CR_a = \frac{\text{PLER `a'}}{\text{PLER `b'}} \times \frac{Zba}{Zab}$$

Where CR_a = Competitive ratio of `a' component crop,

PLER `a' = Partial Land equivalent ratio of crop `a'

PLER `b' = Partial land equivalent ratio of crop `b'

Zba = Proportion of intercropped area initially allocated to crop `b'

Zba = Proportion of intercroped area initially allocated to crop `a'

Similarly CR_b (Competitive ratio of b component crop) was calculated by a formula.

$$CR_b = \frac{PLER \text{ `b'}}{PLER \text{ `a'}} \times \frac{Zab}{Zba}$$

The CR values were calculated for seed yield of sunflower and soybean.

EXPERIMENTAL RESULTS

IV. EXPERIMENTAL RESULTS

The results of the field experiments on plant populations and planting patterns, carbon dioxide fertilization, light enrichment and triacontanol application, organic and lime amendments in sunflower-soybean intercropping system and carbon dioxide evolution studies along with changes in soil properties by organic and lime amendments in lysimeters conducted during 1988 to 1990 at Main Research Station, Hebbal are presented in this chapter.

4.1 Experiment I: Performance of sunflower and soybean in intercropping with varied plant populations and planting patterns

4.1.1 Response of sunflower to populations and planting patterns

Between two years of field experiment, the growth and yield of sunflower was better during second year as compared to first year.

4.1.1.1 Growth components

Plant height to stem girth ratio: The data on ratio of plant height to stem girth of sunflower at maturity as influenced by intercropping of soybean, plant population levels of sunflower and soybean and planting patterns, are presented in Table 4.1.

The ratio was significantly higher in sunflower intercrop (21.08 in 1988 and 18.54 in 1989) than in sole crop during both the years (17.90 in 1988 and 15.50 in 1989). In intercroping, the plant population levels of sunflower did not signficantly affect its ratio of plant height to stem girth in 1988, but in 1989, 100 per cent of sole crop plant population signficatly increased the ratio (18.95) as compared to 75 per cent (18.13). With respect increase in plant population levels of soybean intercrop, the ratio of sunflower was significantly increased with increase in plant population from 50 per cent (20.15) to 75 or 100 per cent of sole crop (21.45 or 21.65) in 1988 but not in 1989 (18.21 to 18.57 or 18.85). And the ratio was not altered significantly by planting pattern of sunflower either as uniform rows or paired rows.

Leaf area and leaf area index (Table 4.2): The leaf area of sunflower at 55 days reduced significantly due to intercropping of soybean. Sunflower pure crop recorded 13.99 dm^2 of leaf area in 1988 and 25.94 dm^2 in 1989 as against 10.55 dm^2 and 19.72 dm^2 in the intercrop respectively. Within intercrop, the leaf area per plant was significantly higher in 75 per cent sunflower population (11.26 dm^2 in 1988, 21.40 dm^2 in

Table 4.1 Plant height to stem girth ratio of sunflower (SF) as influenced by intercropping of soybean (SB), plant populations and planting patterns of intercrops.

Treatments	Plant height/stem girth		
	1988	1989	Mean
1. Sole V/s Intercrop			
(a) Sole crop	17.90	15.50	16.70
(b) Intercrop	21.08	18.54	19.81
'F' test	**	**	
S.Em± (a)	0.81	0.66	
(b)	0.23	0.20	
C.D. at 5%	1.75	1.41	
2. Within intercrop			
a. SF Population			
75% of sole	20.93	18.13	19.53
100% of sole	21.23	18.95	20.09
'F' test	NS	*	
S.Em±	0.33	0.27	
C.D. at 5%	--	0.79	
b. SB population			
50% of sole	20.15	18.21	19.13
75% of sole	21.45	18.57	20.01
100% of sole	21.65	18.85	20.25
'F' test	*	NS	
S.Em±	0.41	0.33	
C.D. at 5%	1.19	--	
c. Planting pattern			
SF uniform rows	20.78	18.37	19.57
SF paired rows	21.38	18.72	20.05
'F' test	NS	NS	
S.Em±	0.33	0.27	
C.D. at 5%	--	--	
C.V. (%)	6.8	6.2	

Table 4.2 Leaf area and leaf area index of sunflower (SF) at 55 days after sowing as influenced by intercropping of soybean (SB), plant populations and planting patterns of intercrops.

Treatments	LA (dm^2/plant)			LAI		
	1988	1989	Mean	1988	1989	Mean
1. Sole V/s Intercrop						
(a) Sole crop	13.99	25.94	19.96	1.16	2.16	1.66
(b) Intercrop	10.55	19.72	15.13	0.76	1.42	1.09
'F' test	**	**		**	**	
S.Em± (a)	0.86	1.15		0.06	0.11	
(b)	0.25	0.33		0.02	0.03	
C.D. at 5%	1.84	3.50		0.13	0.24	
2. Within intercrop						
a. SF Population						
75% of sole	11.26	21.40	16.33	0.70	1.34	1.02
100% of sole	9.85	18.04	13.94	0.82	1.50	1.16
'F' test	**	**		**	**	
S.Em±	0.35	0.67		0.02	0.05	
C.D. at 5%	1.02	1.94		0.07	0.14	
b. SB population						
50% of sole	10.98	20.95	15.96	0.79	1.51	1.15
75% of sole	10.44	19.85	15.14	0.75	1.43	1.09
100% of sole	10.24	18.36	14.30	0.74	1.31	1.02
'F' test	NS	NS		NS	NS	
S.Em±	0.43	0.81		0.03	0.06	
C.D. at 5%						
c. Planting pattern						
SF uniform rows	10.68	19.92	15.3	0.77	1.43	1.10
SF paired rows	10.43	19.52	15.0	0.75	1.40	1.07
'F' test	NS	NS		NS	NS	
S.Em±	0.35	0.67		0.02	0.05	
C.D. at 5%	--	--		--	--	
C.V. (%)	13.7	14.0		13.0	13.4	

1989) than in 100 per cent (9.85 and 18.04 dm^2). Whereas, the soybean population did not affect the leaf area significantly during both 1988 (10.24 to 19.98) and 1989 (18.36 to 20.95) seasons. Planting pattern in intercropping also did not influence the leaf area of sunflower in both the years.

Significant differences in the LAI between sole and intercropped sunflower were observed. Higher LAI was recorded in sole crop (1.16 and 2.16 in 1988 and 1989) than in intercrop (0.76 and 1.42). Between the two plant population levels of sunflower intercrop, 75 per cent population had significantly less LAI in both 1988 (0.70) and 1989 (1.34) seasons than 100 per cent population (0.82 in 1988 and 1.50 in 1989). Whereas, soybean population in intercropping did not affect the LAI of sunflower. Similarly, planting pattern also did not affect the LAI of sunflower in both the years.

Total drymatter production (Table 4.3):

At 55 days after sowing, the total DM production was significantly higher in sole crop of sunflower in both 1988 (20.1 g/plant) and 1989 (40.9 g/plant) seasons as compared to DM production in intercropping (15.3 and 31.0 g/plant in 1988 and 1989, respectively). Increasing the plant population of sunflower in intercropping significantly decreased

Table 4.3 Total dry matter accumulation of sunflower (SF) at 55 days after sowing (DAS) and at maturity as influenced by intercropping of soybean (SB), plant populations and planting patterns of intercrops.

Treatments	Total dry matter (g/plant)					
	at 55 DAS			at maturity		
	1988	1989	Mean	1988	1989	Mean
1. Sole V/s Intercrop						
(a) Sole crop	20.1	40.9	30.5	41.7	63.8	52.7
(b) Intercrop	15.3	31.0	23.1	30.6	48.9	39.7
'F' test	**	**		**	**	
S.Em+ (a)	0.9	1.5		2.4	3.6	
(b)	0.3	0.4		0.7	1.0	
C.D. at 5%	1.9	3.3		5.1	7.8	
2. Within intercrop						
a. SF Population						
75% of sole	17.1	33.5	25.3	33.8	53.6	43.7
100% of sole	13.5	28.5	21.0	27.5	44.1	35.8
'F' test	**	**		**	**	
S.Em+	0.4	0.6		1.0	1.5	
C.D. at 5%	1.1	1.8		2.8	4.3	
b. SB population						
50% of sole	16.3	32.6	24.4	32.0	51.1	41.5
75% of sole	15.2	31.0	23.1	29.9	48.1	39.0
100% of sole	14.5	29.5	22.0	30.0	47.4	38.7
'F' test	**	**		NS	NS	
S.Em+	0.4	0.8		1.2	1.8	
C.D. at 5%	1.3	2.2		--	--	
c. Planting pattern						
SF uniform rows	15.6	31.5	23.5	31.2	49.6	40.4
SF paired rows	15.0	30.6	22.8	30.1	48.2	39.1
'F' test	NS	NS		NS	NS	
S.Em+	0.4	0.6		1.0	1.5	
C.D. at 5%	--	--		--	--	
C.V. (%)	10.0	8.4		13.0	12.6	

its DM production per plant from 17.1 to 13.5 g in 1988 and 33.5 to 28.5 g in 1989 season. Similarly, the DM of sunflower decreased signficanlty with increasing soybean population from 50 to 100 per cent (16.3 to 14.5 g/plant and 32.6 to 29.5 g/plant in 1988 and 1989, respectively) but not as drastic as sunflower population. Planting of sunflower in uniform and in paired rows in intercropping were statistically on par in total DM per plant.

At maturity also, the DM of sunflower followed the same trend of reduction with increasing population of intercropped soybean as at 55 days after sowing but the differences were not significant.

4.1.1.2 **Yield and its components of sunflower**

Number of filled seeds and per cent seed filling per head (Table 4.4):

Sunflower in pure stand bore significantly more number of filled seeds per head of 368 and 598 than with intercropped soybean of 274 and 498 in the two years, respectively. In intercropping, maintaining only 75 per cent of sole crop of sunflower population gave significantly higher filled seeds per head (324 and 534 in 1988 and 1989, respectively) as compared to 100 per cent (264 and 463). Whereas, the plant population

Table 4.4 Number of filled seeds and per cent seed filling per head in sunflower (SF) as influenced by intercropping of soybean (SB), plant populations and planting patterns of intercrops.

Treatments	No. of filled seeds			Filling per cent		
	1988	1989	Mean	1988	1989	Mean
1. Sole V/s Intercrop						
(a) Sole crop	368.0	598.0	483.0	70.2	69.3	69.7
(b) Intercrop	274.2	498.5	396.3	65.9	65.6	65.7
'F' test	*	*		*	**	
S.Em+ (a)	25.8	36.5		1.5	1.3	
(b)	7.5	10.5		0.4	0.4	
C.D. at 5%	55.5	78.4		3.2	2.8	
2. Within intercrop						
a. SF Population						
75% of sole	323.9	533.6	428.7	67.2	66.7	66.9
100% of sole	264.5	463.5	364.0	64.6	64.5	64.5
'F' test	**	**		**	**	
S.Em+	10.5	14.9		0.6	0.5	
C.D. at 5%	30.8	43.5		1.8	1.6	
b. SB population						
50% of sole	298.6	507.7	403.1	66.0	65.5	65.7
75% of sole	293.0	483.8	388.4	65.8	65.7	65.7
100% of sole	291.0	504.2	397.6	65.9	65.6	
'F' test	NS	NS		NS	NS	
S.Em+	12.9	18.2		0.7	0.7	
C.D. at 5%	--	--		--	--	
c. Planting pattern						
SF uniform rows	298.4	499.5	398.9	66.0	65.8	65.9
SF paired rows	289.9	297.5	393.7	65.8	65.4	65.6
'F' test	NS	NS		NS	NS	
S.Em+	10.5	14.9		0.6	0.5	
C.D. at 5%	--	--		--	--	
C.V. (%)	14.9	12.5		3.9	3.4	

of soybean intercrop had no significant effect on the number of filled seeds in sunflower. Similarly, planting pattern also did not affect the number of filled seeds per head.

The seed filling per cent per head was significantly higher in sole cropping (70.2 in 1988 and 69.3 in 1989) as compared to intercropping (65.9 and 65.6). Within intercropping, lower plant population of sunflower gave higher filling per cent (66.7 to 67.2) as compared to higher plant population during both the years (64.5 to 64.6). The soybean population levels did not affect the filling per cent during both the years. Similarly, planting pattern also had no significant influence on the seed filling per cent.

Test weight of sunflower: The test weight of sunflower was neither affected by intercropping with varying plant populations nor by planting pattern (Table 4.5). However, test weight was higher (45.96 to 47.02 g/1000 seeds) in 1988 as compared to 1989 season (39.24 to 39.90 g/1000 seeds).

Seed weight per plant in sunflower: The seed weight of sunflower due to intercropping was reduced from 13.50 to 10.85 g/plant in 1988 and from 20.08 to 16.39 g/plant in 1989 season (Table 4.5). Increasing sunflower population in intercropping from 75 to 100

Table 4.5 Test weight and seed weight of sunflower (SF) as influenced by intercropping of soybean (SB), plant populations and planting patterns of intercrops.

Treatments	Test wt. (g/1000 seeds)			Seed wt. (g/pl.)		
	1988	1989	Mean	1988	1989	Mean
1. Sole V/s Intercrop						
(a) Sole crop	46.53	39.62	43.07	13.50	20.08	16.79
(b) Intercrop	46.44	39.64	43.04	10.85	16.39	13.61
'F' test	NS	NS		**	**	
S.Em± (a)	2.17	2.48		0.77	1.26	
(b)	0.63	0.72		0.22	0.36	
C.D. at 5%	--	--		1.67	2.70	
2. Within intercrop						
a. SF Population						
75% of sole	46.24	39.70	42.97	11.88	17.73	14.80
100% of sole	46.65	39.57	43.11	9.82	15.04	12.43
'F' test	NS	NS		**	**	
S.Em±	0.89	1.01		0.32	0.51	
C.D. at 5%	--	--		0.92	1.50	
b. SB population						
50% of sole	46.36	39.80	43.08	11.06	16.82	13.94
75% of sole	45.96	39.90	42.93	10.76	16.20	13.48
100% of sole	47.02	39.21	43.11	10.73	16.07	13.40
'F' test	NS	NS		NS	NS	
S.Em±	1.09	1.24		0.39	0.63	
C.D. at 5%	--	--		--	--	
c. Planting pattern						
SF uniform rows	46.34	39.80	43.07	11.01	16.63	13.82
SF paired rows	46.55	39.47	43.01	10.68	16.14	13.41
'F' test	NS	NS		NS	NS	
S.Em±	0.89	1.01		0.32	0.51	
C.D. at 5%	--	--		--	--	
C.V. (%)	8.1	10.8		12.1	13.1	

per cent of sole crop, decreased the per plant seed weight in both the years (11.88 to 9.82 g in 1988 and 17.73 to 15.04 g in 1989), whereas increasing soybean population had no significant effect on the seed weight of sunflower. Planting pattern of intercrops also did not significantly affect the seed weight of sunflower.

Seed yield of sunflower (Table 4.6): The seed yeild of sunflower was significantly reduced by intercropping from 8.20 to 6.17 q per ha in the first year and from 13.11 to 10.17 q per ha in the second year. Between plant population levels of sunflower in intercropping, the seed yeild was significantly lower with 75 per cent (5.87 and 9.77 q/ha) than with 100 per cent (6.46 and 10.57 q/ha) in both the years. Among the three population levels of soybean, introducing only 50 per cent of sole crop population in intercropping gave significantly higher yield of sunflower (6.44 q/ha in 1988 and 10.50 q/ha in 1989) as compared to 75 per cent (6.04 q and 10.00 q/ha) or 100 per cent (6.01 and 10.01 q/ha). Sunflower in uniform rows was statistically superior (6.41 and 10.44 q/ha in 1988 and 1989, respectively) to paired rows (5.92 and 9.90 q/ha).

Stalk yield of sunflower (Table 4.6): Intercropping of soybean reduced the stalk yield of sunflower significantly from 15.93 q/ha to 10.46 q/ha in the first year and from 27.87 q/ha to 19.24 q/ha in the

Table 4.6 Seed yield, stalk yield and harvest index of sunflower(SF) as influenced by intercropping of soybean(SB), plant populations and planting patterns of intercrops.

Treatments	Seed yield (q/ha)		Stalk yield (q/ha)		Harvest index	
	1988	1989	1988	1989	1988	1989
1. Sole V/s Intercrop						
(a) Sole crop	8.20	13.11	15.93	27.87	0.340	0.320
(b) Intercrop	6.17	10.17	10.46	19.24	0.371	0.346
'F' test	**	**	**	**	*	*
S.Em± (a)	0.18	0.24	0.68	0.88	0.011	0.011
(b)	0.05	0.07	0.19	0.25	0.003	0.003
C.D. at 5%	0.39	0.52	1.46	1.89	0.027	0.020
2. Within intercrop						
a. SF Population						
75% of sole	5.87	9.77	9.86	18.57	0.373	0.345
100% of sole	6.46	10.57	11.06	19.91	0.369	0.347
'F' test	**	**	**	*	NS	NS
S.Em±	0.07	0.10	0.28	0.36	0.006	0.004
C.D. at 5%	0.22	0.29	0.81	1.05	--	--
b. SB population						
50% of sole	6.44	10.50	11.16	20.55	0.367	0.338
75% of sole	6.04	10.00	10.12	18.59	0.374	0.350
100% of sole	6.01	10.01	10.10	18.60	0.373	0.350
'F' test	**	*	NS	**	NS	NS
S.Em±	0.09	0.12	0.34	0.44	0.006	0.006
C.D. at 5%	0.26	0.36	--	1.28	--	--
c. Planting pattern						
SF uniform rows	6.41	10.44	10.89	19.82	0.371	0.346
SF paired rows	5.92	9.90	10.03	18.67	0.372	0.347
'F' test	**	**	*	*	NS	NS
S.Em±	0.07	0.10	0.28	0.36	0.006	0.006
C.D. at 5%	0.22	0.29	0.81	1.05	--	--
C.V. (%)	5.0	4.1	10.8	7.6	5.8	4.6

second year. In intercropping, increasing the plant population of sunflower significantly increased its stalk yield (9.86 and 18.57 q/ha under 75 per cent population to 11.06 and 19.91 q/ha under 100 per cent population in 1988 and 1989, respectively). Whereas, with increase in soybean population, the decreased stalk yield of sunflower was not significant in the first year but significant in the second year (20.55 q/ha under 50 per cent population to 18.60 q/ha under 100 per cent population). Between two planting patterns, sunflower grown in uniform rows gave higher stalk yeild (10.89 and 19.82 q/ha) as compared to paired rows (10.03 and 18.67 q/ha) in intercropping.

Harvest index of sunflower (Table 4.6): Intercropping increased the harvest index of sunflower significantly from 0.340 to 0.371 and from 0.320 to 0.346 in first and second years, respectively. While in intercropping, altering the plant population of sunflower or soybean component had no significant effect on harvest index of sunflower. The harvest index was also not affected by planting pattern.

4.1.2 Response of soybean to population and planting pattern

The growth and yield of soybean was slightly better in 1988 than in 1989 season.

4.1.2.1 Growth components

Plant height of soybean (Table 4.7): Plant height of soybean was increased when intercropped with sunflower from 34.80 to 40.17 cm in 1988 and 43.80 to 52.80 cm in 1989. And in intercropping, the plant population levels of sunflower did not influence the plant height significantly, whereas plant height increased significantly with increase in plant population in both 1988 (37.54, 39.92 and 43.05 cm under 50, 75 and 100 per cent. population, respectively) and 1989 (48.77, 52.79 and 56.83 cm). Planting pattern of intercrops had no significant effect on plant height of soybean.

Number of primary branches in sunflower (Table 4.7): The number of primary branches were significantly higher when soybean was grown alone, (4.33 and 4.26 in 1988 and 1989) as compared to soybean grown with sunflower (2.46 and 2.30). Between the two sunflower populations in intercropping, no significant difference in number of primary branches were observed. Whereas, significant decrease in the number of branches were observed with increase in soybean population in 1988 (3.05, 2.57 and 1.75 under 50, 75 and 100 per cent populations, respectively) and 1989 (2.90, 2.32 and 1.62). Planting pattern also affected the number of primary branches under sunflower uniform rows (2.70 and

Table 4.7 Plant height and number of primary branches of soybean (SB) as influenced by intercropping with sunflower (SF), plant populations and planting patterns of intercrops.

Treatments	Plant height (cm)			Primary branches		
	1988	1989	Mean	1988	1989	Mean
1. Sole V/s Intercrop						
(a) Sole crop	34.80	43.80	39.30	4.33	4.26	4.29
(b) Intercrop	40.17	52.80	46.48	2.46	2.30	2.38
'F' test	**	**		**	**	
S.Em± (a)	1.79	2.28		0.31	0.23	
(b)	0.52	0.66		0.09	0.06	
C.D. at 5%	3.85	4.89		0.66	0.50	
2. Within intercrop						
a. SF Population						
75% of sole	39.24	52.01	45.62	2.61	2.39	2.50
100% of sole	41.10	53.59	47.34	2.31	2.22	2.26
'F' test	NS	NS		NS	NS	
S.Em±	0.73	0.93		0.13	0.09	
C.D. at 5%	--	--				
b. SB population						
50% of sole	37.54	48.77	43.15	3.05	2.90	2.97
75% of sole	39.92	52.79	46.35	2.57	2.32	2.44
100% of sole	43.05	56.83	49.94	1.75	1.62	1.71
'F' test	**	**		**	**	
S.Em±	0.90	1.14		0.15	0.12	
C.D. at 5%	2.61	3.32		0.45	0.34	
c. Planting pattern						
SF uniform rows	39.22	52.00	45.61	2.70	2.47	2.58
SF paired rows	41.12	53.59	47.35	2.21	2.14	2.17
'F' test	*	**		**	**	
S.Em±	0.73	0.93		0.13	0.09	
C.D. at 5%	--	--		0.37	0.28	
C.V. (%)	7.8	7.6		20.6	16.3	

2.47 in 1988 and 1989, respectively) as compared to sunflower paired rows (2.21 and 2.14).

Leaf area and leaf area index of soybean (Table 4.8): The LA of soybean reduced significantly due to intercropping with sunflower (12.85 to 9.81 dm^2/plant in 1988 and 11.18 to 7.73 dm^2/plant). During 1988 season LA did not differ significantly between two plant population levels of sunflower in intercropping, whereas during 1989 season, the LA of soybean was reduced from 8.39 dm^2 when intercropped with 75 per cent of sunflower population to 7.07 dm^2 with 100 per cent population. Among the soybean plant populations in intercropping, 50 per cent of sole crop population gave highest LA per plant (10.59 dm^2 in 1988, 8.77 dm^2 in 1989) followed by 75 per cent (10.31 and 7.58 dm^2) of sole crop population. Between the two planting patterns, the LA did not vary significantly in the first year, whereas in the second year, soybean introduced in between the uniform rows of sunflower gave higher LA per plant (8.22 dm^2) as compared to soybean introduced in between the paired rows (7.24 dm^2).

The significant interaction between plant population levels of sunflower and soybean on LA during 1989, showed that the lowest population levels of both the component crops (75 per cent sunflower and 50 per

Table 4.8 Leaf area and leaf area index of soybean (SB) at 55 days after sowing as influenced by intercropping with sunflower (SF), plant populations and planting patterns of intercrops.

Treatments	LA (dm^2/plant)			LAI		
	1988	1989	Mean	1988	1989	Mean
1. Sole V/s Intercrop						
(a) Sole crop	12.85	11.18	12.01	4.28	3.73	4.00
(b) Intercrop	9.81	7.73	8.77	2.39	1.88	2.13
'F' test	**	**		**	**	
S.Em± (a)	0.81	0.51		0.21	0.13	
(b)	0.23	0.15		0.06	0.04	
C.D. at 5%	1.74	1.09		0.45	0.28	
2. Within intercrop						
a. SF Population						
75% of sole	9.84	8.39	9.11	2.40	2.07	2.23
100% of sole	9.77	7.07	8.42	2.38	1.69	2.03
'F' test	NS	**		NS	**	
S.Em±	0.33	0.21		0.09	0.05	
C.D. at 5%	--	0.61		--	0.16	
b. SB population						
50% of sole	10.59	8.77	9.68	1.76	1.46	1.61
75% of sole	10.31	7.58	8.94	2.58	1.89	2.23
100% of sole	8.52	6.84	7.68	2.84	2.28	2.56
'F' test	**	**		**	**	
S.Em±	0.41	0.25		0.11	0.07	
C.D. at 5%	1.19	0.74		0.31	0.19	
c. Planting pattern						
SF uniform rows	10.23	8.22	9.22	2.50	1.99	2.24
SF paired rows	9.38	7.24	8.31	2.29	1.77	2.03
'F' test	NS	**		NS	**	
S.Em±	0.33	0.21		0.09	0.05	
C.D. at 5%	--	0.61		--	0.16	
C.V. (%)	14.0	11.0		14.3	11.3	

cent soybean population) produced highest LA per plant (8.85 dm^2) and vice versa (5.76 dm^2 at 100 per cent population of both soybean and sunflower) (Table 4.9).

With respect to LAI, the pure crop of soybean had significantly higher LAI (4.28 in 1988 and 3.73 in 1989) than intercrop (2.39 and 1.88) in both the years, as like LA per plant. Increasing the population of sunflower in intercropping did not bring significant changes in LAI of soybean in first year but decreased significantly (2.07 to 1.69) in second year. Unlike LA per plant, the LAI of soybean was significantly increased with increase in its population both during first (1.76, 2.58 and 2.84 at 50, 75 and 100 per cent, respectively) and second years (1.46, 1.89 and 2.28). Between planting patterns, the LAI followed the same trend as LA per plant with nonsignificant difference in the first year and significantly lower LAI under sunflower paired rows (1.77) than under uniform rows (1.99), during second year.

Interaction between plant population levels of sunflower and soybean on LAI of soybean was significant in second year. Intercropping of sunflower and soybean by maintaining 75 and 100 per cent of their sole crop population, respectively gave highest LAI(2.64) of soybean followed by 75 per cent of each (2.09), and

Table 4.9 Interaction effect between the plant populations of intercrops on leaf area (dm^2/plant) and leaf area index of soybean at 55 DAS in sunflower - soybean intercropping system during 1989 kharif season.

Plant population	**soybean**		
	50%	75%	100%
Sunflower			
75%	8.85(1.48)	8.38(2.09)	7.93(2.64)
100%	8.68(1.45)	6.79(1.69)	5.76(1.92)
F test		* (*)	
S.E.m±		0.36(0.09)	
C.D. at 5%		1.05(0.27)	

Figures in parenthesis are LAI values.

was lowest in 100 per cent sunflower and 50 per cent soybean (1.45) combination (Table 4.9).

Total dry matter production of soybean (Table 4.10): The DM production of soybean was significantly higher in pure crop at both 55 days after sowing and maturity during both the years. During first year, soybean as an intercrop produced 70.4 per cent of total DM of sole soybean crop at 55 days after sowing, and it was further decreased to 68.2 per cent at maturity. During second year, the corresponding values were 70.2 and 70.3 per cent of pure crop.

In intercropping, at 75 per cent of sole crop of sunflower significantly higher DM per plant of soybean was obtained during second year at 55 days after sowing (6.95g) and during both the years at maturity (11.79 and 9.35g) as compared to 100 per cent (6.03, 10.27 and 8.07g, respectively). Among the three population levels of soybean in intercropping, lowest population (50 per cent of sole) produced highest DM per plant (7.71 and 7.51 g at 55 DAS and 12.29 and 10.13 at maturity during first and second years, respectively) followed by 75 per cent and was lowest in 100 per cent (6.49, 5.62 g at 55 DAS and 9.35 and 6.89 g at maturity). Between the planting patterns, soybean intercropped under sunflower uniform rows accumulated significantly more DM per plant as compared to soybean

Table 4.10 Total dry matter production of soybean (SB) at 55 days after sowing (DAS) and at maturity as influenced by intercropping with sunflower (SF), plant populations and planting patterns of intercrops.

Treatments	Total dry matter (g/plant)					
	at 55 DAS			at maturity		
	1988	1989	Mean	1988	1989	Mean
1. Sole V/s Intercrop						
(a) Sole crop	10.21	9.24	9.72	16.18	12.38	14.28
(b) Intercrop	7.19	6.49	6.84	11.03	8.71	9.87
'F' test	**	**		**	**	
S.Em± (a)	0.42	0.52		0.68	0.60	
(b)	0.12	0.15		0.19	0.17	
C.D. at 5%	0.91	1.12		1.45	1.28	
2. Within intercrop						
a. SF Population						
75% of sole	7.28	6.95	7.11	11.79	9.35	10.57
100% of sole	7.11	6.03	6.57	10.27	8.07	9.17
'F' test	NS	**		**	**	
S.Em±	0.17	0.21		0.28	0.24	
C.D. at 5%	--	0.62		0.81	0.71	
b. SB population						
50% of sole	7.71	7.51	7.61	12.29	10.13	11.21
75% of sole	7.38	6.33	6.85	11.45	9.11	10.28
100% of sole	6.49	5.62	6.05	9.35	6.89	8.12
'F' test	**	**		**	**	
S.Em±	0.21	0.26	-	0.34	0.30	
C.D. at 5%	0.62	0.76		0.99	0.87	
c. Planting pattern						
SF uniform rows	7.47	6.82	7.14	11.62	9.50	10.56
SF paired rows	6.92	6.16	6.54	10.44	7.92	9.18
'F' test	*	*		**	**	
S.Em±	0.17	0.21		0.28	0.24	
C.D. at 5%	0.50	0.62		0.81	0.71	
C.V. (%)	9.8	13.5		10.2	11.5	

under sunflower paired rows during both stages of two years.

4.1.2.2 Yield and its components in soybean

Number of pods per plant in soybean: The data on number of pods per plant of soybean as influenced by intercropping with sunflower with different plant population levels and planting patterns (Table 4.11) indicated that in both the years, sole crop of soybean produced significantly higher number of pods (21.2 and 20.0) as compared to intercrop (14.8 and 13.3).

In intercropping, soybean bore significantly higher number of pods at 75 per cent population of sunflower (14.1) than at 100 per cent (12.5) during second year, while the differences were nonsignificant in first year. Among the soybean population levels, intercropping of soybean with 50 per cent population of its sole crop, resulted in highest number of pods per plant (16.8 and 15.9) followed by 75 per cent and was lowest in 100 per cent (13.1 and 9.8). The number of pods per plant did not vary significantly due to planting pattern.

Number of seeds per pod in soybean: Sole crop of soybean had significantly lower number of seeds per pod (2.30 and 2.20) than soybean intercrop (2.58 and 2.53)

Table 4.11 Number of pods per plant, number of seeds per pod, test weight and seed weight of soybean (SB) as influenced by intercropping with sunflower (SF), plant populations and planting patterns of intercrops.

Treatments	No. of pods		No. of seeds/ pods		Test wt. (g/100 seeds)		Seed wt. (g/pl.)	
	1988	1989	1988	1989	1988	1989	1988	1989
1. Sole V/s Intercrop								
(a) Sole crop	21.2	20.0	2.30	2.20	17.61	16.52	7.70	6.32
(b) Intercrop	14.8	13.3	2.58	2.53	15.46	14.09	5.41	4.51
'F' test	**	**	*	*	**	**	**	**
S.Em+ (a)	1.4	1.3	0.13	0.13	0.32	0.34	0.49	0.42
(b)	0.4	0.4	0.04	0.04	0.09	0.10	0.14	0.12
C.D. at 5%	3.01	2.8	0.27	0.28	0.69	0.73	1.06	0.91
2. Within intercrop								
a. SF Population								
75% of sole	15.6	14.1	2.61	2.48	15.33	14.39	5.92	4.77
100% of sole	14.0	12.5	2.55	2.58	15.59	13.79	4.90	4.25
'F' test	NS	*	NS	NS	NS	**	**	*
S.Em+	0.66	0.5	0.05	0.05	0.13	0.14	0.20	0.17
C.D. at 5%	--	1.6	--	--	--	0.41	0.59	0.51
b. SB population								
50% of sole	16.8	15.9	2.49	2.41	16.78	15.02	6.08	5.31
75% of sole	14.5	14.2	2.59	2.53	15.54	14.12	5.57	4.70
100% of sole	13.1	9.8	2.66	2.65	14.06	13.12	4.57	3.53
'F' test	**	**	NS	NS	**	**	**	**
S.Em+	0.7	0.7	0.06	0.06	0.16	0.17	0.25	0.21
C.D. at 5%	2.0	1.9	--	--	0.47	0.50	0.72	0.62
c. Planting pattern								
SF uniform rows	15.4	13.6	2.59	2.53	15.50	14.16	5.67	4.91
SF paired rows	14.2	13.0	2.57	2.53	15.42	14.01	5.15	4.12
'F' test	NS	NS	NS	NS	NS	NS	NS	**
S.Em+	0.6	0.5	0.05	0.05	0.13	0.14	0.20	0.17
C.D. at 5%	--	--	--	--	--	--	--	0.51
C.V. (%)	15.7	16.5	8.6	9.0	3.5	4.1	15.3	15.8

during both the years. Within intercrop, plant population levels of sunflower and soybean, and planting pattern had no significant influence on the number of seeds per pod. However increase in soybean population increased the number of seeds per pod consistently during both the years (2.49 to 2.66 in 1988 and 2.41 to 2.65 in 1989).

Test weight of soybean: The test weight of seeds was significantly more in sole crop (17.61 and 16.52 g/100 seeds) as compared to intercrop (15.46 and 14.09) during both years. In intercropping, sunflower with 75 per cent of its sole crop population gave higher test weight (14.39 g/100 seeds) than 100 per cent during 1989, while no such differences were observed in 1988. Fifty per cent soybean population in intercropping gave highest test weight in 1988 (16.78g/100 seeds) and also in 1989 (15.02 g/100 seed) and they were decreased with increase in plant population to lowest values at 100 per cent population (14.06 and 13.12 g/100 seeds in 1988 and 1989, respectively). Planting patterns in intercropping did not influence the test weight significantly although lower test weight of soybean was observed when grown in between paired rows as compared to uniform rows of sunflower.

Seed weight per plant in soybean: The seed weight of soybean was significantly reduced from 7.70 g to 5.41 g per plant in first year and from 6.32 g to 4.51 g per plant in second year. The extent of reduction in seed weight per plant was around 29 per cent in the two years.

Within intercropping, the differences in the seed weight between plant population levels of sunflower were significant. Increasing sunflower population from 75 per cent to 100 per cent of its sole decreased the seed weight per plant of soybean from 5.92 to 4.90 g and 4.77 to 4.25 g in the first and second years, respectively. Similarly, plant population levels of soybean also affected its seed weight per plant significantly during both the years (6.08 and 5.31 g in 1988 and 1989) and they were decreased with increase in plant population levels to lowest values (4.57 and 3.53 g) at 100 per cent. Between uniform and paired rows, the seed weight per plant was higher under uniform rows of sunflower (5.67 in 1988 and 4.91 in 1989) as compared to paired rows (5.15 and 4.12). However, the differences were nonsignificant during 1988.

Seed yield in soybean : The results obtained on the effect of intercropping with different plant populations and planting patterns on seed yield of soybean are presented in Table 4.12. Intercropping of

Table 4.12 Seed yield, stover yield and harvest index of soybean as influenced by intercropping with sunflower, plant populations and planting patterns of intercrops.

Treatments	Seed yield (q/ha)		Stover yield (q/ha)		Harvest index	
	1988	1989	1988	1989	1988	1989
1. Sole V/s Intercrop						
(a) Sole crop	15.60	13.13	17.61	11.51	0.470	0.533
(b) Intercrop	9.81	8.24	10.51	7.31	0.484	0.531
'F' test	**	**	**	**	NS	NS
S.Em± (a)	0.45	0.54	0.86	0.75	0.011	0.016
(b)	0.13	0.16	0.25	0.22	0.003	0.005
C.D. at 5%	0.97	1.16	1.84	1.61	--	--
2. Within intercrop						
a. SF Population						
75% of sole	10.27	8.65	10.63	7.61	0.493	0.533
100% of sole	9.35	7.82	10.40	7.01	0.475	0.529
'F' test	**	*	NS	NS	*	NS
S.Em±	0.18	0.22	0.35	0.31	0.006	0.006
C.D. at 5%	0.54	0.65	--	--	0.016	--
b. SB population						
50% of sole	6.66	6.30	6.91	5.30	0.491	0.543
75% of sole	11.26	9.27	12.28	8.27	0.478	0.528
100% of sole	11.50	9.15	12.35	8.36	0.482	0.522
'F' test	**	**	**	**	NS	NS
S.Em±	0.23	0.27	0.43	0.38	0.008	0.008
C.D. at 5%	0.66	0.79	1.25	1.09	--	--
c. Planting pattern						
SF uniform rows	10.34	9.16	11.10	8.11	0.483	0.532
SF paired rows	9.28	7.31	9.92	6.51	0.484	0.531
'F' test	**	**	*	**	NS	NS
S.Em±	0.18	0.22	0.35	0.31	0.006	0.006
C.D. at 5%	0.54	0.65	1.02	0.89	--	--
C.V. (%)	7.6	10.9	13.4	17.0	5.0	4.7

soybean with sunflower significantly lowered the seed yield both during 1988 (15.60 to 9.81 a/ha) and 1989 (13.13 to 8.24 q/ha). The extent of reduction in yield due to intercropping was around 37 per cent.

In intercropping, the seed yields were significantly higher with 75 per cent sunflower population (10.27 and 8.65 q/ha) as compared to 100 per cent (9.35 and 7.82 q/ha) both during first and second years, respectively. Among the soybean populations, the seed yields were significantly increased with increase in population from 50 per cent to 75 per cent during first year (6.66 to 11.26 q/ha) and also during second year (6.30 to 9.27 q/ha), and further increase in population did not bring significant increase in seed yield (11.50 and 9.15 q/ha during 1st and 2nd years). Between the planting patterns in intercropping, soybean grown in between sunflower uniform rows yielded significantly higher (10.34 and 9.16 q/ha in 1988 and 1989) as compared to soybean in between the sunflower paired rows (9.28 and 7.31 q/ha).

Stover yields in soybean: The data on stover yield of soybean are given in Table 4.12. Soybean in pure stand gave significantly higher stover yield (17.61 q/ha in 1988 and 11.51 q/ha in 1989) than in mixed stand with sunflower (10.51 and 7.31 q/ha). The stover yields did not vary significantly between plant populations of sunflower in intercropping. However, lower populations of sunflower favoured slightly higher soybean yields in both the years. The increase in soybean population from 50 to 75 per cent in intercropping had a direct and significant effect in enhancing the stover yield from 6.91 to 12.28 q/ha during first year and from 5.30 to 8.27 q/ha during second year, while further increase in population to 100 per cent did not bring significant increase. Planting patterns in intercropping also brought significant change with higher stover yield of soybean under sunflower uniform rows (11.10 q/ha in 1988 and 8.11 q/ha in 1989) as compared to paired rows (9.92 and 6.51 q/ha).

Harvest index of soybean (Table 4.12): Intercropping did not bring any significant change in HI of soybean during both the years. However, in intercropping, 100 per cent plant population of sunflower significantly decreased HI (0.475) as compared to 75 per cent (0.493) during 1988. It was nonsignificant during 1989 (0.533 to 0.529). Among the soybean populations, the observed variation in HI both during first and second years were not statistically significant. However, the treatments with higher plant populations showed trends in decreased HI. Similarly, planting pattern also did not bring any significant change in HI of soybean.

4.1.3 Canopy architecture and light transmission in intercropping

Crop canopy architecture and light transmission per cent at 60 days after sowing as affected by pure and intercropping system, planting geometry and plant populations of intercrops are graphically depicted in Fig. 4.1 to 4.6.

4.1.3.1 Canopy architecture

It is observed that the leaf area per plant of sunflower was higher in pure crop (Fig. 4.1, 2796 cm^2) than in sunflower intercrop (mean = 2083, Fig. 4.3 to 4.6). And in intercrop, the leaf area per plant of sunflower was decreased with increase in population of component crops (2418 cm^2 in Fig. 4.3 to 1830 cm^2 in Fig. 4.5). Similar to leaf area per plant, the vertical canopy area per plant of sunflower was also higher in pure crop (4049 cm^2, Fig. 4.1) as compared to intercrop (mean= 2731 cm^2, Fig. 4.3 to 4.6). And the vertical canopy area of sunflower in intercropping was higher in treatment of lower plant populations (2971 cm^2, Fig. 4.3) and it decreased with increase in the population pressure of component crops (2728 cm^2 in Fig. 4.4 to 2393 cm^2 in Fig. 4.5). Howerver, paired row planting of sunflower resulted in higher canopy area although the leaf area per plant was less (Fig. 4.6, LA = 1809 cm^2

and canopy area = 2832 cm^2) as compared to uniform rows (Fig. 4.5, LA = 1830 cm^2 and canopy area = 2393 cm^2) of sunflower at a given population of component crops (100% sunflower + 100% soybean population).

The leaf area of soybean was higher in sole stand (1307 cm^2/plant, Fig. 4.2) as compared to mixed stand (mean = 1114 cm^2/plant, Fig. 4.3 to 4.6). Within mixed stand, the leaf area of soybean was ~~was~~ more in treatments with lower plant populations (1198 and 1156 cm^2/plant in Fig 4.3 and 4.4, respectively) and less in treatments with higher population pressure (983 and 923 cm^2/plant in Fig 4.5 and 4.6, respectively). Similarly, the vertical canopy area also followed the same trend with highest canopy area in sole crop of soybean (1190 cm^2/plant Fig. 4.2) followed by intercropped soybean of treatments with lower population pressure (1166 and 1080 cm^2/plant, Fig. 4.3 and 4.4) and was lowest in treatments of highest population pressure accompanied by paired row planting (Fig. 4.6, 950 cm^2).

The per cent canopy overlapping was calculated by a formula

$$= \frac{\text{Canopy area overlapped X 2}}{\text{Total canopy area of both sunflower and soybean}} \times 100$$

The factor 2 is used because the canopy area overlapped is the area of individual plant involved in overlapping. So for two plants, the total canopy area overlapped is twice the actual overlapping area.

There was no overlapping of the canopy in pure sunflower crop, rather there was a wastage of space (Fig 4.1). Wheareas in the pure crop of soybean, the overlapping was to the extent of 9.24 per cent (Fig. 4.2). In sunflower-soybean intercropping with 75 and 50 per cent population levels (Fig. 4.3), respectively no overlapping was observed and in 75+75 per cent combination also, the overlapping per cent was very negligible (Fig. 4.4, 0.94%). Whereas, in 100+100 per cent intercropping combination with uniform row planting of sunflower (Fig. 4.5) the extent of overlapping was 12.60 per cent and it further increased to 14.48 per cent with paired row planting of sunflower (Fig. 4.6).

There was no much variation in the plant height of sunflower. However, in intercrop treatment, with highest plant population pressure accompanied by pairing of sunflower rows (Fig.4.6), the plant height was increased by about 10 cm over pure crop. The height of main stem at the base of the plant without leaves, was around 10 cm in pure crop of sunflower (Fig. 4.1) and also in intercropped sunflower with lowest population levels (Fig. 4.3, 75% sunflower + 50% soybean population) while it was increased to around 22 cm in treatment with 75+75 per cent combination (Fig. 4.4), 30 cm in 100+100 per cent combination with uniform row planting (Fig. 4.5) and to around 38 cm in 100 + 100 per cent combination with paired row planting (Fig. 4.6).

Soybean pure crop (Fig. 4.2) had lower plant height (44 cm) than intercrop (mean = 63 cm, Fig. 4.3 to 4.6). In intercropping, the plant height was less in treatments with lower plant populations of intercrops (58 cm in Fig. 4.3 to 4.6) as compared to those with higher plant populations (70 cm in Fig. 4.5 and 74 cm in Fig. 4.4). Similar to sunflower, the basal height of the main stem in soybean without leaves was comparatively high in intercrop (Fig. 4.3 to 4.6) than in pure crop (Fig. 4.2). And within the intercrop, the height was increased from around 5 cm (Fig. 4.3) in treatment with 75 + 50 per cent population of sunflower and soybean, respectively to as high as 12 to 28 cm in treatments with 100 + 100 per cent combination (Fig. 4.5 and 4.6).

4.1.3.2 Light interception

The intensity expressed as per cent of total solar radiation (% TSR) available at the ground level

Fig 4.1 to 4.6 Horizontal and vertical spread of the plant with its leaf area (values at the mid vertical axis of each plant canopy) at different canopy heights and per cent total solar radiation (% TSR) available at the top of soybean (--x--x--x--) and at ground level (-----) in sunflower (SF)-soybean (SB) intercropping system

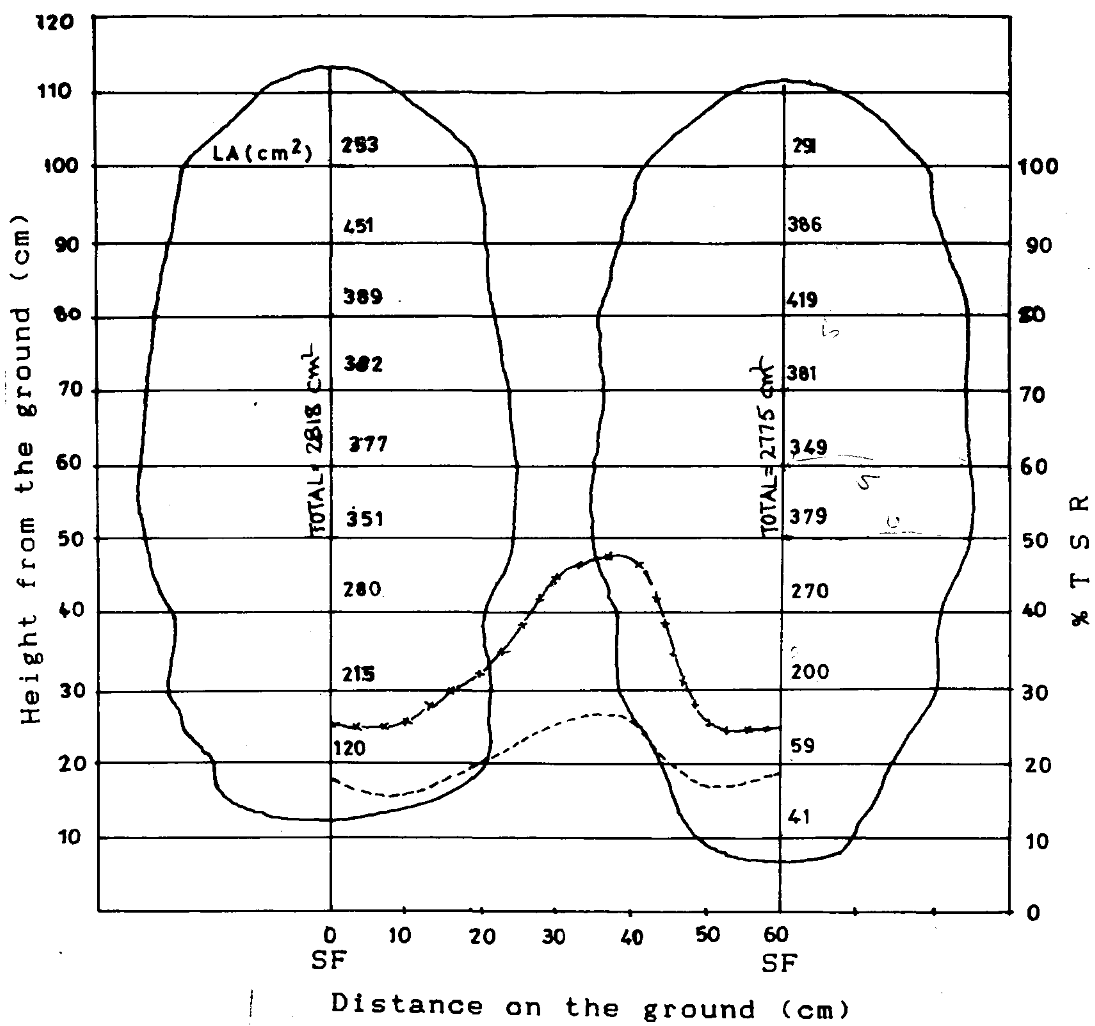


Fig 4.1 Sunflower alone (SF)

Canopy characters	SF
1. Leaf area (cm^2/plant)	2796
2. Vertical canopy area (cm^2/plant)	4049
3. Per cent canopy overlapping	0

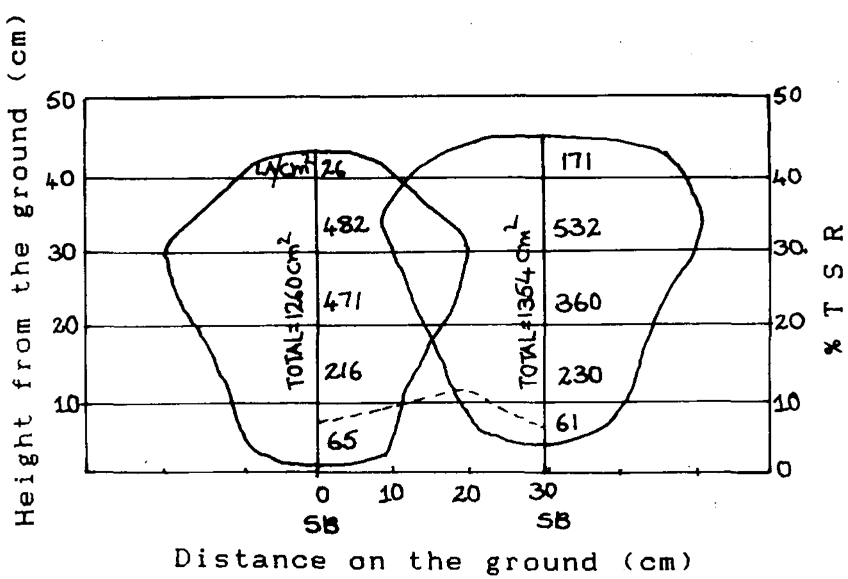
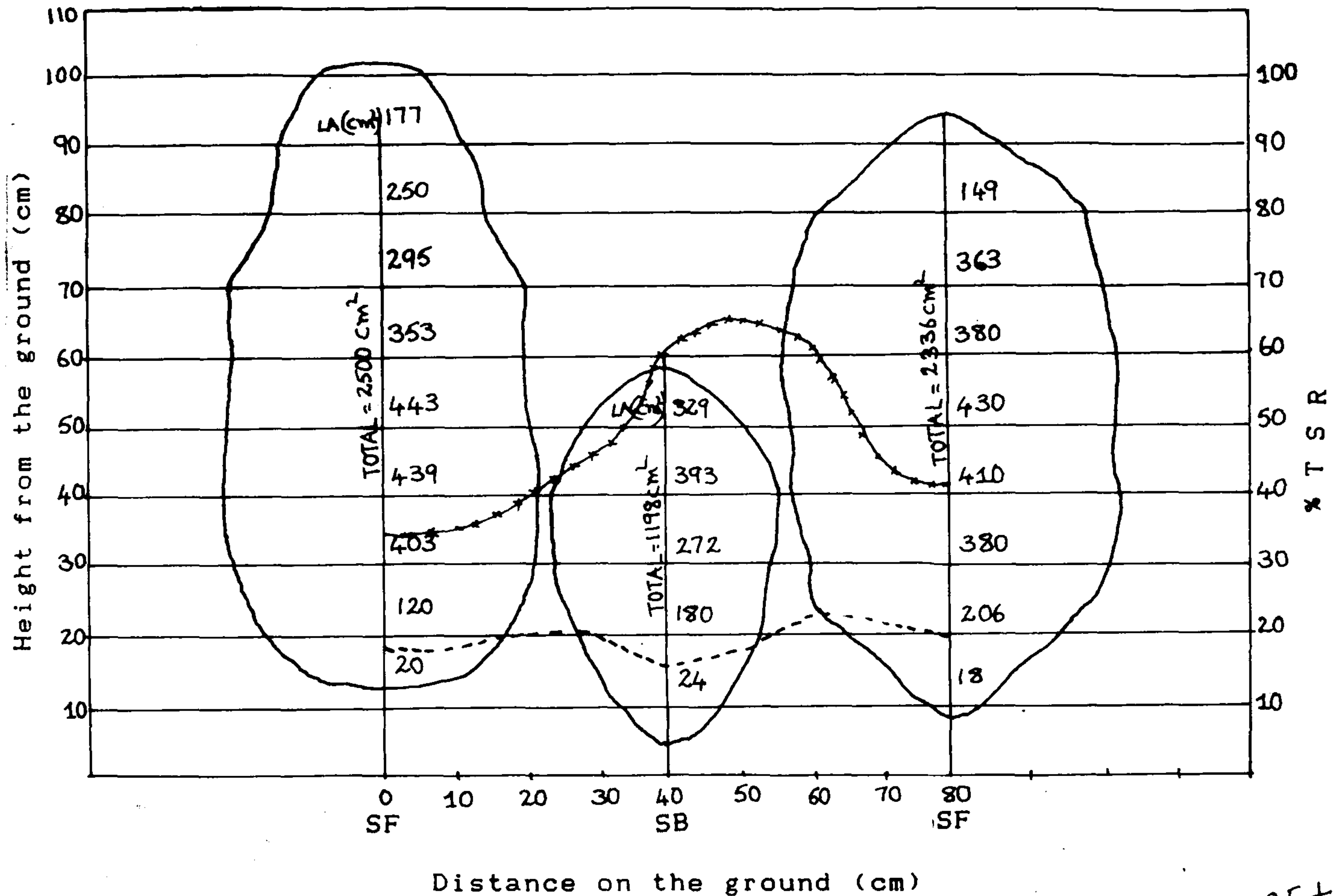


Fig 4.2 Soybean alone (SB)

Canopy characters	SB
1. Leaf area (cm^2/plant)	1307
2. Vertioal oanopy area (om^2/plant)	1190
3. Per cent canopy overlapping	9.24



SF+SB (75:50)

Fig 4.3 Sunflower+soybean - alternate rows with 75% sunflower and 50% soybean population

Canopy characters	SF	SB
1. Leaf area (cm^2/plant)	2418	1198
2. Vertical canopy area (cm^2/plant)	2971	1166
3. Per oent oanopy overlapping	0	
4. Canopy surface area inorease over pure crop	1.35 times	

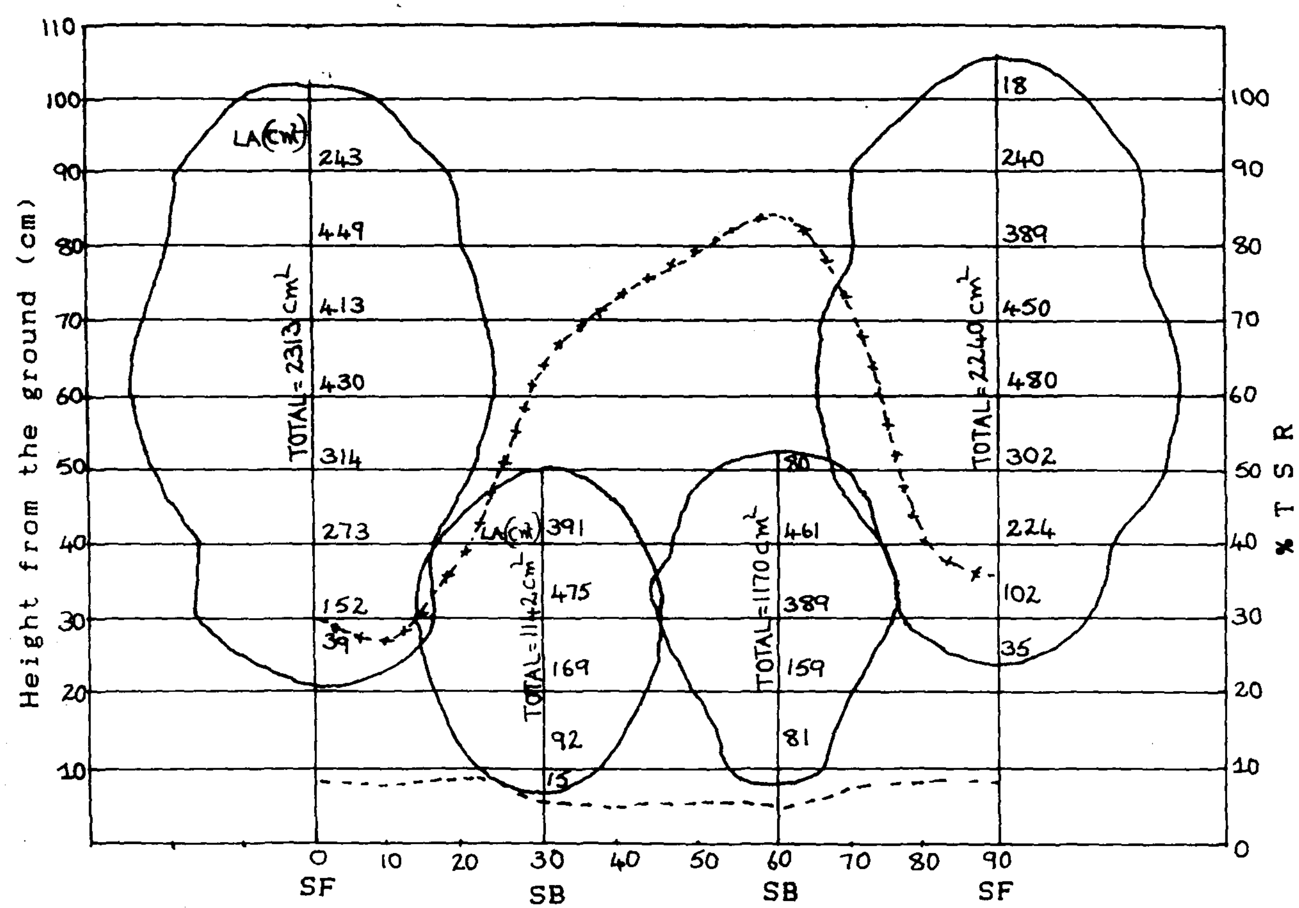


Fig 4.4 Uniform rows of sunflower and two rows of soybean in between, with 75% sunflower+75% soybean population

Canopy characters	SF	SB
1. Leaf area (cm^2/plant)	2276	1156
2. Vertical canopy area (cm^2/plant)	2728	1080
3. Per oent canopy cverlapping	0.94	
4. Canopy surface area increase over pure crop	1.51 times	

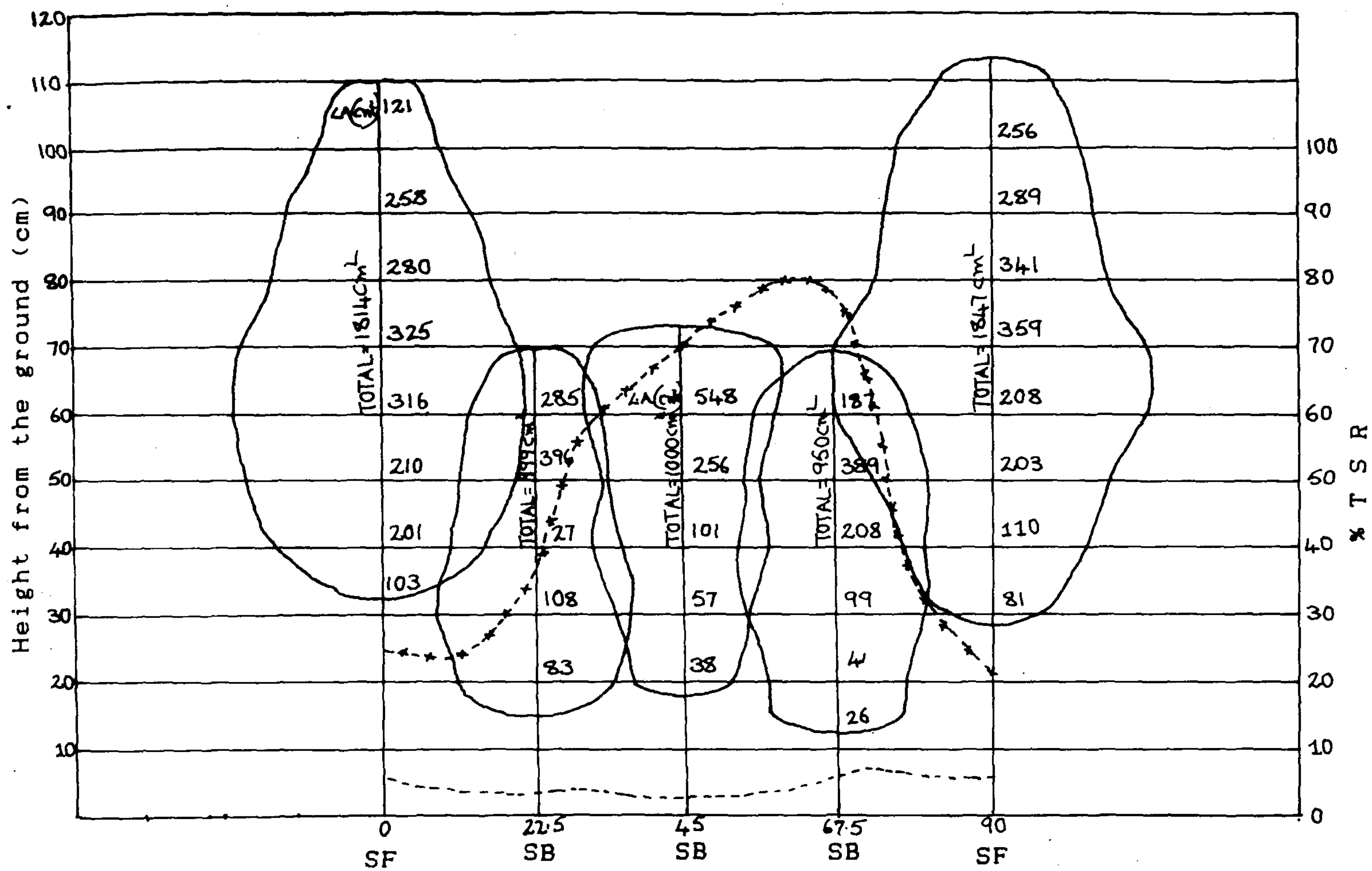


Fig 4.5 Uniform rows of sunflower and three rows of soybean in between them with 100% sunflower+100% soybean population

Canopy characters	SF	SB
1. Leaf area (cm^2/plant)	1830	983
2. Vertical canopy area (cm^2/plant)	2393	1261
3. Per cent canopy overlapping	12.6	
4. Canopy surface area increase over pure crop	1.33	times

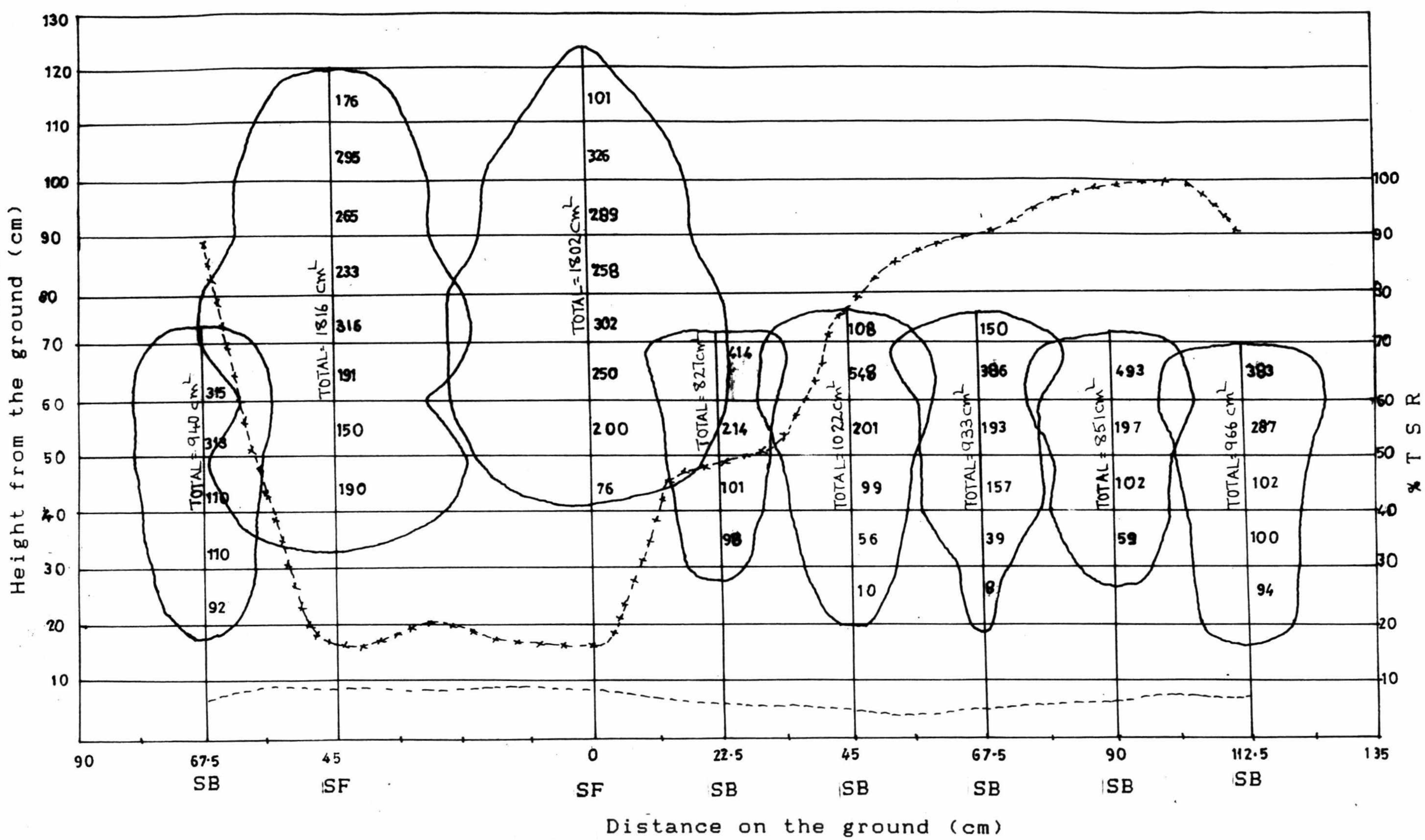


Fig 4.6 Paired rows of sunflower and five rows of soybean in between them with 100% sunflower+100% soybean population

Canopy characters	SF	SB
1. Leaf area (cm^2/plant)	1809	923
2. Vertical canopy area (cm^2/plant)	2832	950
3. Per cent canopy overlapping	14.48	
4. Canopy surface area increase over pure crop	1.16 times	

and at the top of soybean component in intercropping, was measured.

In pure sunflower, the light intensity available on the ground was considerably higher (Fig. 4.1, 18% of TSR at the base of the plant and 26 % at the middle of two rows). At 50 cm height from the ground (assuming the canopy height of soybean) the light intensity available in middle of two sunflower rows was around 48 per cent (Fig. 4.1) of the total solar radiation.

In pure crop of soybean, the light intensity available near the ground level was less than 10 per cent towards the rows and slightly more than 10 per cent in the middle of two rows (Fig. 4.2).

In the intercropping treatment with 75 and 50 per cent population of sunflower and soybean respectively, (Fig. 4.3) the light intensity near the ground was around 16 to 23 per cent, and at the top of soybean canopy, it was less than 50 per cent towards the sunflower rows and 50 to 65 per cent at the center of the rows. In treatment with (Fig. 4.5) 75 per cent population of each component, the light intensity near the ground was around 6 to 8 per cent and at the top canopy of soybean, it ranged from 60 to 85 per cent towards the middle of sunflower rows and less than 60 to as low as 30 per cent near the main stems of sunflower.

At 100 per cent population levels of each component in sunflower-soybean intercropping, the light intensity at the bottom ranged from 3 to 7 per cent in uniform row planting of sunflower (Fig. 4.5) 4 to 9 per cent in paired row planting (Fig. 4.6). Near the top of soybean canopy the maximum light intensity was around 80 per cent near the center and it decreased towards the sunflower rows to as low as 21 per cent (Fig. 4.5). Whereas in paired row planting (Fig. 4.6), the light intensity at the top of soybean was as high as 100 per cent and decreased towards the sunflower rows to a minimum of slightly less than 20 per cent near the mainstems of sunflower. It was also observed from the two light intensity curves (drawn using the light intensities at the ground and at the top of soybean) that the distance between them was widened with increase in spacing between the sunflower rows.

4.1.3.3 Area of canopy surface exposed to the sun

The methodology of calculating the canopy surface exposed to the sun is depicted in Fig. 4.4a and 4.6a along with the calculations. The top canopy surface of any crop of a given variety is flat and the area of it is exactly equal to the land area sown (eg.

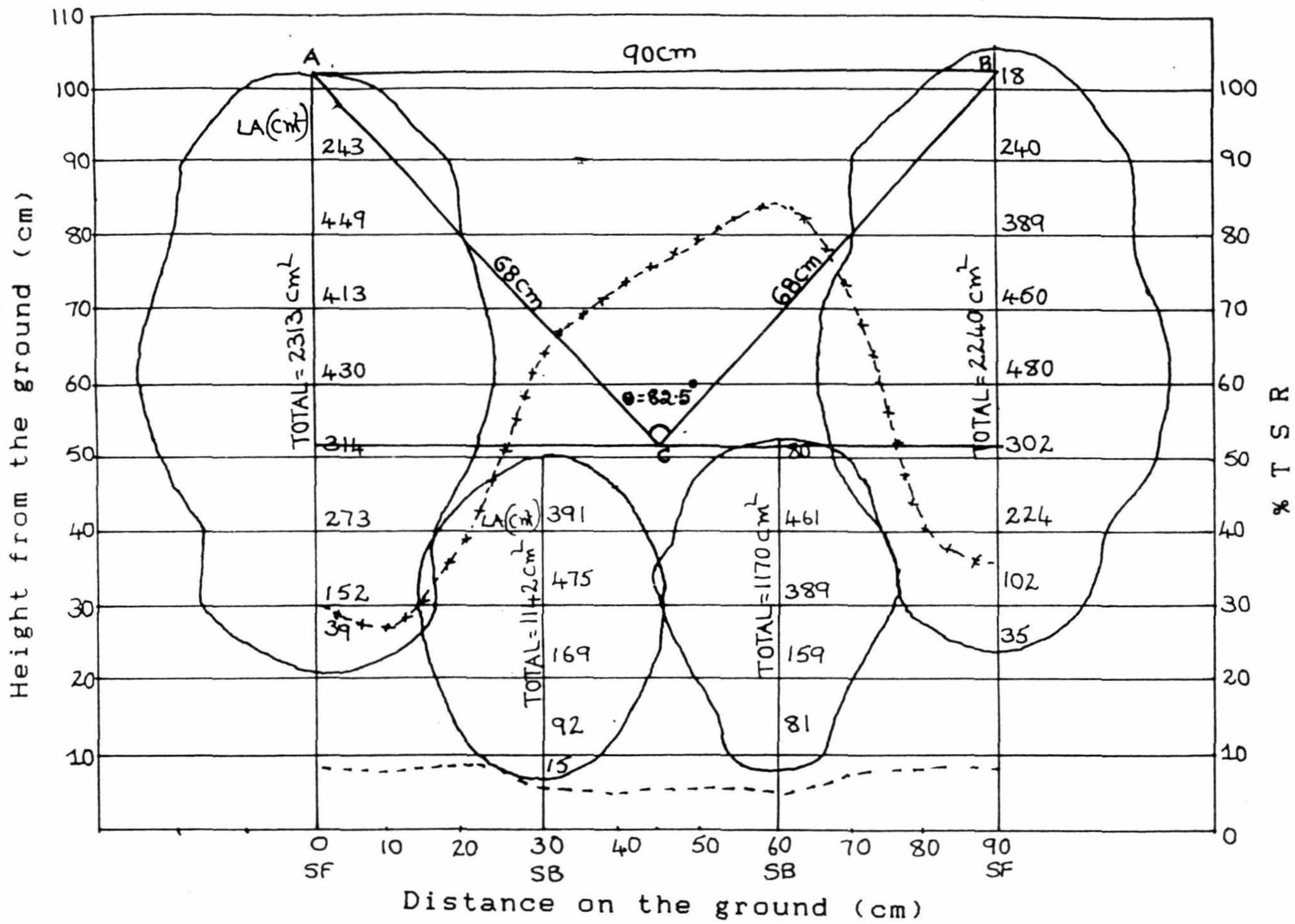


Fig 4.4a Uniform rows of sunflower and two rows of soybean in between, with 75% sunflower+75% soybean population

$$\text{Canopy surface area} = \frac{AC+BC}{AB} = 1.51 \text{ times more than pure crop}$$

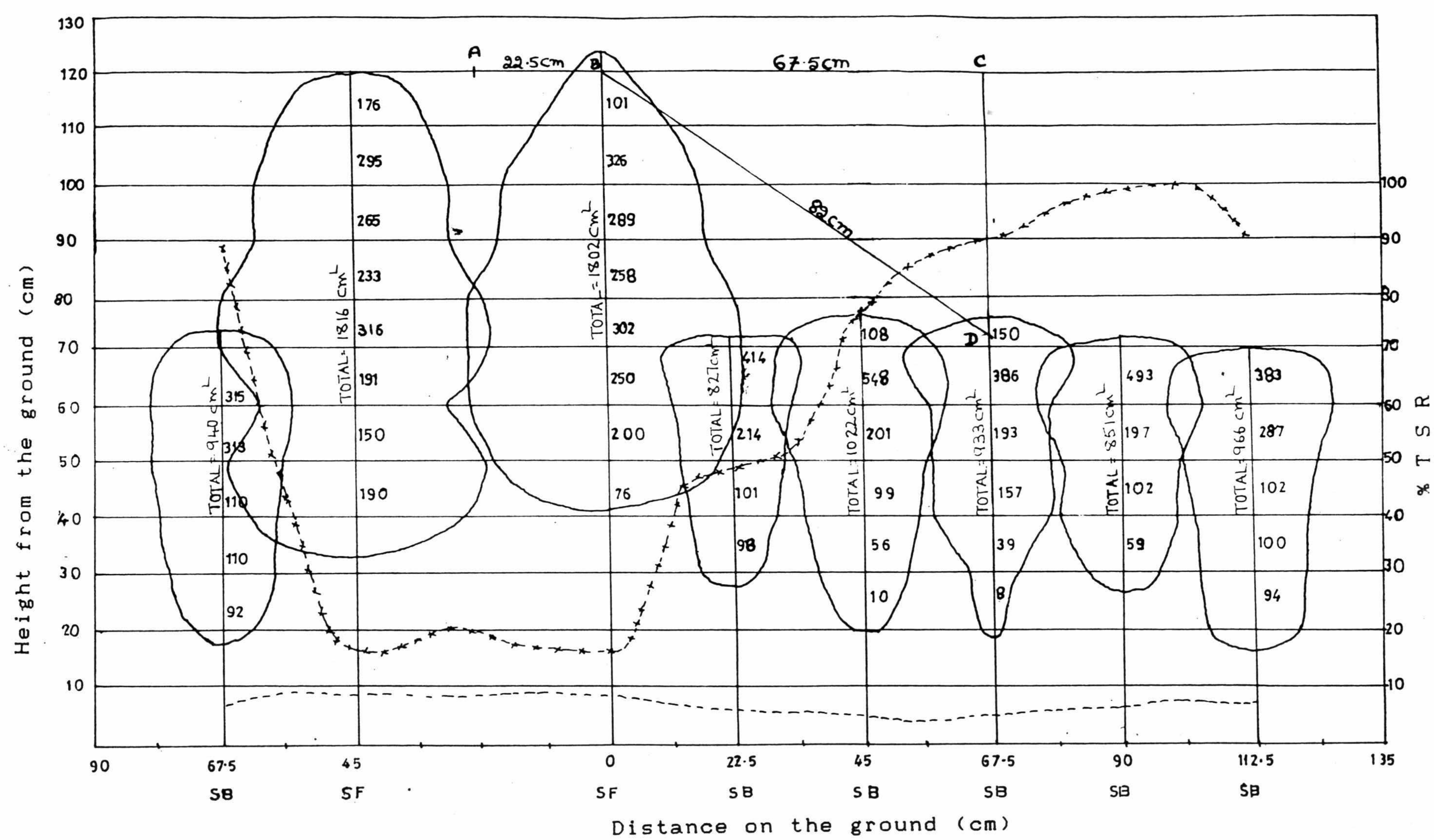


Fig 4.6a Paired rows of sunflower and five rows of soybean in between them with 100% sunflower+!00% soybean population

$$\text{Canopy surface area} = \frac{2\ (AB + BD)}{2\ (AB + BC)} = 1.16 \text{ times more than pure crop}$$

pure crops of sunflower and soybean in this study). The sunflower -soybean intercropping produced a pyramidal canopy instead of a flat one (see Fig. 4.4a). The angle (θ) between the two adjoining pyramids (Fig. 4.4a) is inversely proportional to the area of the canopy surface and hence the area of the canopy increases with decreases in the angle.

Among the different intercropping treatments of this study, it was observed that the treatment combination of uniform rows of sunflower and two rows of soybean in between with 75% population of each (Fig 4.4) produced the highest canopy surface area of 1.51 times that of either sole crops followed by the treatments viz., sunflower + soybean alternate rows with 75% + 50% populations (1.35 times, Fig. 4.3), uniform rows of sunflower and three rows of soybean in between them with 100% population of each (1.33, Fig 4.5) and was lowest in treatment combination of paired rows of sunflower and five rows of soybean in between them with 100% population of each (1.16, Fig. 4.6).

4.4 Combined growth, yield and income of sunflower - soybean intercropping

4.4.1 Total leaf area index (LAI)

The data on the sum of LAI of two component crops as influenced by the cropping system, plant populations and planting patterns of intercrops are presented in Table 4.13. Amdng the systems, soybean pure crop had highest LAI (4.28 and 3.73) followed by sunflower-soybean intercrop (3.16 and 3.30) and was lowest in sunflower sole crop (1.16 and 2.16) in both first and second years, respectively. In intercropping, sunflower population did not significantly influence the total LAI during 1988 (3.11 to 3.21), while during 1989 lower sunflower population resulted in significantly higher LAI (3.41 at 75%) as compared to higher population (3.19 at 100%). On the contrary, soybean population had significant positive effect on the total LAI. The total LAI was increased from 2.55 at 50 per cent of soybean population to 3.33 at 75 per cent and 3.58 at 100 per cent during 1988 and during 1989, the corresponding figures were 2.97, 3.32 and 3.60. Between the planting patterns, sunflower in uniform rows with soybean introduced in between, displayed significantly higher canopy cover (3.27 and 3.42) than paired rows of sunflower with soybean intercropped between them (3.04 and 3.17) during both the years.

The interaction effect between plant populations of sunflower and soybean on total LAI proved significant during 1989 season (Table 4.14). Lowest total LAI of 2.87 was recorded at minimum plant

Table 4.13 Total leaf area index at 55 days after sowing and total biomass yield of sunflower (SF) - soybean (SB) intercropping system as influenced by plant populations of component crops and planting patterns.

Treatments	Total LAI			Total biomass (q/ha)		
	1988	1989	Mean	1988	1989	Mean
1. Between systems (S)						
SF sole crop (S_1)	1.16	2.16	1.66	24.13	40.98	32.55
SB sole crop (S_2)	4.28	3.73	4.00	33.21	24.64	28.92
Intercrop (S_3)	3.16	3.30	3.23	36.92	44.96	40.94
'F' test	**	**		**	**	
S.Em± (S_1)	0.20	0.17		1.25	1.38	
(S_2)	0.20	0.17		1.25	1.38	
(S_3)	0.06	0.05		0.36	0.40	
C.D. at 5% S_1 & S_2	0.58	0.50		3.64	4.03	
S_1 & S_3	0.43	0.37		2.68	2.96	
S_2 & S_3	0.43	0.37		2.68	2.96	
2. Within intercrop						
a. SF Population						
75% of sole	3.11	3.41	3.26	35.56	44.60	40.08
100% of sole	3.21	3.19	3.20	37.27	45.33	41.30
'F' test	NS	*		*	NS	
S.Em±	0.08	0.07		0.51	0.56	
C.D. at 5%	--	0.11		1.49	--	
b. SB population						
50% of sole	2.55	2.97	2.76	31.09	42.64	36.86
75% of sole	3.33	3.32	3.32	39.95	46.13	43.04
100% of sole	3.58	3.60	3.59	39.97	46.11	43.04
'F' test	**	**		*	NS	
S.Em±	0.10	0.09		0.62	0.69	
C.D. at 5%	0.30	0.25		1.82	2.01	
c. Planting pattern						
SF uniform rows	3.27	3.42	3.34	38.74	47.52	43.13
SF paired rows	3.04	3.17	6.21	35.10	42.40	38.75
'F' test	*	*		**	**	
S.Em±	0.08	0.07		0.51	0.56	
C.D. at 5%	0.24	0.11		1.49	1.64	
C.V. (%)	11.49	9.3		6.1	5.5	

Table 4.14 Total leaf area index of sunflower-soybean intercropping system at 55 days after sowing as influenced by the interaction between plant populations of component crops during 1989.

Plant Population	soybean		
	50%	75%	100
Sunflower			
75%	2.87	3.41	3.94
100%	3.07	3.24	3.25
F test		**	
S.E.m±		0.12	
C.D. at 5%		0.36	

populations of both the components (at 50% of soybean and 75% of sunflower), whereas highest total LAI of 3.94 was observed in a treatment combination of 75 per cent sunflower and 100 per cent soybean populations.

4.1.4.2 The total biomass (Table 4.13): The biomass production differed significantly among the systems. Highest biomass was produced from sunflower - soybean intercropping in both first (36.92 q/ha) and second (44.96 q/ha) years followed by pure crop of soybean (33.21 q/ha) and sunflower (24.13 q/ha) in first year and pure crop of sunflower (40.98 q/ha) and soybean (24.64 q/ha) in the second year.

Between sunflower populations in intercropping, maintaining 100 per cent population as in sole crop, gave significantly higher biomass yield (37.27 q/ha) as against 75 per cent (35.56 q/ha) during 1988. However, the differences were nonsignificant in 1989. During both the years, with increasing soybean population from 50 to 75 or 100 per cent, there was significant raise in the biomass yield (31.09 to 39.95 or 39.97 q/ha in 1988 and 42.64 to 46.13 or 46.11 q/ha in 1989). Planting geometry in intercropping also brought out a significant change in the biomass yield. Intercropping of sunflower and soybean with sunflower in uniform rows and soybean introduced in between resulted in higher total biomass (38.74 q/ha and 47.52 q/ha) as compared to sunflower in paired rows with soybean in between them (35.10 and 42.40 q/ha) during first year and also second year, respectively.

4.1.4.4 Total oil yield : The data on the total oil yield as influenced by pure and intercropping system of sunflower and soybean, plant populations and planting patterns of intercrops are presented in Table 4.15. From among the crops and cropping systems, the total oil yield varied significantly in both the years. Intercropping of sunflower and soybean resulted in maximum oil yield of 4.22 and 5.43 q per ha followed by pure crop of sunflower (3.19 and 4.98 q/ha) and lowest was in soybean pure crop (2.89 and 2.49 q/ha) during first and second years, respectively.

Within intercropping, plant populations of sunflower did not bring any significant changes in total oil yield. Whereas, increase in the total plant population of soybean intercrop from 50 to 75 per cent resulted in additional oil yield of 0.70 and 0.37 q

Table 4.15 Total oil yield and gross income from sunflower (SF) - soybean (SB) intercropping system as influenced by plant populations of component crops and planting patterns.

Treatments	Oil yield (q/ha)			Gross income (Rs./ha)		
	1988	1989	Mean	1988	1989	Mean
1. Between systems (S)						
SF sole crop (S_1)	3.19	4.98	4.08	3278	5244	4261
SB sole crop (S_2)	2.89	2.49	2.69	4680	3938	4309
Intercrop (S_3)	4.22	5.43	4.82	5410	6539	5974
'F' test	**	**		**	**	
S.Em± (S_1)	0.10	0.14		137	163	
(S_2)	0.10	0.14		137	163	
(S_3)	0.03	0.04		40	50	
C.D. at 5% S_1 & S_2	0.28	0.40		399	473	
S_1 & S_3	0.20	0.30		294	348	
S_2 & S_3	0.20	0.30		294	348	
2. Within intercrop						
a. SF Population						
75% of sole	4.18	5.35	4.76	5427	6502	5964
100% of sole	4.25	5.50	4.87	5392	6576	5984
'F' test	NS	NS		NS	NS	
S.Em±	0.04	0.06		56	66	
C.D. at 5%	--	--		--	--	
b. SB population						
50% of sole	3.74	5.18	4.46	4577	6088	5332
75% of sole	4.44	5.55	4.99	5796	6779	6287
100% of sole	4.47	5.54	5.00	5857	6749	6303
'F' test	**	*		**	**	
S.Em±	0.05	0.07		69	81	
C.D. at 5%	0.14	0.20		200	236	
c. Planting pattern						
SF uniform rows	4.41	5.70	5.05	5665	6924	6294
SF paired rows	4.02	5.15	4.58	5154	6154	5654
'F' test	**	**		**	**	
S.Em±	0.04	0.06		56	66	
C.D. at 5%	0.11	0.16		163	193	
C.V. (%)	4.1	4.6		4.6	4.5	

per ha. Further increase in population to 100 per cent did not bring any significant change. Between the planting patterns, intercropping of sunflower in uniform rows and soybean introduced in between gave significantly higher oil yield (4.41 q/ha in 1988 and 5.70 q/ha in 1989) as compared to the planting geometry of sunflower in paired rows and soybean grown in between (4.02 and 5.15 q/ha).

4.1.4.5 Gross income from sunflower and soybean (Table 4.15):

Between the systems, the gross income derived from sunflower-soybean intercrop was significantly higher (Rs. 5410 and 6539/ha) as compared to pure crops of either sunflower or soybean. Whereas within pure crops, soybean yielded significantly higher income (Rs. 4680/ha) as compared to sunflower (Rs. 3278/ha) during first year, while in the second year, sunflower gave significantly higher income (Rs. 5444/ha) than soybean (Rs. 3938/ha). The extent of increase in gross income due to intercropping over mean of sunflower and soybean pure crops was 36.0 and 42.4 per cent during first and second years, respectively.

Between plant populations of sunflower in intercropping, the difference in income was statistically nonsignificant. Whereas, increase in the plant population of soybean intercrop from 50 per cent to 75 or 100 per cent significantly increased the income (Rs. 4577 at 50% to Rs. 5796 at 75% or Rs. 5857/ha at 100 % in first year and Rs. 6088 to 6779 or 6749 /ha in second year). Planting pattern in intercropping also affected the gross income significantly. Intercropping of soybean with uniform row planting of sunflower gave Rs. 511 and 770 more per ha as against paired row planting during 1988 and 1989, respectively.

4.1.5 Competition functions

4.1.5.1 Land equivalent ratio (LER) (Table 4.16):

Partial Land equivalent ratio (PLER) of sunflower: Keeping 75 per cent of sunflower population in intercropping resulted lower PLER values (0.71 in 1988 and 0.74 in 1989) as compared to 100 per cent (0.79 and 0.80). Among soybean populations, introducing only 50 per cent of its sole crop population in intercropping resulted in highest PLER of sunflower (0.78 and 0.80) followed by 75 (0.74 and 0.76) or 100 per cent (0.73 and 0.76) both during first and second years, respectively. Between planting patterns higher PLER of sunflower was obtained from its uniform rows (0.78 in 1988 and 0.79 in 1989) than paired rows (0.72 and 0.75) in intercropping.

Table 4.16 Partial and total land equivalent ratios (PLER & LER) of sunflower (SF) - soybean (SB) intercropping system as influenced by plant populations of component crops and planting patterns.

Treatments	1988			1989			Mean LER
	PLER of SF	PLER of SB	LER	PLER of SF	PLER of SB	LER	
1. Between systems(S)							
SF sole crop	1.00	--	1.00	1.00	--	1.00	1.00
SB sole crop	--	1.00	1.00	--	1.00	1.00	1.00
Intercrop	0.75	0.63	1.38	0.77	0.63	1.40	1.39
2. Within intercrop							
a. SF Population							
75% of sole	0.71	0.66	1.37	0.74	0.66	1.40	1.38
100% of sole	0.79	0.60	1.39	0.80	0.59	1.39	1.39
b. SB population							
50% of sole	0.78	0.43	1.21	0.80	0.48	1.28	1.24
75% of sole	0.74	0.72	1.46	0.76	0.70	1.46	1.46
100% of sole	0.73	0.73	1.46	0.76	0.69	1.45	1.45
c. Planting pattern							
SF uniform rows	0.78	0.66	1.44	0.79	0.70	1.49	1.46
SF paired rows	0.72	0.59	1.31	0.75	0.56	1.31	1.31

Partial Land equivalent ratio (PLER) of soybean: In intercropping, with 75 per cent of sunflower population resulted in higher PLER of soybean (0.66 in 1988 and 1989) than 100 per cent population (0.60 and 0.59). Increase in plant population of soybean from 50 to 75 per cent brought a remarkable increase in its PLER from 0.43 to 0.72 in 1988 and from 0.48 to 0.70 in 1989, while further increase in plant population slightly altered the PLER values during both the years. Introducing soybean in between uniform rows of sunflower gave higher PLER (0.66 and 0.70) than between paired rows (0.59 and 0.56).

Total Land equivalent ratio (LER): The results of total LER values revealed the advantages of going for sunflower-soybean intercropping (1.38 and 1.40 in 1988 and 1989) than either pure crops (1.00).

Sunflower population in intercropping did not bring considerable change in the total LER values during both the years. Whereas, increase in soybean population from 50 to 75 per cent increased the total LER from 1.21 to 1.46 in first year and from 1.28 to 1.46 in the second year and further increase in the population to 100 per cent, did not affect the LER.

Between the planting patterns, in intercropping, sunflower in uniform rows gave higher

LER of 1.44 and 1.49 in 1988 and 1989, respectively as against 1.31 in paired rows during both the years.

Interaction among plant population levels of component crops and planting patterns showed that the treatment combinations of either 75+75, 75+100, 100+75 or 100+100 per cent plant populations of sunflower + soybean respectively, complementing with uniform rows of sunflower in intercropping were found to be superior in terms of land equivalent ratios (1.51 to 1.56) to other treatment combinations during both the years (1.17 to 1.42, Table 4.17).

4.1.5.2 Competitive ratio

The data on competitive ratio (CR) values of sunflower and soybean in intercropping in respect of seed yield per ha as influenced by population levels of component crops and planting pattern are presented in Table 4.18. In general, the competitive ability of sunflower was more (1.96) than soybean (0.54) on an average of two years.

Between the population levels of sunflower in intercropping, with 75 per cent of sole crop population competitive ability was less (1.74 and 1.80) than 100 per cent population (2.13 and 2.18) in influencing the seed yield of sunflower during both 1988 and 1989,

Table 4.17 Interaction effects among plant populations of component crops and planting patterns on land equivalent ratio in sunflower-soybean intercropping system.

Year		1988		1989	
Treatments		Uniform rows	Paired rows	Uniform rows	Paired rows
Population of					
SF	SB				
75%	50%	1.24	1.13	1.37	1.17
	75%	1.51	1.42	1.55	1.39
	100%	1.53	1.39	1.56	1.37
100%	50%	1.29	1.19	1.37	1.21
	75%	1.53	1.37	1.56	1.36
	100%	1.54	1.40	1.54	1.36

Table 4.18 Competitive ratio (CR) values for seed yields of sunflower (SF) and soybean (SB) in intercropping as influenced by population levels of component crops and planting patterns.

Treatments	CR of sunflower			CR of soybean		
	1988	1989	Mean	1988	1989	Mean
1. SF population						
75% of sole	1.74	1.80	1.77	0.60	0.59	0.59
100% of sole	2.13	2.18	2.15	0.49	0.48	0.48
2. SB population						
50% of sole	1.60	1.46	1.53	0.63	0.69	0.66
75% of sole	1.88	1.98	1.93	0.54	0.51	0.52
100% of sole	2.31	2.53	2.42	0.47	0.41	0.44
3. Planting pattern						
SF uniform rows	2.25	2.19	2.22	0.47	0.50	0.48
SF paired rows	1.61	1.78	1.69	0.63	0.58	0.60
Mean	1.93	1.99	1.96	0.55	0.54	0.54

respectively. Among the soybean populations, 50 per cent of sole crop population in intercropping resulted in lowest values of competitive ratio (1.60 and 1.46 and 1988 and 1989) for sunflower. With increase in its population, the competitive ability of sunflower was increased to a maximum of 2.31 and 2.53 at 100% during first and second years, respectively. Sunflower in uniform rows was competitive to a greater extent (2.25 in 1988 and 2.19 in 1989) than in paired rows (1.61 and 1.78).

In soybean, the competitive ability was weakened (0.60 to 0.49 in 1988 and 0.59 to 0.48 in 1989) with increase in sunflower population from 75 to 100 per cent. The soybean population itself also had an adverse effect in its competitive ability and hence the CR values decreased with increase in its population from 50 (0.63 and 0.69) to 75 per cent (0.54 and 0.51) and 100 per cent (0.47 and 0.41) during 1988 and 1989, respectively. Soybean introduced in between sunflower uniform rows were less competitive (0.47 and 0.50) than soybean introduced between pairs (0.63 and 0.58) during both the years.

The interaction effects among plant populations of sunflower and soybean and planting patterns on CR values are presented in Table 4.19. The 100 per cent population of each component with uniform row planting

Table 4.19 Competitive ratio (CR) values for seed yields of sunflower (SF) and soybean (SB) in intercropping as influenced by the interaction among plant population levels of component crops and planting patterns.

Treatments		Mean CR of SF		Mean CR of SB	
		Uniform rows	Paired rows	Uniform rows	Paired rows
Population of					
SF	SB				
75%	50%	1.47	1.31	0.68	0.76
	75%	1.87	1.47	0.53	0.68
	100%	2.79	1.70	0.35	0.53
100%	50%	1.78	1.57	0.56	0.63
	75%	2.23	2.14	0.44	0.46
	100%	3.20	1.99	0.31	0.50

of sunflower, imparted highest competitive ability to sunflower (3.20) followed by treatment combinations of 75 per cent sunflower+100 per cent soybean with sunflower in uniform rows (2.79) and 100 per cent sunflower+75 per cent soybean with sunflower in uniform rows (2.23), while lowest competitive ratio of sunflower (1.31) was observed in lowest population levels of both sunflower (75%) and soybean (50%) with sunflower in paired rows.

The CR value of soybean was highest (0.76) in treatment where it was lowest (1.31) for sunflower (75% sunflower+50% soybean population with sunflower paired rows) and it was lowest (0.31) in treatment where it was highest (3.20) for sunflower (100% population on each sunflower and soybean and sunflower uniform rows).

4.2 Experiment II: Effect of CO_2 fertilization, light enrichment and triacontanol sprays in sunflower-soybean intercropping

4.2.1 Response of sunflower to CO_2, light and triacontanol

4.2.1.1 Growth components of sunflower (Table 4.20)

The growth and yield of sunflower in general was superior during 1988 as compared to 1989 season.

Table 4.20 Growth characters of sunflower as influenced by CO_2 fertilization ($+CO_2$), light enrichment (+ Light) and triacontanol application (+Tria) in sunflower-soybean intercropping system

Treatments	LAI at 68 DAS		Chlorophyll (1989) (mg/g fresh leaf)		Stem girth (cm)		Total DM (g/plant) at 68 DAS		Total DM (g/plant) at maturity	
	1988	1989	Total	Chl.a	1988	1989	1988	1989	1988	1989
1. CO_2										
Control	1.07	1.76	2.24	0.61	6.19	6.84	25.9	43.0	38.2	59.4
$+CO_2$	1.18	1.99	2.23	0.61	6.30	6.91	30.1	49.4	41.4	64.9
'F' test	*	*	NS	NS	NS	NS	**	**	**	**
2. Light										
Control	1.09	1.79	2.23	0.62	5.74	6.32	27.6	44.4	38.6	59.1
+Light	1.17	1.96	2.24	0.60	6.75	7.43	28.4	48.0	41.0	65.3
'F' test	NS	NS	NS	NS	**	**	NS	*	**	**
3. Triacontanol										
Control	1.09	1.80	2.18	0.59	6.02	6.76	28.4	44.4	40.0	59.2
+Tria	1.16	1.96	2.29	0.63	6.47	6.99	27.6	48.0	39.6	65.2
'F' test	NS	NS	**	NS	*	NS	NS	*	NS	**
S.Em±	0.03	0.07	0.01	0.01	0.11	0.13	0.6	0.9	0.3	0.6
C.D. at 5%	0.10	0.21	0.04	--	0.34	0.41	1.9	2.9	0.8	1.7
C.V. (%)	10.2	12.7	1.8	6.3	6.2	6.8	7.9	7.1	2.6	3.2

Leaf area index (LAI): The LAI of sunflower at 68 DAS indicated that CO_2 fertilization to plants significantly improved the LAI of sunflower (1.07 to 1.18 in 1988 and 1.76 to 1.99 in 1989). Whereas, light enrichment to the crop canopy did not prove significant although an increase in the LAI was observed (1.09 to 1.17 and 1.79 to 1.96).

Spraying triacontanol to the crop at three stages viz., Button stage, mid Flowering stage and at mid Seed Filling stage of sunflower, improved the LAI nonsignificantly (1.09 to 1.16 in 1988 and 1.80 to 1.96 in 1989).

Chlorphyll content of sunflower: The total chlorophyll and chlorophyll b content of sunflower in 1989 did not vary significantly by CO_2 and light enrichment to the crop canopy. Whereas, the total chlorophyll content increased significantly from 2.18 to 2.29 mg/g leaf and the chlorophyll b content increased nonsignificantly from 0.59 to 0.63 mg/g leaf material with triacontanol sprays.

Stem girth of sunflower: Stem girth of the plants measured at physiological maturity stage did not vary significantly due to CO_2 treatment, though a trend in increased girth by CO_2 treatment was observed.

Supplemental light to the crop canopy significantly improved the girth of the stem from 5.74 to 6.75 cm in first year and from 6.32 to 7.43 cm in second year. Application of triacontanol increased the stem girth (6.02 to 6.47 cm) in first year, but proved nonsignificant in the second year (6.76 to 6.99 cm).

Interaction between light and triacontanol during 1989 indicated that in the absence of supplemental light, triacontanol application significantly increased the stem girth from 5.33 to 6.14 cm (Table 4.20 a), whereas in the presence of supplemental light, the increase in stem girth due to triacontanol application was not significant (6.70 to 6.80 cm).

Total dry matter production in sunflower: The total DMP of sunflower at 68 DAS and at maturity (Table 4.20) indicated that sunflower responded significantly to the increased CO_2 concentration of the canopy (16.2 % and 14.9 % increase at 68 DAS and 8.4 % and 9.2 % increase at maturity).

Additional light to the canopy did not raise the DM accumulation significantly (27.6 to 28.4 g/plant) in first year, whereas it improved significantly in the second year at 68 DAS (44.4 to 48.0 g/plant). And at maturity significant raise in the DM accumulation by light enrichment was observed during

Table 4.20a Stem girth of sunflower as influenced by the interaction of light and triacontanol in sunflower-soybean intercropping system during 1989 *kharif* season.

	Stem girth (cm)	
	Control	+ tria
Control	5.33	6.14
+ Light	6.70	6.80
F-test	*	
S.Em$\pm$	0.16	
C.D. at 5%	0.48	

both the years (38.6 to 41.0 g/plant and 59.1 to 65.3 g/plant).

Triacontanol application was not effective in increasing the total DM of sunflower during first year while DM increased from 44.4 g to 48.0 g per plant at 68 DAS and from 59.2 to 65.2 g per plant at maturity during the second year.

4.2.1.2 Yield and yield components of sunflower

The results relating to yield components of sunflower viz. head diameter, the number of filled seeds, seed filling per cent per head, test weight, seed weight per plant are presented in Table 4.21, while the seed yield, stalk yield and harvest index are presented in Table 4.22.

Head diameter of sunflower: It was not imporved significantly, though it showed a positive trend towards CO_2 fertilization. Light enrichment of the canopy increased the head diameter from 11.47 to 12.58 cm in 1988 and from 12.84 to 14.19 cm in 1989. Triacontanol application had meagre effect in increasing the head size.

Number of filled seeds in sunflower: The CO_2 fertilization was not effective in increasing number of filled seeds per head. Whereas, supplemental light to

Table 4.21 Yield attributes of sunflower as influenced by CO_2 fertilization (+CO_2), light enrichment (+Light) and triacontanol application (+Tria) in sunflower-soybean inter-cropping system.

Treatments	Head diameter (cm)		No. of filled seeds		Filling per cent		Test weight (g/1000 seeds)		Seed weight (g/plant)	
	1988	1989	1988	1989	1988	1989	1988	1989	1988	1989
1. CO_2										
Control	11.90	13.47	435.2	518.1	74.0	72.3	48.8	44.7	14.71	21.92
+CO_2	12.14	13.56	438.5	524.1	69.4	69.4	47.1	42.8	14.70	22.02
'F' test	NS	NS	NS	NS	**	**	NS	NS	NS	NS
2. Light										
Control	11.47	12.84	412.7	496.7	70.6	70.0	47.3	43.0	14.16	20.65
+Light	12.58	14.19	460.9	545.5	72.8	71.7	48.6	44.5	15.25	23.30
'F' test	*	**	**	**	**	*	NS	NS	**	**
3. Triacontanol										
Control	11.61	13.27	431.4	499.4	70.5	70.0	47.3	43.1	14.58	20.68
+Tria	12.43	13.77	442.2	542.7	72.9	71.7	48.6	44.3	14.83	23.27
'F' test	NS	NS	NS	**	**	*	NS	NS	NS	**
S.Em±	0.30	0.19	10.0	9.7	0.5	0.5	0.9	0.7	0.22	0.51
C.D. at 5%	0.91	0.58	30.3	29.3	1.6	1.4	--	--	0.66	1.54
C.V.(%)	8.6	4.9	7.9	6.5	2.6	2.2	6.6	5.8	5.1	8.0

the canopy increased the number of filled seeds from 412.7 to 460.9 seeds/head in 1988 and from 496.7 to 545.5 seeds/head in 1989. Triacontanol sprays increased the filled seed number insignificantly in the first year (431.4 to 442.2 seeds/head), significantly during second year (499.4 to 542.7 seeds/head).

Seed filling per cent per head in sunflower: The per cent seed filling per head was significantly lower in CO_2 fertilized treatments by 4.6 and 2.9, respectively during 1988 and 1989. On the contrary, light enrichment improved significantly the seed filling per cent from 70.6 to 72.8 during 1988 and 70.0 to 71.7 during 1989. Similarly, triacontanol sprays brought significant enhancement in the seed filling per cent in the two years (70.5 to 72.9 and 70.0 to 71.7).

Test weight of sunflower: The test weight of sunflower did not vary significantly among the different treatments. However, there was a slight reduction in test weight with CO_2 and slight improvement with light enrichment and triacontanol application.

Seed weight per plant in sunflower: The seed weight per plant of sunflower in CO_2 treatment was on par with that of no CO_2 treatments. Additional light brought significant improvement in the seed weight per plant both during 1988 (14.16 to 15.25 g/plant) and 1989

(20.65 to 23.30 g/plant). Triacontanol application proved nonsignificant in the first year, while it increased the seed weight significantly in second year (20.68 to 23.27 g/plant).

Seed yield of sunflower: The seed yield of sunflower in CO_2 enriched treatment (8.58 and 13.39 q/ha) was on par with control (8.50 and 13.28 q/ha) during 1988 and also during 1989, respectively. Supplemental light significantly improved the seed yield from 7.86 in control to 9.22 q per ha in first year and from 12.69 to 13.98 q per ha in second year. Triacontanol application too gave significant improvements in the seed yields by 0.55 and 0.76 q per ha over no triacontanol application in 1988 and 1989, respectively.

Stalk yield of sunflower: Stalk yield was significantly increased due to CO_2 enrichment from 14.07 to 16.47 q per ha in 1988 and from 24.09 to 27.48 q per ha in 1989. Similarly, light enrichment also improved the stalk yield significantly during 1988 (14.24 to 16.31 q/ha) and 1989 (24.97 to 26.60 q/ha). Whereas, application of triacontanol brought slight improvement in stalk yield both during 1988 (14.98 to 15.56 q/ha) and 1989 (25.49 to 26.08 q/ha) and hence the differences were statistically nonsignificant.

Table 4.22 Seed yield, stalk yield and harvest index of sunflower as influenced by CO_2 fertilization ($+CO_2$), light enrichment (+Light) and triacontanol (+Tria) application in sunflower-soybean intercropping system.

Treatments	Seed yield (q/ha)		Stalk yield (q/ha)		Harvest index	
	1988	1989	1988	1989	1988	1989
1. CO_2						
Control	8.50	13.28	14.07	24.09	0.383	0.369
+ CO_2	8.58	13.39	16.47	27.48	0.353	0.337
'F'test	NS	NS	**	**	**	**
2. Light						
Control	7.86	12.69	14.24	24.97	0.366	0.349
+ Light	9.22	13.98	16.31	26.60	0.371	0.359
'F'test	**	**	**	*	NS	NS
3. Triacontanol						
Control	8.27	12.95	14.98	25.49	0.364	0.348
+ Tria	8.82	13.71	15.56	26.08	0.372	0.357
'F'test	*	**	NS	NS	NS	NS
S.Em±	0.13	0.16	0.24	0.46	0.006	0.008
C.D. at 5%	0.41	0.49	0.73	1.40	0.020	0.022
C.V.(%)	5.5	4.2	5.5	6.2	6.1	7.4

Harvest index of sunflower: CO_2 enrichment showed significantly lower HI (0.353 in 1988 and 0.337 in 1989) as compared to the treatment with no CO_2 enrichment (0.383 and 0.369). Among the light and triacontanol treatments, the HI did not vary significantly though light enrichment (0.366 to 0.371 in 1988 and 0.349 to 0.359 in 1989) and triacontanol application (0.364 to 0.372 and 0.348 to 0.357) improved during both the years.

4.2.1.3 Maturity duration of sunflower (Table 4.23):

Between two years of experimentation, the crop took 5.3 days more in 1988 than in 1989 to complete its life cycle. And within a particular year, the duration of sunflower was significantly reduced by CO_2 fertilization. In the first year the duration of sunflower was shortened by 4.5 days and in the second year by 4.9 days due to CO_2 fertilization.

Light enrichment to the crop canopy had no influence on maturity duration of sunflower and so also the triacontanol application.

4.2.2 Response of soybean to CO_2, light and triacontanol:

Between two years, the performance of soybean with respect to growth and yield was better during 1988 season as compared to 1989.

Table 4.23 Maturity duration of sunflower as influenced by CO_2 fertilization ($+CO_2$), light enrichment (+Light) and triacontanol application (+Tria) in sunflower-soybean intercropping system.

Treatments	Duration (in days)		
	1988	1989	Mean
1. CO_2			
Control	101.0	95.9	98.4
+ CO_2	96.5	91.0	93.7
'F'test	**	**	-
2. Light			
Control	99.0	93.4	96.2
+ Light	98.5	93.5	96.0
'F'test	NS	NS	-
3. Triacontanol:			
Control	98.3	93.2	95.7
+ Tria	99.2	93.7	96.4
'F'test	NS	NS	-
S.Em±	0.3	0.3	-
C.D. at 5%	0.8	0.8	-
C.V.(%)	1.0	1.0	-

4.2.2.1 Growth components of soybean (Table4.24)

Plant height of soybean : The CO_2 fertilization to the canopy significantly increased the plant height of soybean from 37.2 cm in control to 44.1 cm in 1988 and from 52.7 cm to 63.8 cm in 1989. Other treatments of supplemental light and triacontanol application did not prove significant in influencing the plant height either in 1988 or in 1989 season.

Number of primary branches in soybean : The number of primary branches did not vary significantly due to CO_2 treatment although a trend in decreased primary branches by CO_2 fertilization was observed during first year. Supplemental light to the crop canopy significantly enhanced the number of branches from 3.16 to 3.88 in first year and from 2.96 to 3.60 in second year. Application of triacontanol did not bring any significant effect on primary branches both during 1988 and 1989.

Interaction effects between light and CO_2 on the number of primary branches (Table 4.25a) indicated that during 1988, without CO_2 fertilization, the light enrichment significantly increased the primary branches (3.07 to 4.16) but not with CO_2 fertilization (3.24 to 3.59, nonsignificant). However, light enrichment with CO_2 fertilization significantly reduced the number of

Table 4.24 Growth characters of soybean as influenced by CO_2 fertilization (+CO_2), light enrichment (+Light) an triacontanol application (+Tria) in sunflower - soybean intercropping system.

Treatments	Plant height (cm)		No. of primary branches		LAI at 68 DAS		Chlorophyll (1989) (mg/g fresh leaf)		Total DM (g/pl) at 68 DAS		Total DM (g/pl) at maturity	
	1988	1989	1988	1989	1988	1989	Total	Chla	1988	1989	1988	1989
1. CO_2												
Control	37.19	52.71	3.62	3.27	2.18	1.54	4.19	1.66	10.57	7.46	11.22	8.09
+CO_2	44.06	63.79	3.42	3.29	2.61	1.85	4.22	1.69	12.74	9.10	13.54	9.86
'F' test	**	**	NS	NS	**	**	NS	NS	**	**	**	**
2. Light												
Control	40.65	58.81	3.16	2.96	2.31	1.65	4.25	1.68	11.43	8.03	12.12	8.60
+Light	40.61	57.69	3.88	3.60	2.43	1.75	4.15	1.67	11.88	8.53	12.63	9.35
'F' test	NS	NS	**	**	NS	NS	NS	NS	NS	*	NS	**
3. Triacontanol												
Control	39.90	57.96	3.53	3.27	2.30	1.63	4.07	1.64	11.28	8.01	12.16	8.80
+Tria	41.35	58.54	3.51	3.29	2.49	1.76	4.34	1.71	12.03	8.55	12.59	9.35
'F' test	NS	NS	NS	NS	**	*	**	**	*	**	NS	**
S.Em±	0.94	0.87	0.08	0.06	0.03	0.04	0.04	0.03	0.19	0.12	0.19	0.10
C.D. at 5%	2.86	2.64	0.26	0.17	0.09	0.12	0.11	0.01	0.57	0.36	0.57	0.29
C.V.(%)	8.0	5.2	8.3	6.0	4.4	8.3	3.0	2.2	5.6	5.0	5.3	3.7

Table 4.25 Interaction effect of CO_2 and light on the number of primary branches and total dry matter production of soybean at maturity in sunflower-soybean intercropping system.

Table 4.25a: Number of primary branches.

	1988		1989	
	Control	+ Light	Control	+ Light
Control	3.07	4.16	2.85	3.69
+ CO_2	3.24	3.59	3.06	3.51
F-test	**		*	
S.Em±	0.12		0.08	
C.D. at 5%	0.36		0.24	

Table 4.25b: Total dry weight at maturity (g/plant), 1989.

	Control	+ Light
Control	8.01	8.16
+ CO_2	9.18	10.54
F-test	**	
S.Em±	0.14	
C.D. at 5%	0.41	

primary branches (4.16 to 3.59) as compared to light enrichment alone which gave the highest value (4.16). Similarly, in the second year also light enrichment alone gave the highest number of primary branches (3.69) which was significantly higher than that with CO_2 fertilization alone (3.06), whereas, the treatments CO_2 and light enrichment in combination (3.51) and light enrichment alone (3.69) were on par.

Leaf area index (LAI) (Table 4.24): The CO_2 fertilization significantly enhanced the LAI of soybean (2.18 to 2.61 in 1988 and 1.54 to 1.85 in 1989). Light enrichment to the crop canopy did not show significant response although an increase in the LAI was observed both during 1988 (2.31 to 2.43) and 1989 (1.65 to 1.75). Spraying of triacontanol to the crop at three stages viz., 40 days (vegetative stage), 55 days (mid flowering) and at 75 days (early pod filling stage) after sowing, improved the LAI significantly (2.30 to 2.49 in 1988 and 1.63 to 1.76 in 1989).

Chlorophyll content of soybean (Table 4.24): The total chlorophyll content and chlorophyll b content of leaves did not vary significantly by CO_2 and light treatments. The total chlorophyll content increased from 4.07 to 4.34 mg per g leaf, the chlorophyll b content from 1.64 to 1.71 mg per g of fresh leaf material with triacontanol.

Total dry matter production in soybean (Table 4.24): Soybean responded significantly to CO_2 fertilization both at 68 DAS and at maturity. At 68 DAS, the DM per plant was 12.74 and 9.10 g per plant in CO_2 treatments as against 10.57 and 7.46 g per plant in no CO_2 treatments during 1988 and 1989, respectively. At maturity, the corresponding figures were 13.54 and 9.86 g per plant in CO_2 treatments as compared to 11.22 and 8.09 g per plant in treatments with no CO_2 fertilization.

Additional light to canopy did not raise the DM per plant significantly in the first year, whereas the increase was significant in the second year both at 68 DAS (8.03 to 8.53 g) and at maturity (8.60 to 9.35 g).

The difference in the DM accumulation between treatments with and without triacontanol sprays was significant at 68 DAS but nonsignificant at maturity during first year. Whereas, during second year significant response in increased DM was seen both at 68 DAS (8.01 to 8.55 g/plant) and at maturity (8.80 to 9.35 g/plant).

The combination of CO_2 fertilization and light enrichment markedly influenced the DM production of soybean (Table 4.25 b) at maturity druing 1989. In the absence of elevated CO_2 concentration, light enrichment did not bring a significant increase in DM production (8.01 to 8.16 g/plant) while in the presence of elevated CO_2 concentration, light enrichment significantly increased the DM per plant from 9.18 g to 10.54 g per plant.

4.2.2.2 Yield and yield attributes of soybean:

The results relating to yield components of soybean viz., number of pods per plant, number of seeds per pod, test weight and seed weight are presented in Table 4.26, while the seed yield, stover yield (q/ha) and harvest index are given in Table 4.27.

Number of pods per plant in soybean: The pod number per plant were significantly higher in CO_2 fertilized treatments (19.9 in 1988 and 18.2 in 1989) as compared to treatment with no CO_2 fertilization (16.3 and 15.0). The plants bore significantly more pods (18.6 and 17.3) in treatment with supplemental light than the treatment with no supplemental light (17.6 and 16.0). Triacontanol sprays also brought a significant enhancement in the number of pods per plant only during 1988 (17.7 to 18.6) while it was nonsignificant during 1989.

Number of seeds per pod in soybean: CO_2 enrichment significantly increased the number of seeds per pod (2.46 to 2.66 in 1988 and 2.44 to 2.70 in 1989),

Table 4.26 Yield attributes of soybean as influenced by CO_2 fertilization (+CO_2), light enrichment (+ Light) and triacontanol application (+Tria) in sunflower-soybean intercropping system.

Treatments	No. of pods /plant		No. of seeds /pod		Test weight (g /100 seeds)		Seed weight (g/plant)	
	1988	1989	1988	1989	1988	1989	1988	1989
1. CO_2								
Control	16.3	15.0	2.46	2.44	16.00	14.99	5.36	4.21
+CO_2	19.9	18.2	2.66	2.70	16.91	15.97	6.81	5.40
'F' test	**	**	*	*	**	**	**	**
2. Light								
Control	17.6	16.0	2.59	2.58	16.36	15.48	5.89	4.59
+Light	18.6	17.3	2.53	2.56	16.56	15.48	6.27	5.02
'F' test	**	**	NS	NS	NS	NS	**	**
3. Triacontanol								
Control	17.7	16.3	2.53	2.51	16.59	15.53	6.01	4.72
+Tria	18.6	17.0	2.59	2.63	16.33	15.43	6.15	4.89
'F' test	**	NS	NS	NS	NS	NS	NS	NS
S.Em±	0.2	0.2	0.05	0.07	0.16	0.13	0.12	0.10
C.D. at 5%	0.6	0.8	0.15	0.22	0.50	0.41	0.37	0.29
C.V. (%)	3.9	5.3	6.6	10.0	3.5	3.0	6.9	7.0

whereas the light treatment had no significant influence. However, a slight decrease was observed due to light enrichment. Triacontanol application also did not influence the number of seeds per pod.

Test weight of soybean: The test weight of soybean was significantly improved by maintaining higher CO_2 concentration in the canopy (from 16.00 to 16.91 g/100 seeds in 1988 and 14.99 to 15.97 g/100 seed in 1989). The test weight was neither influenced by light enrichment nor by triacontanol application.

Seed weight per plant in soybean: The seed weight per plant of soybean in CO_2 treatments was significantly improved (6.81 and 5.40 g) as compared with no CO_2 treatments (5.36 and 4.21 g) during 1988 and 1989, respectively. Supplemental light to the canopy also brought significant improvement in the seed weight both during 1988 (5.89 to 6.27 g) and 1989 (4.59 to 5.02 g). A marginal nonsignificant raise in the seed weight per plant was effected by triacontanol application during both the years.

The highest seed weight per plant of soybean (5.80 g) was obtained with CO_2 fertilization when complemented with light enrichment during 1989 followed by the treatment with CO_2 fertilization alone (5.00 g), light enrichment alone (4.24 g) and was lowest in control (4.17 g) (Table 4.26a).

Seed yield of soybean (Table 4.27): The seed yield of soybean significantly enhanced from 9.4 to 11.5 q per ha in 1988 and from 7.5 to 10.0 q per ha with CO_2 fertilization. Supplemental light or triacontanol sprays did not improve the seed yield significantly although marginal improvements were observed during both the years.

Stover yield of soybean: Stover yield of soybean showed varied response between first and second years. Stover yield increased nonsignificantly due to CO_2 enrichment during 1988 (10.64 to 11.66 q/ha) as against a significant improvement in 1989 (7.13 to 8.70 q/ha). Light enrichment and triacontanol application, as like seed yield, did not bring significant improvements in stover yield during both the years.

Harvest index of soybean: The harvest index of soybean was significantly increased by CO_2 fertilization (0.475 to 0.502) in first year, and the increase was statistically nonsignificant in second year (0.518 to 0.545). Light and triacontanol had no significant effect on harvest index.

Table 4.26a Interaction effect between CO_2 and light on seed weight of soybean in sunflower-soybean intercropping system during 1989.

	seed weight (g/plant)	
	Control	+ Light
Control	4.17	4.24
+ CO_2	5.00	5.80
F-test	*	
S.Em±	0.14	
C.D. at 5%	0.42	

Table 4.27 Seed yield, stover yield and harvest index of soybean as influenced by CO_2 fertilization (+CO_2), light enrichment (+Light) and triacontanol application (+Tria) in sunflower-soybean intercropping system.

Treatments	Seed yield(q/ha)		Stover yield(q/ha)		Harvest index	
	1988	1989	1988	1989	1988	1989
1. CO_2						
Control	9.42	7.54	10.64	7.13	0.475	0.518
+ CO_2	11.46	10.00	11.66	8.70	0.502	0.545
'F'test	**	**	NS	**	**	NS
2. Light						
Control	10.18	8.50	11.11	7.90	0.484	0.531
+ Light	10.75	9.04	11.19	7.94	0.494	0.532
'F'test	NS	NS	NS	NS	NS	NS
3. Triacontanol						
Control	10.09	8.58	10.65	7.79	0.492	0.532
+ Tria	10.84	8.96	11.65	8.04	0.486	0.531
'F'test	NS	NS	NS	NS	NS	NS
S.Em$\pm$	0.25	0.20	0.43	0.13	0.006	0.010
C.D. at 5%	0.74	0.61	-	0.38	0.016	-
C.V. (%)	8.1	7.9	13.3	5.5	3.7	6.1

4.2.2.3 Crude portein content of soybean (Table 4.28):

The CO_2 fertilization gave nonsignificant improvements in the crude protein content of seeds during 1988 (45.07 to 45.25%) and 1989 (45.40 to 45.45%). Light enrichment too did not bring significant improvement in the seed quality in terms of crude protein content. Whereas, triacontanol sprays to soybean significantly increased the crude protein content of seed both during 1988 (44.62 to 45.70%) and 1989 (44.90 to 45.95%).

4.2.3 Total growth, yield and income from the intercrop:

The total LAI, total biomass yield, total oil yield and gross income from sunflower-soybean intercropping are presented in Table 4.29.

4.2.3.1 Total leaf area index (LAI):

The sum of LAI of two component crops as influenced by CO_2 fertilization, light enrichment and triacontanol indicated that it was improved significantly due to CO_2 enrichment from 3.25 to 3.79 in 1988 and 3.30 to 3.84 in 1989. Similarly, light enrichment to the intercropped canopy brought significant increase in the total LAI both during 1988 (3.45 to 3.60) and 1989 (3.44 to 3.71) seasons.

Table 4.28 Crude protein content of soybean seeds as influenced by CO_2 fertilization (+CO_2), light enrichment (+Light) and triacontanol application (+Tria) in sunflower-soybean intercropping system.

Treatments	Crude protein (Per cent)		
	1988	1989	Mean
1. CO_2			
Control	45.07	45.40	45.23
+ CO_2	45.25	45.45	45.35
'F'test	NS	NS	-
2. Light			
Control	45.20	45.42	45.31
+ Light	45.12	45.42	45.27
'F'test	NS	NS	-
3. Triacontanol			
Control	44.62	44.90	44.76
+ Tria	45.70	45.95	45.82
'F'test	**	**	-
S.Em±	0.19	0.18	-
C.D. at 5%	0.57	0.53	-
C.V.(%)	1.4	1.3	-

Table 4.29 Total leaf area index, total biomass and oil yield and gross income from sunflower - soybean intercropping system as influenced by CO_2 fertilization ($+CO_2$), light enrichment (+Light) and triacontanol application (+Tria).

Treatments	Total LAI		Total biomass yield (q/ha)		Total oil yield (q/ha)		Gross income (Rs./ha)	
	1988	1989	1988	1989	1988	1989	1988	1989
1. CO_2								
Control	3.25	3.30	42.7	52.0	6.67	5.02	6631	8126
$+CO_2$	3.79	3.84	48.2	59.6	7.19	5.41	7334	9076
'F' test	**	*	**	**	**	**	**	**
2. Light								
Control	3.45	3.44	43.4	54.1	6.63	4.89	6640	8287
+Light	3.60	3.71	47.5	57.6	7.24	5.53	7325	8915
'F' test	*	*	**	**	**	**	**	**
3. Triacontanol								
Control	3.40	3.30	44.0	54.8	6.75	5.04	6757	8427
+Tria	3.65	3.84	46.9	56.8	7.12	5.39	7208	8775
'F' test	**	**	**	*	**	**	*	*
S.Em±	0.04	0.08	0.5	0.6	0.06	0.06	135	118
C.D. at 5%	0.13	0.25	1.7	1.9	0.20	0.17	410	358
C.V.(%)	4.3	8.0	4.2	3.9	3.2	3.6	6.7	4.7

Triacontanol application too, significantly enhanced the total LAI by 0.25 and 0.54 during first and second years, respectively.

4.2.3.2 Total biomass yield:

The total biomass production from sunflower and soybean varied significantly between two levels of all the factors studied. The CO_2 enrichment gave 5.5 and 7.6 q more biomass per ha during first and second years, respectively. Similarly light enrichment also enhanced the biomass yield from 43.4 to 47.5 q and 54.1 to 57.6 q per ha. Application of triacontanol to the intercrop 3 times during the crop growth period enhanced the total biomass yield by 2.9 q per ha in the first year and 2.0 q per ha in the second year.

Interactions among CO_2, light and triacontanol treatments were not significant in 1989. However in the second year, the treatment which received supplemental CO_2 and light in conjunction with triacontanol sprays yielded 14.6 q more total biomass per hectare over control (Table 4.29a).

Total oil yield from sunflower and soybean: The total oil yield from intercropping system varied significantly between two levels of all factors studied. (Table 4.29). CO_2 enrichment increased the

Table 4.29a Interaction effect of CO_2, light and triacontanol on total biomass yield from sunflolwer + soybean inter-cropping system during 1989 *kharif* season.

	Total biomass yield (q/ha)			
	Control		+ Light	
	Control	+ Tria	Control	+ Tria
Control	48.1	52.3	53.21	54.6
+ CO_2	58.3	57.6	59.73	62.7
'F'test	NS			
S.Em$\pm$	1.20			
C.D. at 5%	-			

total yield of the system from 6.67 to 7.19 q per ha in first year and from 5.02 to 5.41 q per ha in second year. Light enrichment also increased the oil yield from 6.63 to 7.24 q and 4.89 to 5.53 q per ha during first and second years, respectively. The intercropping system responded significantly to triacontanol sprays also, with 5.5 and 6.9 per cent increase in oil yield over no triacontanol sprayings during first and second years, respectively.

Gross income from sunflower and soybean: The gross income derived from sunflower-soybean intercropping was significantly increased due to the individual effects of CO_2 fertilization, light enrichment and triacontanol sprays. The CO_2 treatment increased the gross income from Rs. 6631 to 7734 per ha in first year and Rs. 8126 to 9076 per ha in second year. And supplemental light to the intercropped canopy also enhanced the income from Rs. 6640 to Rs. 7325 and from Rs. 8237 to Rs. 8915 per ha during 1988 and 1989, respectively. Spraying triacontanol to the intercrop, three times during crop growth period, enhanced the gross income by Rs. 551 and Rs. 348, respectively during 1988 and 1989 seasons.

4.3 Studies on CO_2 evolution rate and change in physical, chemical and biological properties of soil by organic and lime amendments

4.3.1 CO_2 evolution rate

The results on the course of CO_2 evolution rate from soil as influenced by the quantity and type of amendments under controlled conditions in lysimeters are presented in Table 4.30 and graphically illustrated in Fig 4.7. In general, it was observed from all the treatments that the CO_2 releasing capacity of soil decreased with time (16.0 kg CO_2/ha/hr during first 6 days of incubation to 2.6 kg CO_2/ha/hr at 55 days). From among the treatments, maize stover incorporation at 4 and 8 t per ha increased the soil respiration from 10.2 kg CO_2 per ha per hr in control to 20.2 and 27.3 kg CO_2 per ha per hr, respectively during first 6 days, while the corresponding values for same levels of paddy straw were 15.3 and 18.3 kg CO_2 per ha per hr. Paddy straw incorporation maintained relatively higher CO_2 evolution rate for longer period as compared to maize stover. Lime application did not increase the CO_2 evolution rate of soil during first 6 days. Thereafter it increased the CO_2 evolution rate and maintained it at relatively higher level upto 24 days (10.2 to 12.2 kg CO_2/ha/hr at 4 t/ha and 14.0 to 14.3 at 8 t/ha). Even after 55 to 60 days of incorporation, the soil

Table 4.30 Course of CO_2 evolution rate from soil measured at 1 PM as influenced by the quantity and type of amendments applied (kg CO_2/ha/hr)

Treatments	Days after incorporation									
	0-6	7-12	13-18	19-24	25-30	31-36	37-42	43-48	49-54	55-60
1. Control	10.2	8.3	6.8	6.4	3.9	2.4	2.5	2.5	2.3	2.4
2. Maize stover @ 4 t/ha	20.2	15.7	7.8	7.5	5.1	4.2	3.3	3.0	2.6	2.6
3. Maize stover @ 8 t/ha	27.3	19.8	12.7	10.0	7.7	5.5	4.3	3.6	3.1	3.0
4. Paddy straw @ 4 t/ha	15.3	14.7	13.2	10.2	6.2	5.6	4.8	3.9	3.1	2.9
5. Paddy straw @ 8 t/ha	18.3	17.3	15.5	13.1	9.5	6.8	6.1	5.1	3.5	3.1
6. Lime @ 4 t/ha	10.3	10.2	12.1	12.2	6.8	4.5	2.9	2.6	2.4	2.1
7. Lime @ 8 t/ha	10.3	14.0	14.0	14.3	8.3	5.1	3.6	3.1	2.6	2.5
Mean	16.0	14.3	11.7	10.5	6.8	4.9	3.9	3.4	2.8	2.6

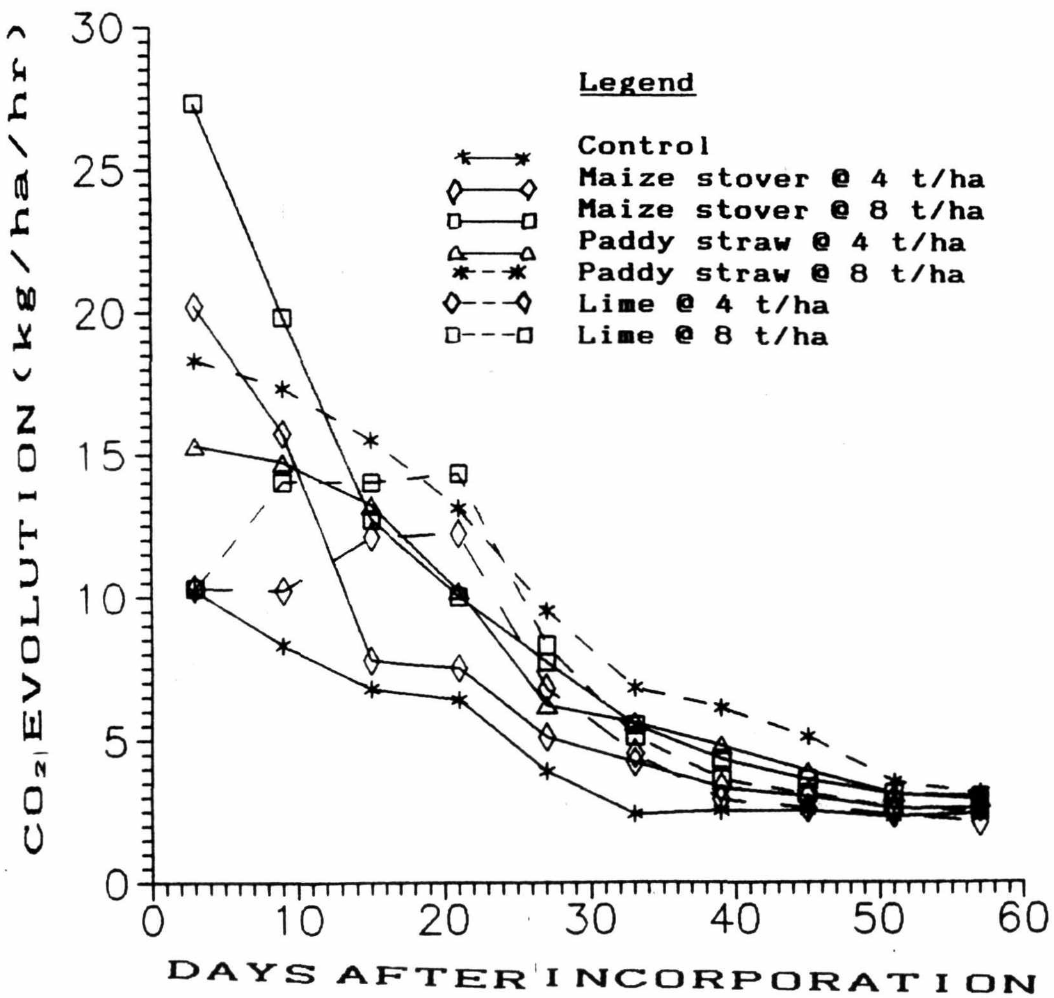


Fig 4.7 CO_2 evolution rate from soil as influenced by the quantity and type of amendments at different days after incorporation

respiration was comparatively higher in maize stover (2.6 and 3.0 kg CO_2/ha/hr at 4 and 8 t/ha, respectively) and paddy straw (2.9 and 3.1) treated plots as against control (2.4) or lime treatments (2.1 and 2.5 at 4 and 8 t/ha, respectively).

4.3.2 Soil dehydrogenase activity (Table 4.31)

In all the treatments except those with lime application, the activity of the enzyme increased initially as was observed at 10 days after incorporation of amendments (Fig 4.8). Thereafter, the dehydrogenase activity gradually decreased. Among the treatments, organic amndments markedly increased the dehydrogenase activity (0.42 to 0.71 mg TPF/g of soil/hr) over control (0.31 to 0.47 mg TPF/g of soil/hr) as was observed during 10 to 60 days after incorporation. Lime application decreased the enzyme activity (from initial 0.40 to 0.31 mg TPF/g of soil/hr at 4 t of lime/ha and 0.38 to 0.29 at 8 t/ha).

4.3.3 Soil physical and chemical properties

4.3.3.1 Soil pH (Table 4.32)

Soil pH was not altered either by quantity or by type of organic amendments as was observed upto 60 days after incorporation, whereas application of unburnt lime ($CaCO_3$) increased the soil pH from initial

Table 4.31 Course of dehydrogenase activity in soil as influenced by the quantity and type of amendments (mg TPF/g of soil/hr).

Treatments	Days after incorporation						
	Initial	10	20	30	40	50	60
1. Control	0.39	0.47	0.40	0.35	0.36	0.35	0.31
2. Maize stover @ 4 t/ha	0.40	0.68	0.58	0.45	0.46	0.43	0.46
3. Maize stover @ 8 t/ha	0.36	0.71	0.61	0.48	0.49	0.48	0.46
4. Paddy straw @ 4 t/ha	0.39	0.63	0.60	0.43	0.43	0.45	0.42
5. Paddy straw @ 8 t/ha	0.41	0.70	0.63	0.48	0.48	0.49	0.46
6. Lime @ 4 t/ha	0.40	0.38	0.31	0.32	031	0.31	0.37
7. Lime @ 8 t/ha	0.38	0.36	0.29	0.30	0.30	0.32	0.33
Mean	0.39	0.56	0.49	0.40	0.41	0.40	0.40

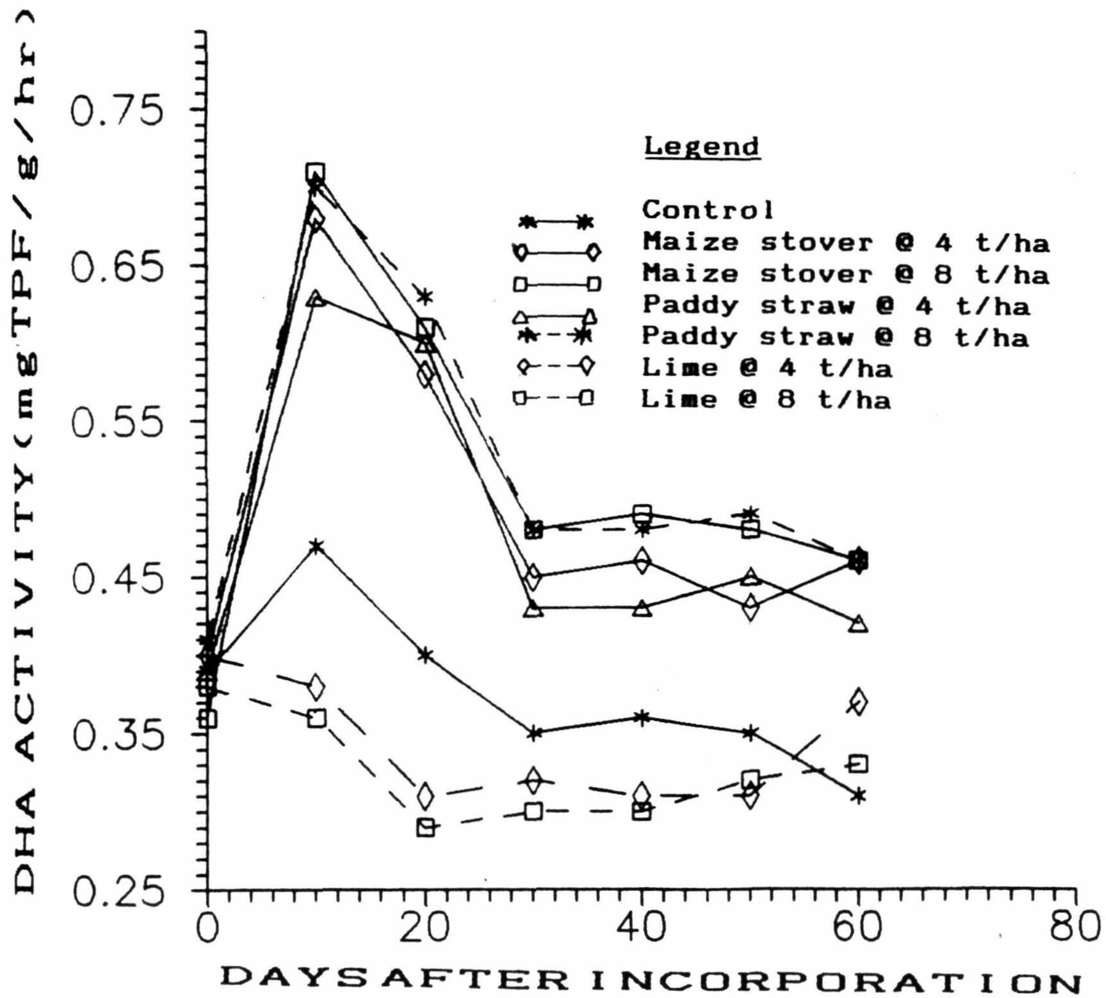


Fig 4.8 Dehydrogenase (DHA) activity in soil as influenced by the quantity and type of amendments at different days after incorporation

Table 4.32 Course of soil pH as influenced by the quantity and type of amendments applied.

Treatments	Days after incorporation			
	Initial	20	40	60
1. Control	6.9	6.9	6.9	6.9
2. Maize stover @ 4 t/ha	6.9	7.0	6.9	6.9
3. Maize stover @ 8 t/ha	7.0	7.0	7.0	6.9
4. Paddy straw @ 4 t/ha	6.9	7.1	7.0	7.0
5. Paddy straw @ 8 t/ha	7.0	7.0	6.9	7.0
6. Lime @ 4 t/ha	7.0	7.4	7.8	7.8
7. Lime @ 8 t/ha	7.0	7.4	8.0	7.9
Mean	6.9	7.1	7.2	7.2

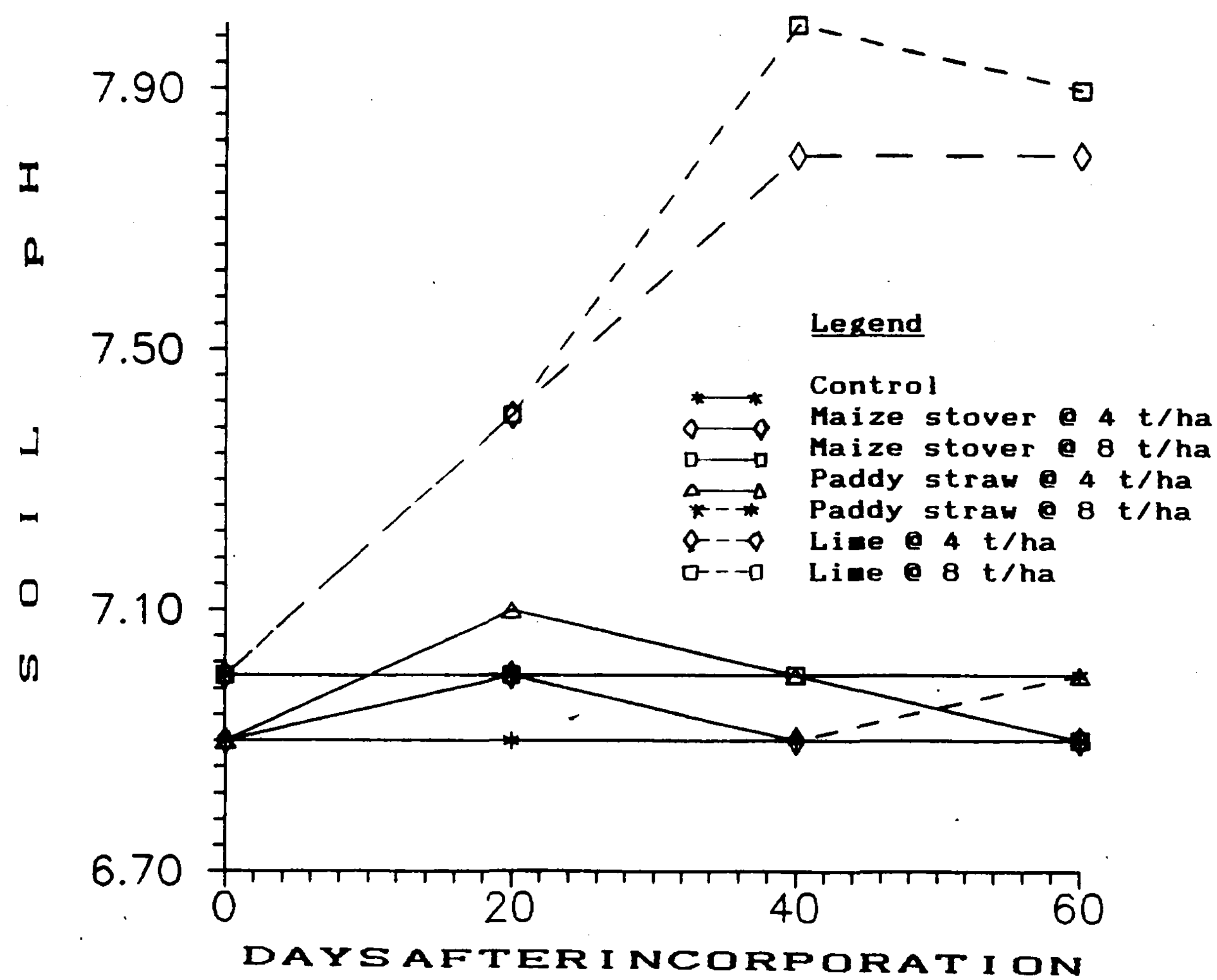


Fig 4.9 pH of soil as influenced by the quantity and type of amendments at different days after incorporation

7.0 to 7.8 at 4 t per ha and to 8.0 at 8 t per ha as was observed at 40th day of incorporation and maintained almost the same higher levels at 60 days after incorporation also (Fig 4.9).

4.3.3.2 Organic matter content of soil

The orginal status of organic matter of 0.85 per cent in control declined to 0.52 per cent after 20 days, and to 0.43 per cent and 0.38 per cent after 40 and 60 days (Table 4.33). In case of lime at 4 t per ha, there was a decline from 0.81 per cent to 0.75 per cent, 0.68 per cent and 0.65 per cent at these stages of incorporation. Similar trend was seen at 8 t lime per ha. Both maize stover and paddy straw at both the levels increased the organic matter content of soil at all stages reaching a maximum around 40 days of incorporation and still maintaining original level or higher than original status at 60 days. At 40 days after incorporation the organic matter increased from the initial status of 0.78 and 0.79 per cent to 0.96 and 1.01 per cent with 4 and 8 t maize stover and from 0.82 and 0.85 per cent to 0.95 and 1.05 per cent with paddy straw at 4 and 8 t per ha, respectively.

4.3.3.3 Soil available nitrogen (Table 4.34)

The available nitrogen status of soil decreased in control and lime treatments with time. Maize stover

Table 4.33 Course of soil organic matter as influenced by the quantity and type of amendments applied (per cent).

Treatments	Days after incorporation			
	Initial	20	40	60
1. Control	0.85	0.52	0.43	0.38
2. Maize stover @ 4 t/ha	0.78	0.92	0.96	0.86
3. Maize stover @ 8 t/ha	0.79	1.01	1.01	0.99
4. Paddy straw @ 4 t/ha	0.82	0.95	0.95	0.88
5. Paddy straw @ 8 t/ha	0.85	0.95	1.05	1.01
6. Lime @ 4 t/ha	0.81	0.75	0.68	0.65
7. Lime @ 8 t/ha	0.78	0.74	0.69	0.68
Mean	0.81	0.83	0.82	0.78

Table 4.34 Course of available N content of soil as influenced by the quantity and type of amendments applied (kg/ha).

Treatments	Days after incorporation			
	Initial	20	40	60
1. Control	360.9	345.2	339.1	326.4
2. Maize stover @ 4 t/ha	359.3	260.8	370.2	386.8
3. Maize stover @ 8 t/ha	346.0	200.1	385.2	400.2
4. Paddy straw @ 4 t/ha	345.0	240.2	362.9	380.4
5. Paddy straw @ 8 t/ha	360.2	206.8	390.1	405.4
6. Lime @ 4 t/ha	350.2	320.5	320.6	309.6
7. Lime @ 8 t/ha	360.9	325.2	330.3	338.2
Mean	354.6	271.2	356.9	363.8

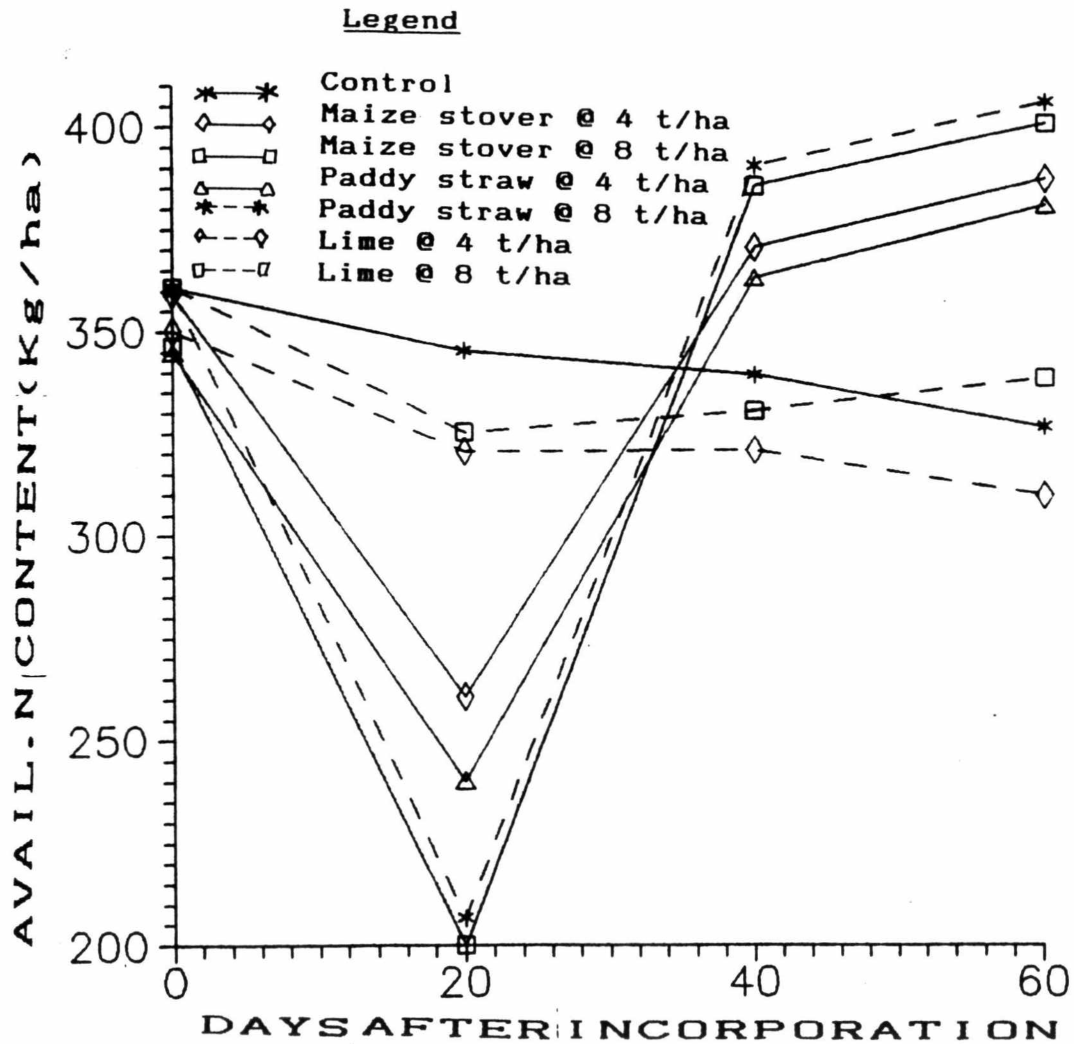


Fig 4.10 Available N content of soil as influenced by the quantity and type of amendments at different days after incorporation

and paddy straw application resulted in very low available nitrogen (260.8 and 240.2 kg/ha at 4 t and 200.1 and 206.8 kg/ha at 8 t of maize stover and paddy straw, respectively) at 20 days after incorporation as compared to the initial level of 352.1 kg per ha (Fig 4.10). Further, at 40 and 60 days after incorporation, the available nitrogen status was markedly improved in organic amended soils. Maize stover incorporation improved the available nitrogen content to 386.8 and 400.2 kg, while paddy straw 380.4 and 405.4 kg at 4 and 8 t per ha, respectively at 60 days after incorporation.

4.3.3.4 Available P_2O_5 content of soil (Table 4.35)

The available phosphorus status of soil was by and large same in control and lime treated plots as observed at 20, 40 and 60 days, whereas it was improved by organic amendments. At 60 days after incorporation, maize stover at 4 and 8 t per ha enhanced the available phosphorus by 8.9 and 17.0 kg per ha, while paddy straw enhanced its content by 15.4 and 26.6 kg per ha, respectively.

4.3.3.5 Available K_2O content of soil (Table 4.36)

As in the case of available phosphorus, control and lime treatments showed no trends of either

Table 4.35 Course of available P_2O_5 content of soil as influenced by the quantity and type of amendments applied (kg/ha)

Treatments	Days after incorporation			
	Initial	20	40	60
1. Control	46.9	43.2	49.3	46.8
2. Maize stover @ 4 t/ha	46.2	47.2	50.9	55.1
3. Maize stover @ 8 t/ha	44.3	48.3	58.4	61.3
4. Paddy straw @ 4 t/ha	48.4	50.1	59.9	63.8
5. Paddy straw @ 8 t/ha	49.6	56.2	60.9	76.2
6. Lime @ 4 t/ha	48.6	47.1	50.3	50.8
7. Lime @ 8 t/ha	47.8	48.2	45.3	46.8
Mean	47.4	48.6	53.6	57.2

Table 4.36 Course of available K_2O content of soil as influenced by quantity and type of amendments applied (kg/ha).

Treatments	Days after incorporation			
	Initial	20	40	60
1. Control	326.3	325.3	320.5	325.2
2. Maize stover @ 4 t/ha	332.5	320.7	347.8	360.6
3. Maize stover @ 8 t/ha	328.6	336.5	360.8	380.9
4. Paddy straw @ 4 t/ha	310.5	308.4	350.3	375.3
5. Paddy straw @ 8 t/ha	308.9	315.6	359.3	390.3
6. Lime @ 4 t/ha	332.6	315.2	329.6	340.2
7. Lime @ 8 t/ha	339.4	329.5	340.3	339.3
Mean	325.5	321.6	344.1	358.8

decrease or increase in available K_2O content of soil during 60 days of experimentation. While organic amendments brought considerable enhancement by 40 and 60 days after incorporation. At 60 days, the improvement was to the extent of 28.1 to 52.3 kg per ha by maize stover and 64.8 to 81.4 kg per ha by paddy straw at 4 to 8 t per ha, respectively.

4.4 Experiment III: Studies on CO_2 fertilization and time of application of lime and organic amendments in sunflower - soybean intercropping

4.4.1 CO_2 Concentration in the intercrop canopy

The data on carbon dioxide concentration of the intercropped canopy atmosphere at 60 DAS as influenced by CO_2 enrichment and application of amendments are presented in Table 4.37.

The CO_2 enrichment significantly increased its concentration in the canopy atmosphere (726 and 768 ppm) during first and second years as compared to control (332 and 325 ppm).

Types of amendments did not bring significant change in the CO_2 concentration at 60 DAS during both the years. However, organic amendments slightly improved the CO_2 concentration of the canopy atmosphere as compared to lime.

Table 4.37 Carbon dioxide concentration of the crop canopy atmosphere at 60 days after sowing as influenced by its enrichment, amendments and time of their application in sunflower - soybean intercropping system.

Treatments	1989	1990	Mean
1. Control	318	332	325
$+CO_2$	726	768	747
'F' test	**	**	
S.Em±	14	15	
C.D. at 5%	43	42	
2. Type of amendments			
Maize stover	350	353	351
Paddy straw	359	356	357
Lime	338	342	340
'F' test	NS	NS	
S.Em±	7	7	
C.D. at 5%	-	-	
3. Time of application			
20 days before sowing	318	330	324
At sowing	320	333	326
20 days after sowing	359	360	359
40 days after sowing	400	377	388
'F' test	**	**	
S.Em±	8	8	
C.D. at 5%	24	24	
C.V.(%)	6.7	6.7	
Ambient CO_2 Conc.	343	341	

Time of application of amendments proved significant in influencing the CO_2 content of the canopy atmosphere at 60 DAS. Amendments applied at 40 DAS produced highest CO_2 content in the canopy atmosphere (400 ppm in 1989 and 377 ppm in 1990) followed by application at 20 DAS (359 and 360 ppm), at sowing (320 ad 333 ppm) and was lowest (318 and 330 ppm) in treatments where application was done at 20 days before sowing, both during 1989 and 1990. However, the treatments viz., application of amendments at 20 days before sowing and at sowing were on par during both the years. Further, the treatments with application at 20 and 40 DAS were statistically on par during 1990.

4.4.2 Response of sunflower to CO_2, lime and organic amendments

Between two years of experimentation, the performance of sunflower with respect to growth and yield was slightly better in 1989 than 1990, although the intitial growth rate was higher during 1990.

4.4.2.1 Growth components of sunflower

Leaf area index (LAI) of sunflower: The data on LAI of sunflower at three stages viz., 35, 55 and 75 days after sowing (DAS) as inlfuenced by CO_2 fertilization, soil amendments and time of their application in sunflower-soybean intercropping system are presented in Table 4.38.

Among three groups of treatments viz., control, CO_2 fertilizaton and amendments, the LAI was more in CO_2 treatments at 35 and 55 DAS during both the years. However, the differences were significant only during first year at 55 DAS. At 75 DAS, soil amendments proved superior than CO_2 fertilization or control during both the years, but the differences were marginal and statistically nonsignificant.

Comparison among the types of soil amendments used viz., maize stover, paddy straw and lime, showed nonsignificant differences in LAI of sunflower at all the stages of both during first and second years.

Time of application of amendments significantly influenced the LAI at all the stages of each year. At 35 DAS, the LAI was highest (0.50 in 1989 and 0.92 in 1990) in treatment which received the amendments three weeks before sowing and was significantly superior to all others, while it was lowest in treatment which received the amendments at the time of sowing (0.27 and 0.61) during both the years. At 55 DAS also, the LAI was highest (2.71 in 1989 and 3.50 in 1990) in treatment which received the amendments at three weeks

Table 4.38 Leaf area index of sunflower at different stages as influenced by CO_2 fertilization, amendments and time of their application in sunflower-soybean intercropping system

Treatments	LAI of sunflower					
	35 DAS		55 DAS		75 DAS	
	1989	1990	1989	1990	1989	1990
1. (a) Control	0.37	0.81	2.56	3.39	1.65	1.68
(b) + CO_2	0.40	0.84	2.84	3.51	1.75	1.84
(c) Amendments	0.38	0.76	2.48	3.23	1.78	1.86
'F' test	NS	NS	*	NS	NS	NS
S.Em± (a)	0.02	0.05	0.16	0.19	0.07	0.08
(b)	0.02	0.05	0.16	0.19	0.07	0.08
(c)	0.01	0.02	0.05	0.06	0.02	0.02
C.D. at 5% (a) & (b)	-	-	0.48	-	-	-
(a) & (c)	-	-	0.35	-	-	-
(b) & (c)	-	-	0.35	-	-	-
2. Within amendments						
(a) Type of amendments						
Maize stover	0.38	0.74	2.51	3.25	1.82	1.88
Paddy straw	0.37	0.74	2.44	3.28	1.79	1.86
Lime	0.38	0.80	2.50	3.17	1.72	1.85
'F' test	NS	NS	NS	NS	NS	NS
S.Em±	0.01	0.02	0.08	0.10	0.04	0.04
CD at 5%	-	-	-	-	-	-
(b) Time of application						
20 days before sowing	0.50	0.92	2.71	3.50	1.91	2.00
At sowing	0.27	0.61	2.37	3.20	1.93	2.02
20 days after sowing	0.36	0.70	2.35	2.99	1.58	1.67
40 days after sowing	0.38	0.82	2.50	3.25	1.70	1.77
'F' test	**	**	*	*	**	**
S.Em±	0.01	0.03	0.09	0.11	0.04	0.04
C.D. at 5%	0.04	0.08	0.28	0.33	0.12	0.13
C.V. (%)	11.2	11.0	11.3	10.4	7.2	7.2

before sowing and significant over all other treatments viz., incorporation of amendments at sowing, 20 and 40 DAS which altogether were statistically on par (2.37 to 2.50 in 1989 and 2.99 to 3.25 in 1990).

Interaction between soil amendments and time of their application on LAI of sunflower was significant at 35 DAS during 1989. Application of paddy straw or maize stover at the time of sowing gave very low LAI of sunflower (0.20 and 0.26). However, this was not so with **lime** (0.36) (Table 4.38a). And also it was observed that incorporation of organic amendments at 20 days before sowing gave significantly higher LAI (0.54) than lime incorporated at the same time.

Leaf area duration (LAD) of sunflower: The data pertaining to leaf area duration of sunflower from 0 to 55 days, 55 days to maturity and the total LAD of both first and second years are presented in Table 4.39. The LAD for the first 55 days of crop growth period was statistically on par among control, CO_2 and amendments both during 1989 (33.7 to 38.0 days) and 1990 (50.4 to 55.3 days). However CO_2 fertilization marginally improved the LAD. And the LAD from 55 DAS to maturity was significantly higher in treatment which received the amendments (60.8 days in 1989 and 67.6 days in 1990) as compared to the treatment with CO_2

Table 4.38a Interaction effect between amendments and time of their application on leaf area index of sunflower at 35 days after sowing in sunflower-soybean intercropping system during 1989 summer season.

	Amendments		
Time of application	Maize stover	Paddy straw	Lime
20 days before sowing	0.54	0.54	0.41
At sowing	0.26	0.20	0.36
20 days after sowing	0.36	0.35	0.37
40 days after sowing	0.38	0.38	0.37
'F' test		**	
S.Em±		0.02	
C.D. at 5%		0.07	

Table 4.39 Leaf area duration of sunflower as influenced by CO_2 fertilization, amendments and time of their application in sunflower-soybean intercropping system.

Treatments	LAD (1989)			LAD (1990)		
	0-55 DAS	55 DAS-maturity	Total	0-55 DAS	55 DAS-maturity	Total
1. (a) Control	34.5	58.2	92.7	53.3	64.9	118.2
(b) + CO_2	38.0	56.3	94.3	55.3	62.0	117.3
(c) Amendments	33.7	60.8	94.4	50.4	67.6	118.2
'F' test	NS	*	NS	NS	**	NS
S.Em± (a)	2.2	1.9	3.0	2.2	1.8	2.4
(b)	2.2	1.9	3.0	2.2	1.8	2.4
(c)	0.6	0.5	0.9	0.6	0.5	0.7
C.D. at 5% (a) & (b)	-	5.5	-	-	5.1	-
(a) & (c)	-	4.0	-	-	3.8	-
(b) & (c)	-	4.0	-	-	3.8	-
2. Within amendments						
(a) Type of amendments						
Maize stover	34.3	62.2	96.5	50.1	68.7	118.8
Paddy straw	32.6	61.1	93.7	50.6	68.7	119.4
Lime	34.1	59.0	95.1	51.0	65.3	116.3
'F'test	NS	NS	NS	NS	*	NS
S.Em±	1.1	0.9	1.5	1.1	0.9	1.2
C.D. at 5%	-	-	-	-	2.6	-
(b) Time of application						
20 days before sowing	39.1	64.2	103.2	57.2	70.9	128.1
At sowing	29.6	65.4	95.0	46.6	73.3	119.9
20 days after sowing	32.0	55.0	87.1	46.5	61.1	107.7
40 days after sowing	34.0	58.5	92.5	52.1	64.9	117.0
'F'test	**	**	**	**	**	**
S.Em±	1.3	1.1	1.7	1.3	1.0	1.4
C.D. at 5%	3.7	3.2	5.0	1.8	3.0	4.0
C.V.(%)	11.2	5.4	5.5	7.4	4.6	3.5

fertilization (56.3 and 62.0 days) and control (58.3 and 64.9 days) during both the years. The total LAD did not differ significantly when compared between all combinations of control, CO_2 and amendments both during 1989 (92.7 to 94.4 days) and 1990 (117.3 to 118.2 days).

The differences in LAD of 0-55 DAS and the total LAD among three types of soil amendments were statistically nonsignificant during both the years, whereas the LAD of 55 DAS to maturity was more in organic amended treatments as compared to lime amended treatments during both 1989 (61.1 days in paddy straw, 62.2 days in maize stover and 59.0 days in lime amended soil) and 1990 (68.7 days in maize stover and paddy straw, 65.3 days in lime amended soil), although significant only during second year.

Time of application of amendments significantly varied the LAD of sunflower from 0-55 DAS, 55 DAS to maturity and the total LAD, during both the years. LAD of 0 - 55 days was highest (39.1 and 57.2 days in 1989 and 1990) in treatment which received the amendments 20 days in advance, whereas the amendments applied at sowing gave lowest LAD (29.6 and 46.6 days). On contrary, the LAD during 55 DAS to maturity was highest when amendments were applied at sowing (65.4 and 73.3 days during 1989 and 1990). However, it was on par with application at 20 days before sowing and statistically superior to the application at 20 and 40 DAS. Further, the treatments which was applied with amendments at 20 DAS showed the lowest LAD from 55 DAS to maturity (55.0 days in 1989 and 61.1 days in 1990) during both the years.

With regards to total LAD, amendments applied at 20 days before sowing gave highest values (103.2 and 128.1 days) followed by application of amendments at sowing (95.0 and 119.9 days) and were lowest in treatment applied 20 DAS (87.1 and 107.7 days) during both first and second years, respectively.

Chlorophyll contents of sunflower: Chlorophyll content of sunflower at 30 and 60 days after sowing in second year are presented in Tables 4.40 and 4.41, respectively. At 30 days, the chlorophyll content of sunflower was higher in treatments applied with organic amendments at 20 days before sowing (2.70 and 2.65 mg/g fresh leaf in paddy and maize residue incorporation) as compared to control (2.61), whereas organic amendments applied at sowing gave comparatively very low chlorophyll content (2.19 and 2.29 in paddy and maize amendments) than control.

Total chlorophyll content of sunflower at 60th day of sowing, was significantly higher in amended soil

Table 4.40 Chlorophyll content of sunflower at 30 days after sowing as influenced by organic amendments in sunflower-soybean intercropping system during 1990 summer season (mean of two replications) (mg/g fresh leaf)

Treatments		Total Chl.
1.	Control	2.61
2.	Maize stover incorporated 20 days before sowing	2.65
3.	Maize stover incorporated at the time of sowing	2.29
4.	Paddy straw incorporated 20 days before sowing	2.70
5.	Paddy straw incorporated at the time of sowing	2.19
	Mean	2.49

Table 4.41 Chlorophyll content of sunflower at 60 days after sowing as influenced by CO_2 fertilization, amendments and time of their application in sunflower-soybean intercropping system during 1990 summer season.

Treatments	Total Chl. (mg/g fresh leaf)	Chl.'b' (mg/g fresh leaf)
1. (a) Control	2.58	0.78
(b) + CO_2	2.60	0.78
(c) Amendments	2.79	0.80
'F'test	*	NS
S.Em± (a)	0.09	0.03
(b)	0.09	0.03
(c)	0.03	0.01
C.D. at 5% (a) & (b)	0.27	-
(a) & (c)	0.20	-
(b) & (c)	0.20	-
2. Within amendments		
(a) Type of amendments		
Maize stover	2.87	0.82
Paddy straw	2.83	0.82
Lime	2.66	0.76
'F'test	**	**
S.Em±	0.04	0.01
C.D. at 5%	0.13	0.04
(b) Time of application		
20 days before sowing	2.89	0.83
At sowing	2.92	0.83
20 days after sowing	2.67	0.78
40 days after sowing	2.67	0.77
'F'test	**	**
S.Em±	0.05	0.02
C.D. at 5%	0.15	0.05
C.V.(%)	5.7	6.0

(2.79 mg/g/ fresh leaf) over control (2.58). Within amendments, the chlorophyll content of sunflower in maize stover (2.87) and paddy straw (2.83) incorporated treatments were on par and significantly higher than the chlorophyll content in lime amended treatment (2.66). Among the times of application of soil amendments, incorporation at 20 days before or at sowing were found superior (2.89 and 2.92, respectively) to 20 or 40 DAS (2.67).

Chlorophyll b content of sunflower was statistically on par when the treatments viz., CO_2 fertilization and soil amendments were compared individually with control or between them. Whereas within amendments, the chlorophyll b content of maize stover and paddy straw incorporated treatments were same (0.82 mg/g fresh leaf) and statistically higher than lime applied treatment (0.76). Amendments incorporated either 20 days before or at sowing did not result in any significant difference in chlorophyll b content (0.83) but statistically superior when compared to incorporation at 20 (0.78) or 40 (0.77) DAS.

Interaction between soil amendments and time of application on total chlorophyll content of sunflower was significant at 60 DAS. Application of maize stover or paddy straw either at 20 days before or at sowing were found statistically superior (3.00 to 3.10 mg/g leaf) than application of lime at the same times (2.59 to 2.63) and also they were superior to all the three amendments applied at 20 and 40 DAS (2.59 to 2.73) (Table 4.41a).

Total dry matter production of sunflower (Table 4.42): At 35 DAS, the differences in DM was nonsignificant among control, CO_2 fertilization and amendments. While at 55 and 75 DAS, CO_2 fertilization significantly improved the DM per plant when compared to control or soil amendments. However, the enhanced DM became nonsignificant at maturity during both the years.

Within different types of amendments, the DM production did not differ significantly at all the stages during both the years except at 35 DAS during 1990, where lime application gave higher DM (8.35 g/plant) than maize stover (7.67), and at 55 DAS during 1989, where lime application gave higher DM (53.2 g/plant) than paddy straw (50.0).

Time of application of amendments brought significant variations in the DM production of sunflower at all the stages during both the years. Highest DM per plant was recorded in treatment supplied with amendments at 20 days before sowing in most of the stages and lowest DM production was recorded on

Table 4.41a Total chlorophyll content of sunflower at 60 days after sowing as influenced by the interaction between amendments and times of their application in sunflower-soybean intercropping system during 1990 summer season (mg/g fresh leaf)

Time of application	Amendments		
	Maize stover	Paddy straw	Lime
20 days before sowing	3.08	3.00	2.59
At sowing	3.10	3.02	2.63
20 days after sowing	2.70	2.60	2.70
40 days after sowing	2.59	2.71	2.73
'F'test		*	
S.Em±		0.09	
C.D. at 5%		0.27	

Table 4.42 Total dry matter production in sunflower at different stages as influenced by CO_2 fertilization, amendments and time of their application in sunflower-soybean intercropping system

Treatments		Total DM (g/plant)							
		at 35 DAS		at 55 DAS		at 75 DAS		at maturity	
		1989	1990	1989	1990	1989	1990	1989	1990
1. (a) Control		5.03	8.45	54.9	60.2	70.8	68.1	85.7	77.9
(b) + CO_2		5.20	8.62	60.2	65.9	75.9	74.1	90.0	85.0
(c) Amendments		5.17	7.95	51.8	59.1	69.2	68.6	88.6	84.1
'F'test		NS	NS	**	**	*	**	NS	NS
S.Em±	(a)	0.23	0.35	1.1	1.5	2.1	1.3	2.8	3.1
	(b)	0.23	0.35	1.1	1.5	2.1	1.3	2.8	3.1
	(c)	0.07	0.10	0.3	0.4	0.6	0.4	0.8	0.9
C.D. at 5%	(a) & (b)	-	-	3.1	4.3	6.1	3.8	-	-
	(a) & (c)	-	-	2.3	3.2	4.5	2.8	-	-
	(b) & (c)	-	-	2.3	3.2	4.5	2.8	-	-
2. Within amendments									
(a) Type of amendments									
Maize stover		5.38	7.67	52.4	58.8	70.1	68.5	90.5	83.9
Paddy straw		5.07	7.84	50.0	58.6	67.8	68.6	87.5	84.9
Lime		5.04	8.35	53.2	60.0	69.8	68.6	87.6	83.5
'F'test		NS	*	**	NS	NS	NS	NS	NS
S.Em±		0.12	0.18	0.5	0.7	1.0	0.6	1.4	1.6
C.D. at 5%		-	0.52	1.6	-	-	-	-	-
(b) Time of application									
20 days before sowing		6.90	9.64	56.6	62.8	72.8	72.0	95.6	89.2
At sowing		3.80	6.42	49.6	58.0	69.0	68.7	93.5	90.2
20 days after sowing		4.90	7.26	48.5	56.3	67.5	65.8	80.2	75.6
40 days after sowing		5.07	8.50	52.6	59.5	67.7	67.8	84.9	81.4
'F'test		**	**	**	**	*	**	**	**
S.Em±		0.13	0.20	0.6	0.9	1.2	0.7	1.6	1.8
C.D. at 5%		0.19	0.60	1.8	2.5	3.5	2.2	4.7	5.2
C.V.(%)		7.8	7.7	3.6	4.3	5.2	3.3	5.5	6.4

35th day when amendments were applied at sowing, whereas at other stages (55, 75 DAS and maturity) the amendments applied at 20 DAS gave lowest DM per plant. At maturity, the DM per plant in treatment which received the amendments at 20 days before sowing (95.6 and 89.2 g in 1989 and 1990) and at sowing (93.5 and 90.2 g) were on par and significantly higher than amendments applied at 20 DAS (80.2 in 1989 and 75.6 g in 1990) and 40 DAS (84.9 and 81.4 g).

Interaction effects between soil amendments and time of application at 35 DAS during first year, indicated that the time of application of lime did not bring significant difference in DMP (4.83 to 5.30 g/plant) whereas, maize stover or paddy straw incorporated at 20 days before sowing gave higher DM per plant (7.89 and 7.50 g) and incorporation at sowing resulted in very low DM per plant (3.56 adn 3.01 g), respectively (Table 4.43a). During second year also, incorporation of maize and paddy residues at 20 days before gave higher DM per plant (9.89 and 10.02 g, respectively) and were statistically superior to those treatments which received organic amendments either at sowing (5.13 and 5.84), 20 DAS (7.18 and 7.00) or 40 DAS (8.50 and 8.49). Lime application at 20 days before sowing (9.00 g/plant) was on par with lime application at sowing (8.3 g/plant) or at 40 DAS (8.51)

Table 4.43 Interaction effect between amendments and time of their application on total dry matter production (g/plant) of sunflower at different stages in sunflower-soybean intercropping system.

Table 4.43(a) At 35 DAS, 1989

Time of application	Amendments		
	Maize stover	Paddy straw	Lime
20 days before sowing	7.89	7.50	5.30
At sowing	3.56	3.01	4.83
20 days after sowing	4.99	4.70	5.00
40 days after sowing	5.10	5.07	5.04
'F'test		**	
S.Em±		0.23	
C.D. at 5%		0.68	

Table 4.43(b) At 35 DAS, 1990.

Time of application	Amendments		
	Maize stover	Paddy straw	Lime
20 days before sowing	9.89	10.02	9.00
At sowing	5.13	5.84	8.30
20 days after sowing	7.18	7.00	7.59
40 days after sowing	8.50	8.49	8.51
'F'test		**	
S.Em±		0.35	
C.D. at 5%		1.03	

Table 4.43(c) At 55.DAS, 1989.

Time of application	Amendments		
	Maize stover	Paddy straw	Lime
20 days before sowing	58.1	56.9	54.9
At sowing	50.1	45.0	53.6
20 days after sowing	48.1	47.1	50.4
40 days after sowing	53.1	50.9	53.9
'F'test		**	
S.Em±		1.1	
C.D. at 5%		3.1	

Table 4.43(d) At 75 DAS, 1990.

Time of application	Amendments		
	Maize stover	Paddy straw	Lime
20 days before sowing	73.1	72.9	70.1
At sowing	67.0	67.1	72.0
20 days after sowing	66.1	65.2	66.1
40 days after sowing	67.9	69.2	66.2
'F'test		*	
S.Em±		1.3	
C.D. at 5%		3.8	

Plate 4. CO_2 fertilized plot in summer experiment III

Plate 5. Growth of sunflower in maize stover incorporated plot at 20 days before sowing

Plate 6. Growth of sunflower in maize stover incorporated plot at sowing

Plate 7. Growth of sunflower in lime incorporated plot at 20 days before sowing

Plate 4

Plate 5

Plate 6

Plate 7

but statistically superior to lime application at 20 DAS (7.59 g/plant) (Table 4.43b).

At 55 DAS during 1989, interaction effects (Table 4.43c) revealed that application of maize stover and paddy straw at 20 days before sowing brought marked improvement in the DM per plant (58.1 and 56.9 g) and they were significantly superior to either application at sowing (50.1 and 45.0 g), 20 DAS (48.1 and 47.1) or 40 DAS (53.1and 50.9 g), respectively. Whereas, lime application at 20 days before sowing (54.9 g/plant), at sowing (53.6 g/plant) and 40 DAS (53.9) were statistically on par and all were statistically superior to lime application at 20 DAS (50.4 g/plant).

At 75 DAS in 1990 also, in interaction effect (Table 4.43d) indicated that maize stover application at 20 days before sowing gave higher DM per plant (73.1 g) and was significantly higher than its application at sowing (67.0 g), 20 DAS (66.1 g) and 40 DAS (67.9 g) which all together were statistically on par. Paddy straw incorporation at 20 days before sowing (72.9 g/plant) was on par with its application at 40 days after (69.2 g/plant) and was statistically superior to application either at sowing (67.1 g/plant) or 20 days later (65.2 g/plant). Whereas, lime application at 20 days before sowing (70.1 g/plant) was on par with that at sowing (72.0 g/plant) and both together were statistically better than lime application either at 20 (66.1 g/plant) or 40 DAS (66.2 g/plant).

4.4.2.2 Yield and its components of sunflower:

Head diameter of sunflower: The data on head diameter of sunflower as influenced by CO_2 treatment amendments and time of their application are presented in Table 4.44. Head diameter of sunflower was marginally improved by CO_2 fertilization (14.01 cm and 14.40 cm in 1989 and 1990) and by application of amendments (14.22 and 13.43 cm) as compared to control (13.81 and 13.02 cm) and the differences were statistically nonsignificant during both the years. There were no differences in the head size within different types of amendments. Application of amendments at 20 days before sowing gave highest head diameter (14.87 in 1989 and 14.31 in 1990) followed by application at sowing (14.71 cm and 13.90 cm) and was lowest in treatments which were applied at 20 DAS (13.58 cm and 12.62 cm).

Number of filled seeds per head: The number of filled seeds per head (Table 4.44) were not significantly influenced but showed trends of increased numbers by CO_2 enrichment (773 in 1989 and 639 in 1990) and soil amendments (695 and 623) over control (680 and 574). Types of amendments also did not bring significant

Table 4.44 Head diameter, number filled seeds and per cent seed filling per head in sunflower as influenced by CO_2 fertilization, amendments and time their application in sunflower-soybean intercropping system.

Treatments		Head diameter (cm)		No.of filled seeds		Filling per cent	
		1989	1990	1989	1990	1989	1990
1. (a) Control		13.81	13.02	680	574	79.3	74.4
(b) + CO_2		14.01	14.40	733	639	76.9	72.3
(c) Amendments		14.22	13.43	695	623	79.8	74.5
'F'test		NS	NS	NS	NS	NS	NS
S.Em± (a)		0.40	0.46	28	23	1.1	0.9
(b)		0.40	0.46	28	23	1.1	0.9
(c)		0.11	0.13	8	6	0.3	0.3
C.D. at 5%	(a) & (b)	-	-	-	-	-	-
	(a) & (c)	-	-	-	-	-	-
	(b) & (c)	-	-	-	-	-	-
2. Within amendments							
(a) Type of amendments							
Maize stover		14.32	13.55	711	622	79.9	75.1
Paddy straw		14.22	13.41	693	627	80.2	75.2
Lime		14.12	13.32	680	619	79.2	73.2
'F'test		NS	NS	NS	NS	NS	*
S.Em±		0.20	0.23	14	11	0.6	0.5
C.D. at 5%		-	-	-	-	-	1.4
(b) Time of application:							
20 days before sowing		14.87	14.31	744	665	81.8	75.1
At sowing		14.71	13.90	745	672	83.2	77.2
20 days after sowing		13.58	12.62	629	562	77.2	73.0
40 days after sowing		13.73	12.88	662	592	76.9	73.0
'F'test		**	**	**	**	**	**
S.Em±		0.23	0.26	16	13	0.6	0.5
C.D. at 5%		0.66	0.77	47	38	1.9	1.6
C.V.(%)		4.8	5.9	7.0	6.3	2.4	2.2

variations in number of filled seeds per head during both the years. Whereas, time of application of these amendments brought significant variations. Application of amendments either at 20 days before sowing (744 and 665) or at sowing (745 and 672) produced significantly higher number of filled seeds per head as compared to their application either at 20 DAS (629 and 562) or at 40 DAS (662mand 592), during both first and second years, respectively.

Filling per cent in sunflower: The CO_2 fertilization brought down the seed filling per cent in sunflower (Table 4.44) during both 1989 (76.9%) and 1990 (72.3%) seasons. However, the differences were nonsignificant either with amendments (79.8 in 1989 and 74.5% in 1990) or with control (79.3 and 74.4%). Among types, maize stover and paddy straw incorporation improved the filling per cent both during 1989 (79.9 and 80.2%) and 1990 (75.1 % and 75.2%), respectively as compared to lime (79.2% in 1989 and 73.2% in 1990). However, the improvements in seed filling by organic amendments were significant only during 1990. Among the timings seed filling per cent was highest in treatment which received the amendents at sowing (83.2 and 77.2%) followed by that which received 20 days before sowing (81.8 and 75.1%) and was lowest in treatment which received at 40 DAS (76.9 and 73.0%). However, it was on par with treatment which received amendment at 20 DAS (77.2 and 73.0%) during 1989 and 1990, respectively.

Test weight in sunflower (Table 4.45): Test weight of sunflower decreased significantly due to CO_2 fertilization (48.51 and 49.03 g/1000 seeds in 1989 and 1990) as compared to control (52.08 and 51.78 g/1000 seeds) and the treatments which recieved soil amendments (52.89 and 52.03 g/1000 seeds). Within soil amendments, there were no statistical differences in test weight both during first and second years. Highest test weight of 54.62 and 53.15 g/1000 seeds were recorded in treatment which received the amendments at sowing followed by the treatment which received at 20 days before sowing (53.14 and 52.22)and the lowest was amendments applied at 40 DAS (51.49 and 51.04 g/1000 seeds) during 1989 and 1990, respectively.

Seed weight per plant in sunflower (Table 4.45): The seed weight of sunflower did not differ significantly among control, CO_2 fertilization and soil amendments in first year; while in second year, the seed weight due to soil amendments was significantly higher (30.19 g/plant) than control (27.56 g/plant). Within amendments, there were no statistical differences. Application of amendments either at sowing (36.93 g/plant in 1989 and 33.71 g/plant in 1990) or 20 days

Table 4.45 Test weight and seed weight of sunflower as influenced by CO_2 fertilization, amendments and time of their application in sunflower-soybean intercropping system.

Treatments		Test weight (g/1000 seeds)		Seed weight (g/plant)	
		1989	1990	1989	1990
1. (a) Control		52.08	51.78	32.21	27.56
(b) + CO_2		48.51	49.03	32.31	28.98
(c) Amendments		52.89	52.03	33.57	30.19
'F'test		**	**	NS	*
S.Em±	(a)	0.59	0.61	2.05	0.89
	(b)	0.59	0.61	2.05	0.89
	(c)	0.17	0.18	0.59	0.26
C.D. at 5%	(a) & (b)	1.70	1.79	-	2.59
	(a) & (c)	1.25	1.32	-	1.91
	(b) & (c)	1.25	1.32	-	1.91
2. Within amendments					
(a) Type of amendments					
Maize stover		52.83	51.94	34.36	30.21
Paddy straw		52.72	52.25	33.50	30.62
Lime		53.11	51.90	32.85	29.73
'F'test		NS	NS	NS	NS
S.Em±		0.29	0.31	1.03	0.45
C.D. at 5%		-	-	-	-
(b) Time of application					
20 days before sowing		53.14	52.22	36.38	32.14
At sowing		54.62	53.15	36.93	33.71
20 days after sowing		52.30	51.70	29.96	26.92
40 days after sowing		51.49	51.04	31.00	27.98
'F'test		**	**	**	**
S.Em±		0.34	0.35	1.18	0.51
C.D. at 5%		0.98	1.03	3.45	1.50
C.V.(%)		1.9	2.1	10.7	5.2

in advance (36.38 and 32.14 g/plant) resulted in marked increase in the seed weight and both were statistically higher as compared to application at 20 DAS (29.96 and 26.92 g/plant) or 40 DAS (31.00 and 27.98 g/plant) in both the years.

Seed yield of sunflower (Table 4.46): There were no significant differences in seed yield although marginal improvements were observed due to CO_2 fertilization and soil amendments. Time of application of amendments brought significant variations in seed yield with highest values of 24.5 and 21.9 q per ha when amendments were applied at sowing followed by application at 20 days in advance of sowing with 24.0 and 21.5 q per ha in the two years. The lowest seed yield of 21.0 q per ha in first year and 17.5 q per ha in second year was recorded in treatment which received amendments at 20 DAS. However, they were on par with yield levels (22.0 and 18.1) obtained in treatment which received at 40 DAS.

Stalk yield of sunflower (Table 4.46) : It was higher with CO_2 (35.9 and 34.5 q/ha in 1989 and 1990) but statistically nonsignificant when compared with control (34.3 and 31.3 q/ha) and amended treatments (35.0 and 33.7 q/ha). Types of amendments also gave the stalk yields which were statistically on par. Stalk yield

Table 4.46 Seed yield, stalk yield and harvest index of sunflower as influenced by CO_2 fertilization, amendments and time of their application in sunflower-soybean intercropping system.

Treatments		Seed yield (q/ha)		Stalk yield (q/ha)		Harvest index	
		1989	1990	1989	1990	1989	1990
1. (a) Control		21.92	18.01	34.28	31.33	0.376	0.354
(b) + CO_2		22.00	18.58	35.89	34.50	0.359	0.341
(c) Amendments		22.87	19.74	34.95	33.65	0.378	0.359
'F' test		NS	NS	NS	NS	**	*
S.Em±	(a)	0.82	1.05	1.55	1.03	0.006	0.006
	(b)	0.82	1.05	1.55	1.03	0.006	0.006
	(c)	0.24	0.30	0.45	0.30	0.002	0.002
C.D. at 5%	(a) & (b)	-	-	-	-	0.017	0.019
	(a) & (c)	-	-	-	-	0.012	0.014
	(b) & (c)	-	-	-	-	0.012	0.014
2. Within amendaents							
(a) Type of amendments							
Maize stover		23.03	20.07	35.29	33.87	0.379	0.360
Paddy straw		22.97	20.23	34.59	34.33	0.381	0.360
Lime		22.60	18.93	34.96	32.14	0.375	0.356
'F' test		NS	NS	NS	NS	NS	NS
S.Em±		0.41	0.53	0.77	0.51	0.003	0.003
C.D. at 5%		-	-	-	-	-	-
(b) Time of application							
20 days before sowing		23.97	21.53	36.14	36.39	0.381	0.360
At sowing		24.52	21.91	35.28	35.16	0.395	0.374
20 days after sowing		21.01	17.48	33.04	30.21	0.373	0.356
40 days after sowing		21.97	18.06	35.34	32.82	0.365	0.344
'F' test		**	**	NS	**	**	**
S.Em±		0.47	0.61	0.89	0.59	0.003	0.004
C.D. at 5%		1.38	1.77	-	1.73	0.010	0.011
C.V. (%)		6.3	9.3	7.7	5.3	2.6	3.1

did not differ significantly also with time of application of amendments during 1989 (33.04 to 36.14 q/ha) but differed significantly during 1990 with highest value (36.39) when amendments were applied 20 days before sowing followed by application at sowing (35.16) and was lowest (30.21) when amendments were applied at 20 DAS.

Interaction effect between soil amendments and their time of application was significant during 1990 (Table 4.46a). Application of maize stover at 20 days before sowing and paddy straw at 20 days before and at sowing gave significantly higher stalk yield (36.75, 38.31 and 36.43 q/ha, respectively) than their application at 20 (29.0 and 29.29 q/ha) and 40 days after sowing (33.61 and 33.28 q/ha). Whereas, the time of application of lime did not bring significant variations in stalk yield (31.58 to 34.10 q/ha).

Harvest index of sunflower: The CO_2 fertilization gave significantly lower harvest index (0.359 in 1989 and 0.341 in 1990) when compared to amended treatments (0.378 and 0.359) (Table 4.46). Whereas, the comparison of control with CO_2 treatment and with amendments did not show significant differences. Types of amendments did not prove significant in influencing the harvest index. However, organic amendments were slightly superior to lime. Highest harvest index was

Table 4.46(a) Interaction effect between amendments and time of their application on stalk yield (q/ha) of sunflower in sunflower-soybean intercropping system during 1990 summer season.

Time of application	Amendments		
	Maize stover	Paddy straw	Lime
20 days before sowing	36.75	38.31	34.10
At sowing	36.13	36.43	32.93
20 days after sowing	29.00	29.29	32.35
40 days after sowing	33.61	33.28	31.58
'F'test		*	
S.Em±		1.03	
C.D. at 5%		2.99	

recorded when the amendments were applied at sowing (0.395 and 0.374 in first and second years) followed by amendments applied at 20 days in advance (0.381 and 0.360) and was lowest (0.365 and 0.344) when applied at 40 DAS both during 1989 and 1990 seasons.

4.4.2.3 Maturity duration of sunflower (Table 4.47)

Between two years of experimentation, the crop took around 2 days more in 1989 than in 1990 to complete its life cycle. And within each year, the duration was significantly reduced by 5.7 days due to CO_2 fertilization (Plate 4). Among different types of soil amendments, application of maize stover and paddy straw significantly extended the duration of sunflower by 1.3 and 1.4 days in 1989 and by 1.4 and 1.7 days in 1990 as compared to lime. Incorporation of amendments at the time of sowing brought significant increase in the duration of sunflower (93.4 days in 1989 and 91.8 days in 1990) as compared to rest of treatments (90.0 to 90.2 days in 1989 and 88.0 to 88.3 days in 1990) which were statistically on par with each other (Plates 5, 6 and 7).

Interaction effects between soil amendments and time of application were significant (Table 4.48a). In the first year, incorporation of maize stover and paddy straw at sowing significantly extended the

Table 4.47 Maturity duration of sunflower as influenced by CO_2 fertilization, amendments and time of their application in sunflower-soybean intercropping system.

Treatments	Duration in days		
	1989	1990	Mean
1. (a) Control	90.0	88.0	89.0
(b) + CO_2	84.0	82.3	83.3
(c) Amendments	90.9	89.0	89.9
'F'test	**	**	
S.Em± (a)	0.6	0.3	
(b)	0.6	0.3	
(c)	0.2	0.1	
C.D. at 5% (a) & (b)	1.8	1.0	
(a) & (c)	1.3	0.7	
(b) & (c)	1.3	0.7	
2. Within amendments			
(a) Type of amendments			
Maize stover	91.3	89.4	90.3
Paddy straw	91.4	89.7	90.5
Lime	90.0	88.0	89.0
'F'test	**	**	
S.Em±	0.3	0.2	
C.D.at 5%	0.9	0.5	
(b) Time of application			
20 days before sowing	90.0	88.0	89.0
At sowing	93.4	91.8	92.6
20 days after sowing	90.2	88.3	89.2
40 days after sowing	90.0	88.0	89.0
'F'test	**	**	
S.Em±	0.3	0.2	
C.D. at 5%	1.0	0.6	
C.V.(%)	1.2	0.7	

Table 4.48 Maturity duration of sunflower as influenced by the interaction between amendments and time of their application in sunflower-soybean inter-cropping system.

Table 4.48(a) Maturity duration in days, 1989.

Time of application	Amendments		
	Maize stover	Paddy straw	Lime
20 days before sowing	90.0	90.0	90.0
At sowing	95.0	95.3	90.0
20 days after sowing	90.3	90.3	90.0
40 days after sowing	90.0	90.0	90.0
'F'test		*	
S.Em±		0.6	
C.D. at 5%		1.8	

Table 4.48(b) Maturity duration in days, 1990.

Time of application	Amendments		
	Maize stover	Paddy straw	Lime
20 days before sowing	88.0	88.0	88.0
At sowing	93.3	94.0	88.0
20 days after sowing	88.3	88.7	88.0
40 days after sowing	88.0	88.0	88.0
'F'test		**	
S.Em±		0.3	
C.D. at 5%		1.0	

duration of sunflower (95.0 and 95.3, respectively) (Plate 6), however not by incorporation of lime (90.0 days). In second year also, similar trend of increased duration of sunflower by maize stover and paddy straw incorporation at sowing (93.3 and 94.0, respectively) was observed without such observation in lime incorporated treatments (88.0 days) (4.48b).

4.4.2.4 Nutrient uptake studies in sunflower (Table 4.49):

Nitrogen uptake in sunflower: It was not significantly influenced by CO_2 fertilization and amendments in general, during both the years (120.3 to 126.0 kg/ha in 1989 and 103.3 to 112.3 kg/ha in 1990). However, CO_2 enrichment showed trends in increased N uptake during both the years. Application of lime brought down the nitrogen uptake by sunflower (121.3 kg/ha in 1989 and 106.4 kg/ha in 1990) as compared to maize stover (125.8 and 114.0 kg/ha) and paddy straw (124.5 and 115.1 kg/ha). However, it was significant only during second year. Among the times of application, highest uptake of nitrogen (132.1 and 124.2 kg/ha in 1989 and 1990) was noticed when amendments were incorporated 20 days in advance of sowing, although they were on par with treatment which received the amendments at sowing (128.4 and 119.8 kg/ha). Lowest uptake of nitrogen (114.5 and 99.0 kg/ha) was with amendments given at 20

Table 4.49 Total nitrogen, phosphorus and potassium uptake by sunflower as influenced by CO_2 fertilization, amendments and time of their application in sunflower-soybean intercropping system.

Treatments	Nutrient uptake (kg/ha)					
	Nitrogen		Phosphorus		Potassium	
	1989	1990	1989	1990	1989	1990
1. (a) Control	120.3	103.3	19.7	16.8	80.0	71.4
(b) + CO_2	126.0	112.3	20.3	17.9	75.6	70.5
(c) Amendments	123.9	111.8	20.4	18.2	79.0	74.1
'F' test	NS	NS	NS	NS	NS	NS
S.Em± (a)	2.9	4.2	0.9	0.6	3.5	2.9
(b)	2.9	4.2	0.9	0.6	3.5	2.9
(c)	0.8	1.2	0.2	0.2	1.0	0.8
C.D. at 5% (a) & (b)	-	-	-	-	-	-
(a) & (c)	-	-	-	-	-	-
(b) & (c)	-	-	-	-	-	-
2. Within amendments						
(a) Type of amendments						
Maize stover	125.8	114.0	20.8	18.7	79.6	74.7
Paddy straw	124.5	115.1	20.4	18.6	78.6	75.9
Lime	121.3	106.4	20.0	17.3	78.6	71.7
'F' test	NS	*	NS	*	NS	NS
S.Em±	1.5	2.1	0.4	0.3	1.8	1.4
C.D. at 5%	-	6.1	-	0.8	-	-
(b) Time of application						
20 days before sowing	132.1	124.2	21.7	20.1	82.4	80.7
At sowing	128.4	119.8	21.5	19.8	80.5	78.1
20 days after sowing	114.5	99.0	18.7	16.0	74.1	66.3
40 days after sowing	120.6	104.4	19.8	16.9	78.9	71.3
'F' test	**	**	**	**	*	**
S.Em±	1.7	2.4	0.3	2.0	1.7	
C.D. at 5%	4.9	7.0	1.4	1.0	5.9	4.8
C.V. (%)	4.1	6.5	7.3	5.6	7.7	6.8

DAS followed by that which received at 40 DAS (120.6 and 104.4 kg/ha) during 1989 and 1990, respectively.

Phosphorus uptake of sunflower: It did not vary significantly although marginal increases were noticed by CO_2 enrichment and application of amendments. Lime application significantly reduced the uptake of phosphorus during 1990 (17.3 kg/ha) as compared to maize stover (18.7 kg/ha) and paddy straw (18.6). However, such differences were not observed in 1989. Application of amendments 20 days before sowing significantly increased the phosphorus uptake (21.7 kg/ha in 1989 and 20.1 kg/ha in 1990) as compared to application at 20 (18.7 and 16.0 kg/ha) and 40 DAS (19.8 and 16.9 kg/ha). However, it was statistically on par with application at sowing (21.5 and 19.8 kg/ha) during both the years.

Interaction effects between soil amendments and time of their application in 1990 indicated that incorporation of maize stover and paddy straw at 20 and 40 DAS significantly reduced the uptake of phosphorus as compared to application at sowing or 20 days before sowing. Lime incorporation significantly reduced the P uptake irrespective of the the time of application (Table 4.49a).

Table 4.49(a) Interaction effect between amendments and time of their application on total phosphorus uptake (kg/ha) of sunflower in sunflower-soybean intercropping system during 1990 summer season.

Time of application	Amendments		
	Maize stover	Paddy straw	Lime
20 days before sowing	21.2	21.2	18.0
At sowing	21.0	21.0	17.4
20 days after sowing	15.4	15.6	17.0
40 days after sowing	17.1	16.6	16.9
'F'test		*	
S.Em±		0.6	
C.D. at 5%		1.7	

Potassium uptake by sunflower: It was not significantly influenced by CO_2 fertilization and amendments during both the years. The uptake of potassium was almost same with the three amendments with no differences. Whereas, the time of application of amendments showed that incorporation either at 20 days before sowing (82.4 kg/ha in 1989 and 80.7 kg in 1990) or at sowing (80.5 and 78.1 kg/ha) did not bring significant difference in uptake, but both together were statistically superior to application either at 20 DAS (74.1 and 66.3 kg/ha) or 40 DAS (78.9 and 71.3 kg/ha).

4.4.3 Response of soybean to CO_2, lime and organic amendments

Between two years of field experiment, the growth and yield of soybean was better during first year as compared to second year.

4.4.3.1 Growth components:

Plant height of soybean (Table 4.50): The plant height of soybean was significantly increased due to CO_2 fertilization (101.2 cm in 1989 and 80.1 cm in 1990) as compared to amendments (82.3 and 70.3 cm) and control (75.6 and 65.2 cm) during 1989 and 1990, respectively. Application of amendments also improved the plant height over control but significant only during second year. Within three types of amendments, the variation

Table 4.50 Plant height, number of primary branches and number of root nodules per plant of soybean as influenced by CO_2 fertilization, amendments and time of their application in sunflower-soybean intercropping system

Treatments	Plant height(cm)		Primary branches		Root nodules	
	1989	1990	1989	1990	1989	1990
1. (a) Control	75.6	65.2	1.70	1.20	36.2	22.5
(b) + CO_2	101.2	80.1	2.00	1.47	37.9	25.7
(c) Amendments	82.3	70.3	1.63	1.16	46.3	29.6
'F'test	**	**	**	**	**	*
S.Em± (a)	2.2	2.6	0.07	0.05	2.7	2.3
(b)	2.2	2.6	0.07	0.05	2.7	2.3
(c)	0.6	0.8	0.02	0.01	0.8	0.7
C.D. at 5% (a) & (b)	6.4	7.7	0.20	0.14	7.8	6.6
(a) & (c)	4.7	5.7	0.15	0.10	5.7	4.9
(b) & (c)	4.7	5.7	0.15	0.10	5.7	4.9
2. Within amendments						
(a) Type of amendments						
Maize stover	80.2	70.6	1.55	1.12	51.4	34.5
Paddy straw	83.0	70.3	1.61	1.20	54.3	35.2
Lime	83.7	70.0	1.72	1.15	33.3	19.2
'F'test	NS	NS	**	NS	**	**
S.Em±	1.1	1.3	0.03	0.02	1.3	1.1
C.D. at 5%	-	-	0.10	0.07	3.9	3.3
(b) Time of application						
20 days before sowing	80.0	71.2	1.70	1.16	45.2	25.5
At sowing	75.1	66.0	1.41	1.09	38.3	24.3
20 days after sowing	86.4	71.9	1.70	1.20	52.0	33.0
40 days after sowing	87.9	72.3	1.70	1.19	49.9	35.7
'F'test	**	**	**	*	**	**
S.Em±	1.3	1.5	0.04	0.03	1.5	1.3
C.D. at 5%	3.7	4.5	0.12	0.08	4.5	3.8
C.V.(%)	4.6	6.5	7.3	7.2	10.3	13.7

in plant height was statistically nonsignificant during both the years. Time of application of amendments brought significant effect on plant height. Highest plant height was observed when amendments were applied at 40 DAS (87.9 in 1989 and 72.3 in 1990) followed by application at 20 DAS (86.4 and 71.9 cm). However, both of them were statistically on par and were significantly superior to application at 20 days before sowing (80.0 cm and 71.2 cm) and at sowing (75.1 cm and 66.0 cm) in influencing the plant height.

Interaction effects between amendments and time of application (Table 4.50a) indicated that application of maize stover at 20 DAS gave highest plant height (85.3 cm) but on par with application at 20 days before (80.3 cm) and 40 days after (82.9 cm) sowing and all these were superior to incorporation at sowing (72.3 cm). Whereas, paddy straw incorporated at 20 days before sowing (81.3 cm), at sowing (78.3 cm) and 20 days after (82.5 cm) were statistically on par and were significantly inferior to the plant height obtained when incorporation was made at 40 DAS (90.1 cm). Lime application at 20 days before (78.3 cm) and at sowing (74.6 cm) were on par and both were statistically inferior to incorporation at 20 (91.3 cm) and 40 (90.6 cm) DAS which were again statistically on par.

Table 4.50(a) Plant height (cm) of soybean as influenced by the interaction of amendments and time of their application in sunflower-soybean intercropping system during 1989 summer season.

	Amendments		
Time of application	Maize stover	Paddy straw	Lime
20 days before sowing	80.3	81.3	78.3
At sowing	72.3	78.3	74.6
20 days after sowing	85.3	82.5	91.3
40 days after sowing	82.9	90.1	90.6
'F'test		*	
S.Em±		2.2	
C.D. at 5%		6.4	

Number of primary branches: The CO_2 fertilization significantly improved the branching (2.00 branches/plant in 1989 and 1.47 branches/plant in 1990) over amendments (1.63 and 1.16) and control (1.70 and 1.20) (Table 4.50). Among three types of amendments, lime application gave significantly higher number of branches (1.72/plant) as compared to maize stover (1.55) but on par with paddy straw application (1.61) during first year. Whereas, in second year the differences were statistically nonsignificant. Among the time of applications of amendments, lowest number of bránches per plant was observed when incorporation was made at sowing both during first (1.41) and second (1.09) years and this was significantly inferior to all other time of applications which were statistically on par (1.70 in 1989 and 1.16 to 1.20 in 1990).

Number of root nodules in soybean (Table 4.50): Nodulation was significantly improved by application of amendments (46.3/plant in 1989 and 29.6/plant in 1990) as compared to CO_2 fertilization (37.9) and control (36.2) in 1989 and when compared to only control (22.5/plant) in 1990. While CO_2 treatments did not improve the nodulation significantly over control during both the years. Application of maize stover and paddy straw significantly improved the nodulation during 1989 (51.4 and 54.3/plant, respectively) and also during 1990 (34.5 and 35.2/plant) as compared to application of lime (33.3/plant in 1989 and 19.2/plant in 1990). There was no statistical differences between two organic amendments. With regard to time of application, amendments incorporated at sowing had an adverse effect on nodulation giving lowest number of nodules (38.3/plant in 1989 and 24.3 in 1990), when compared to other time of applications. While highest number of nodules per plant were obtained in treatment where incorporation was made at 20 DAS (52.0/plant) during first year and 40 DAS in second year (35.7/plant). However, application of amendments either at 20 or 40 DAS did not bring significant differences and both together were statistically superior to application at 20 days before sowing during both the years.

Leaf area index (LAI) of soybean: The data pertaining to LAI of intercropped soybean at four stages viz., 35, 55, 75 and 90 days after sowing (DAS) as influenced by CO_2 fertilization, amendments and time of their application are presented in Table 4.51. CO_2 fertilization significantly improved LAI of soybean as compared to control and amended treatments at all stages except at 35 DAS. Amendments also improved the LAI of soybean at all the stages. However, the improvement was significant only at 75 DAS during 1989.

Table 4.51 Leaf area index of soybean at different stages as influenced by CO_2 fertilization, amendments and time of their application in sunflower - soybean intercropping system.

Treatments	LAI at 35 DAS 1989	35 DAS 1990	55 DAS 1989	55 DAS 1990	75 DAS 1989	75 DAS 1990	90 DAS 1989	90 DAS 1990
1. a. control	0.30	0.36	1.39	1.09	1.71	1.52	2.12	1.74
b. +CO_2	0.37	0.40	2.24	1.65	2.54	1.84	2.69	2.40
c. Amendments	0.32	0.36	1.47	1.09	2.18	1.54	2.34	1.79
'F' test	NS	NS	**	**	**	*	**	**
S.Em± (a)	0.02	0.03	0.06	0.05	0.11	0.10	0.12	0.06
(b)	0.02	0.03	0.06	0.05	0.11	0.10	0.12	0.06
(c)	0.01	0.01	0.02	0.01	0.03	0.03	0.03	0.02
C.D. at 5% (a)&(b)	-	-	0.19	0.14	0.33	0.28	0.34	0.18
(a)&(c)	-	-	0.14	0.10	0.24	0.21	0.25	0.13
(b)&(c)	-	-	0.14	0.10	0.24	0.21	0.25	0.13
2. Within amendments								
a. Type of amendments								
maize stover	0.29	0.36	1.49	1.11	2.21	1.52	2.34	1.76
Paddy straw	0.31	0.35	1.40	1.12	2.18	1.57	2.31	1.81
Lime	0.34	0.36	1.50	1.05	2.17	1.53	2.35	1.79
'F' test	*	NS	NS	NS	NS	NS	NS	NS
S.Em±	0.01	0.01	0.03	0.02	0.06	0.05	0.06	0.03
C.D. at 5%	0.03	-	-	-	-	-	-	-
b. Time of application								
20 days before sowing	0.38	0.40	1.60	1.18	2.25	1.61	2.37	1.84
At sowing	0.25	0.29	1.16	0.91	1.72	1.35	1.94	1.61
20 days after sowing	0.30	0.37	1.61	1.16	2.38	1.59	2.52	1.84
40 days aftersowing	0.33	0.37	1.50	1.23	2.39	1.62	2.52	1.86
'F' test	**	**	**	**	**	**	**	**
S.Em±	0.01	0.02	0.04	0.03	0.07	0.06	0.07	0.04
C.D. at 5%	0.04	0.04	0.11	0.08	0.19	0.16	0.20	0.10
C.V. (%)	11.7	13.0	7.5	7.4	9.0	10.8	8.6	5.9

Types of amendments did not bring significant variations in LAI of soybean except at 35 DAS during 1989, where the lime application was found superior (0.34) to maize stover incorporation.

The LAI of soybean was markedly reduced with amendments given at the time of sowing and the treatment was significantly inferior to all other times of application during both the years. The treatments with application of amendments at 20 days before sowing, 20 and 40 DAS were statistically similar in influencing the LAI of soybean, except at 35 DAS during 1989 where application at 20 days in advance was found superior to the remaining treatments.

Interaction effects indicated that at 35 DAS during 1989, maize stover and paddy straw incorporation either at sowing or at 20 DAS brought down the LAI of soybean significantly as compared to their application at 20 days before sowing (Table 4.52a). Whereas, the time of application of lime did not influence the LAI of soybean. The LAI at 55 DAS, revealed that the incorporation of maize stover and paddy straw at sowing significantly reduced the LAI as compared to all other time of applications, Further, incorporation of these organic amendments at 40 DAS gave significantly lower LAI as compared to their incorporation at 20 days

Table 4.52 Leaf area index of soybean at 35 and 55 days after sowing as influenced by the interaction between amendments and time of application in sunflower-soybean intercropping system during 1989 summer season.

Table 4.52(a) LAI at 35 DAS.

Time of application	Amendments		
	Maize stover	Paddy straw	Lime
20 days before sowing	0.37	0.40	0.38
At sowing	0.19	0.23	0.33
20 days after sowing	0.27	0.32	0.32
40 days after sowing	0.34	0.31	0.33
'F'test		*	
S.Em±		0.02	
C.D. at 5%		0.06	

Table 4.52(b) LAI at 55 DAS.

Time of application	Amendments		
	Maize stover	Paddy straw	Lime
20 days before sowing	1.68	1.59	1.52
At sowing	1.20	0.88	1.40
20 days after sowing	1.63	1.61	1.59
40 days after sowing	1.47	1.54	1.50
'F'test		*	
S.Em±		0.05	
C.D. at 5%		0.19	

before sowing. Whereas, lime application timings had no influence on the LAI (Table 4.52b).

Total leaf area duration (LAD) of soybean: The results of total LAD (Table 4.53) indicated that CO_2 treatment brought out marked and significant increase in LAD of soybean (164.3 and 123.8 days in 1989 and 1990) as compared to amendments (133.0 and 94.5 days)and control (117.8 and 93.2 days) during both the years. The LAD of amended treatments was also significantly higher during 1989. However, it was not significant during 1990. Within the types of amendments, LAD of soybean did not vary significantly. Incorporation of these amendments at sowing resulted in lowest LAD of soybean (107.8 days in 1989 and 82.5 days in 1990) and it was significantly inferior to all other time of applications viz. 20 days before sowing, 20 and 40 DAS which were on par (138.7 to 143.5 days in 1989 and 98.3 to 99.3 days in 1990).

Chlorophyll content of soybean : Chlorophyll contents of soybean at 30 and 60 days after sowing estimated during second year are presented in Table 4.54 and 4.55, respectively. Application of organic amendments at 20 days in advance of sowing gave marked improvement in total chlorophyll content at 30 days of soybean (3.99 and 4.00 mg/g fresh leaf in maize stover and paddy straw incorporated treatments, respectively) as

Table 4.53 Total leaf area duration of soybean as influenced by CO_2 fertilization, amendments and time of their application in sunflower-soybean intercropping system.

Treatments	LAD (days)		
	1989	1990	Mean
1. (a) Control	117.8	93.2	105.5
(b) + CO_2	164.3	123.8	144.0
(c) Amendments	133.0	94.5	113.7
'F' test	**	**	
S.Em± (a)	3.9	3.2	
(b)	3.9	3.2	
(c)	1.1	0.9	
C.D. at 5% (a) & (b)	11.5	9.4	
(a) & (c)	8.4	6.9	
(b) & (c)	8.4	6.9	
2. Within amendments			
(a) Type of amendments			
Maize stover	133.3	94.0	113.6
Paddy straw	131.1	95.8	113.6
Lime	134.5	93.7	114.1
'F' test	NS	NS	
S.Em±	2.0	1.6	
C.D. at 5%	-	-	
(b) Time of application			
20 days before sowing	138.7	99.3	119.0
At sowing	107.8	82.5	95.1
20 days after sowing	143.5	97.8	120.6
40 days after sowing	141.9	98.3	120.1
'F' test	**	**	
S.Em±	2.3	1.9	
C.D. at 5%	6.6	5.4	
C.V. (%)	5.1	5.8	

Table 4.54 Chlorophyll content of soybean at 30 days after sowing as influenced by organic amendments in sunflower-soybean intercropping system during 1990 summer season (mean of 2 replications) (mg/g fresh leaf weight).

Treatments	Total Chl.
1. Control	3.89
2. Maize stover incorporated 20 days before sowing	3.99
3. Maize stover incorporated at the time of sowing	3.51
4. Paddy straw incorporated 20 days before sowing	4.00
5. Paddy straw incorporated at the time of sowing	3.43
Mean	3.76

Table 4.55 Chlorophyll content of soybean at 60 days after sowing as influenced by CO_2 fertilization, amendments and time of their application in sunflower-soybean intercropping system during 1990 summer season (mg/g fresh leaf weight).

Treatments	Total chlorophyll	Chlorophyll 'b'
1. (a) Control	3.91	1.18
(b) + CO_2	3.93	1.18
(c) Amendments	3.93	1.19
'F' test	NS	NS
S.Em± (a)	0.04	0.02
(b)	0.04	0.02
(c)	0.01	0.01
C.D. at 5% (a) & (b)	-	-
(a) & (c)	-	-
(b) & (c)	-	-
2. Within amendments		
(a) Type of amendments		
Maize stover	3.94	1.18
Paddy straw	3.93	1.19
Lime	3.91	1.20
'F' test	NS	NS
S.Em±	0.02	0.01
C.D. at 5%	-	-
(b) Time of application		
20 days before sowing	3.99	1.21
At sowing	3.90	1.18
20 days after sowing	3.91	1.19
40 days after sowing	3.91	1.19
'F' test	*	NS
S.Em±	0.03	0.01
C.D. at 5%	0.07	-
C.V. (%)	2.0	2.7

compared to control (3.89 mg/g fresh leaf). Organic amendments applied at sowing resulted in comparatively less chlorophyll content of soybean (3.51 and 3.43 mg/g leaf in maize stover and paddy straw incorporated treatments).

The total chlorophyll content of soybean of 60 days did not differ significantly among control, CO_2 and amendments. Within the three types of amendments also, the total chlorophyll contents showed nonsignificant differences. However, amendments applied at 20 days before sowing resulted in significant improvement in the total chlorophyll content (3.99 mg/leaf) than amendments applied either at sowing (3.90), 20 DAS (3.91) or 40 DAS (3.91), which were statistically on par.

Chlorophyll b content of soybean showed nonsignificant differences when the treatments viz., CO_2 fertilization and amendments were compared individually with control or between them. Among the three types of amendments also, no significant differences in chlorophyll b content were oberved. Application of amendments 20 days in advance of sowing gave higher chlorophyll b content (1.21 mg/g leaf). However, it was statistically on par with other times of applications (1.18 to 1.19 mg/g leaf).

Total dry matter production: The results related to total DM production of soybean at 35, 55, 75 DAS and at maturity as influenced by CO_2 fertilization, amendments, and time of their application in sunflower-soybean intercropping system are presented in Table 4.56. At 35 DAS, the total DM of soybean did not vary significantly among control, CO_2 fertilization and amendments. While at 55, 75 DAS and at maturity, CO_2 treatment significantly enhanced the DM per plant when compared to control or amended treatments during both the years. Amendments also improved the DM production per plant over control, however being significant only during 1989 at 75 DAS and at maturity.

Among the three types of amendments, no statistical differences were observed at all the stages during both the years, except at 35 DAS during 1989 where lime applied treatment was found superior (0.93 g/plant) to maize stover (0.81 g/plant) and at 75 DAS where paddy straw application gave significantly higher DM (7.07 g/plant) than maize stover (6.75 g/plant).

Time of application of amendments brought out significant variations in total DM per plant of soybean at all the stages. Amendments applied at sowing gave lowest DM production at all the stages and this treatment was statistically inferior to all others.

Table 4.56 Total dry matter production in soybean at different stages as influenced by CO_2 fertilization, amendments and time of their application in sunflower-soybean intercropping system

Treatments		Total DM (g/plant) at							
		35 DAS		55 DAS		75 DAS		maturity	
		1989	1990	1989	1990	1989	1990	1989	1990
1. (a) Control		0.87	1.00	3.53	2.61	6.42	6.79	10.38	8.30
(b) + CO_2		1.00	1.12	5.58	3.98	9.51	8.47	13.63	9.65
(c) Amendments		0.87	0.99	3.69	2.63	8.21	6.89	11.42	8.12
'F'test		NS	NS	**	**	**	**	**	**
S.Em±	(a)	0.05	0.06	0.13	0.13	0.32	0.16	0.40	0.33
	(b)	0.05	0.06	0.13	0.13	0.32	0.16	0.40	0.33
	(c)	0.02	0.02	0.04	0.04	0.09	0.05	0.12	0.10
C.D. at 5%	(a) & (b)	-	-	0.39	0.37	0.94	0.48	1.17	0.97
	(a) & (c)	-	-	0.28	0.28	0.69	0.35	0.86	0.71
	(b) & (c)	-	-	0.28	0.28	0.69	0.35	0.86	0.71
2. Within amendments									
(a) Type of amendments									
Maize stover		0.81	0.99	3.71	2.66	8.29	6.75	11.43	7.96
Paddy straw		0.89	0.98	3.63	2.68	8.20	7.07	11.51	8.25
Lime		0.93	1.01	3.74	2.54	8.14	6.84	11.33	8.18
'F'test		*	NS	NS	NS	NS	*	NS	NS
S.Em±		0.03	0.03	0.07	0.06	0.16	0.08	0.20	0.17
C.D.at 5%		0.08	-	-	-	-	0.24	-	-
(b) Time of application									
20 days before sowing		1.06	1.11	3.95	2.86	8.49	7.19	11.62	8.67
At sowing		0.70	0.83	3.09	2.18	6.45	5.97	9.48	7.47
20 days after sowing		0.85	1.01	3.98	2.79	8.93	7.13	12.20	8.10
40 days after sowing		0.89	1.02	3.76	2.69	8.96	7.26	12.39	8.27
'F'test		**	**	**	**	**	**	**	**
S.Em±		0.03	0.04	0.08	0.07	0.19	0.09	0.23	0.19
C.D. at 5%		0.09	0.10	0.22	0.22	0.54	0.28	0.67	0.56
CV(%)		10.8	10.7	6.0	8.2	6.8	4.1	6.0	7.0

Amendments incorporated at 20 days before sowing gave significantly higher DM per plant when compared to amendments applied at 20 DAS as observed on 35th day of first year crop and at maturity in second year crop.

Interaction effects at 55 DAS, during 1989 (Table 4.56a) indicated that maize stover and paddy straw incorporation at sowing gave lowest DM per plant (3.02 and 2.75 g, respectively) and were significantly inferior to all other times of application (3.71 to 4.10). While, lime application at sowing reduced the DM per plant (3.50) but was on par with application at 20 days before (3.80 g) and 40 days after (3.75 g) sowing although significantly inferior to application at 20 DAS (3.91 g).

4.4.3.2 Yield and yield attributes of soybean

The results related to yield components of soybean viz., number of pods per plant, number of seeds per pod, test weight, and seed weight per plant are presented in Table 4.57, and seed yield, stover yield and harvest index of soybean are presented in Table 4.58.

Number of pods per plant: CO_2 fertilization gave significantly higher number of pods per plant (19.2 in 1989 and 15.9 in 1990) as compared to amendments (16.9 and 13.8) and control (15.5 and 13.7). Amendments also

Table 4.56(a) Total dry matter production of soybean at 55 days after sowing as influenced by the interaction between amendments and time of their application in sunflower-soybean inter-cropping system during 1989 summer season.

Time of application	Amendments		
	Maize stover	Paddy straw	Lime
20 days before sowing	4.10	3.94	3.80
At sowing	3.02	2.75	3.50
20 days after sowing	4.00	4.03	3.91
40 days after sowing	3.71	3.81	3.75
'F'test		*	
S.Em±		0.13	
C.D. at 5%		0.39	

Table 4.57 Number of pods per plant, number of seeds per pod, test weight and seed weight of soybean as influenced by CO_2 fertilization, amendments and time of their application in sunflower-soybean intercropping system.

Treatments		No. of pods		No.of seeds/ pod		Test weight (g/100 seeds)		Seed weight (g/plant)	
		1989	1990	1989	1990	1989	1990	1989	1990
1. (a) Control		15.5	13.7	2.38	2.39	15.15	14.96	4.89	4.02
(b) + CO_2		19.2	15.9	2.60	2.58	16.01	16.03	6.70	4.93
(c) Amendments		16.9	13.8	2.38	2.39	15.28	15.17	5.51	4.00
'F'test		**	*	NS	NS	NS	*	**	**
S.Em±	(a)	0.3	0.6	0.10	0.09	0.28	0.32	0.19	0.15
	(b)	0.3	0.6	0.10	0.09	0.28	0.32	0.19	0.15
	(c)	0.1	0.2	0.03	0.02	0.08	0.09	0.05	0.04
C.D. at 5%	(a) & (b)	0.9	1.8	-	-	-	0.93	0.56	0.45
	(a) & (c)	0.7	1.3	-	-	-	0.69	0.41	0.33
	(b) & (c)	0.7	1.3	-	-	-	0.69	0.41	0.33
2. Within amendments									
(a) Type of amendments									
Maize stover		16.9	13.5	2.38	2.39	15.27	15.21	5.54	3.94
Paddy straw		17.0	14.0	2.39	2.39	15.34	15.24	5.59	4.07
Lime		16.9	13.9	2.38	2.40	15.24	15.04	5.39	3.97
'F'test		NS	NS	NS	NS	NS	NS	NS	NS
S.Em±		0.2	0.3	0.05	0.04	0.14	0.16	0.10	0.08
C.D. at 5%		-	-	-	-	-	-	-	-
(b) Time of application									
20 days before sowing		17.2	14.3	2.38	2.41	15.02	15.08	5.51	4.13
At sowing		14.5	12.7	2.36	2.37	15.00	14.89	4.50	3.62
20 days after sowing		18.1	14.1	2.40	2.40	15.35	15.04	5.96	4.08
40 days after sowing		18.0	13.9	2.40	2.39	15.75	15.66	6.05	4.16
'F'test		**	*	NS	NS	*	*	**	**
S.Em±		0.2	0.4	0.06	0.05	0.16	0.18	0.11	0.09
C.D. at 5%		0.5	1.1	-	-	0.48	0.54	0.32	0.26
C.V.(%)		3.3	7.8	7.5	6.4	3.2	3.7	6.0	6.6

Plate 8. Influence of amendments and CO_2 enrichemnt on plant height and number of pods per plant of intercropped soybean

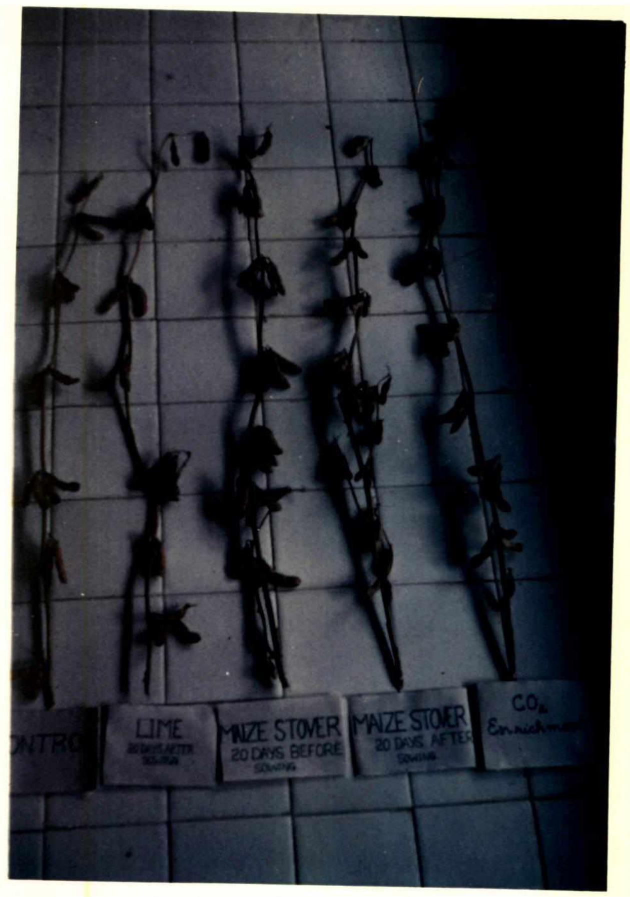


Plate 8

improved the number of pods per plant, however being significant only during 1989 when compared to control. Types of amendments did not affect the number of pods per plant during both the years. Amendments applied at sowing significantly reduced the number of pods (14.5 and 12.7/plant in 1989 and 1990) as compared to all other times of application. Further during 1989, incorporation of amendments either at 20 or at 40 DAS resulted in higher number of pods per plant (18.0 and 18.1) which were statistically superior to 20 days before sowing (17.2). However, such differences were not noticed during 1990.

Significant interaction between amendments and their time of application during 1989 (Table 4.57a) showed that maize stover and paddy straw applied at sowing brought down the number of pods to least (14.19 and 14.3/plant, respectively) which were statistically on par. Lime application at sowing (15.0 pods/plant) was statistically inferior to its application at 20 days before sowing (16.1 pods/plant) and both were statistically inferior to lime applications either at 20 (18.1 pods/plant) or 40 (18.2 pods/plant) DAS.

Number of seeds per pod in soybean: The number of seeds per pod were sligthly improved due to CO_2 fertilization, however being nonsignificant (2.60 in

Table 4.57(a) Number of pods per plant of soybean as influenced by the interaction between amendments and time of their application in sunflower-soybean intercropping system during 1989 summer.

Time of application	Amendments		
	Maize stover	Paddy straw	Lime
20 days before sowing	17.40	18.02	16.18
At sowing	14.19	14.29	15.02
20 days after sowing	18.13	17.95	18.12
40 days after sowing	17.92	17.81	18.17
'F'test		*	
S.Em±		0.33	
C.D. at 5%		0.95	

1989 and 2.58 in 1990) as compared to either amendments or control (2.38 and 2.39) both during first and second years. Application of either maize stover, paddy straw or lime brought no statistical differences in seed number per pod. Similarly, time of application also did not affect the number of seeds per pod significantly during both the years.

Test weight of soybean: Test weight of soybean was increased significantly by CO_2 treatment (16.03 g/100 seeds) during 1990 as compared to control (14.96 g/100 seeds) and amendments (15.17 g/100 seeds). However, during 1989, the increase in test weight was not significant. No statistical differences in test weight were observed among three types of amendments during both the years. With respect to time of application of amendments, highest test weight was recorded in treatment which received the amendments after 40 DAS (15.75 and 15.66 g/100 seeds) and it was significantly superior to treatments applied at sowing (15.00 g/100 seed) and 20 days before sowing (15.02 g/100 seed) during first year and to all other treatments during second year (14.89 to 15.08 g/100 seeds).

Seed weight per plant in soybean: The CO_2 fertilization and soil amendment treatments brought significant improvement in seed weight per plant (6.70 and 5.51 g, respectively) as compared to control (4.89

g) during first year, while during second year only CO_2 fertilization was effective in improving the seed weight per plant (4.93 g) over control (4.02 g). However, the seed weight per plant in amended treatments was significantly lower (5.51 and 4.00 g in 1989 and 1990) than CO_2 treatments (6.70 and 4.93 g) during both the years. Types of amendments did not prove significant in influencing the seed weight per plant both during first year (5.39 to 5.54 g) and second year (3.94 to 4.07 g). Seed weight per plant was significantly higher in treatments which received the amendments at 20 days (5.96 and 4.08 g in 1989 and 1990) and 40 days (6.05 and 4.16 g) after sowing as compared to the treatments which received at 20 days before sowing (5.51 g) and at sowing (4.50 g) in first year and the treatment which received amendments at sowing (3.62 g) during the second year, while application of amendments at 20 days before sowing (4.13 g/plant) was on par with 20 and 40 DAS during second year.

Seed yield of soybean (Table 4.58): Individual effects of CO_2 enrichment and application of amendments resulted in significant increase in seed yield of soybean (12.90 and 10.41 q/ha, respectively) when compared to control (9.57 q/ha) during first year. While during second year, CO_2 fertilization brought

Table 4.58 Seed yield, stover yield and harvest index of soybean as influenced by CO_2 fertilization, soil amendments and time of their application in sunflower-soybean intercropping system.

Treatments		Seed yield (q/ha) 1989	Seed yield (q/ha) 1990	Stover yield (q/ha) 1989	Stover yield (q/ha) 1990	Harvest index 1989	Harvest index 1990
1. (a) Control		9.57	7.25	10.37	7.54	0.471	0.484
(b) + CO_2		12.90	9.28	12.90	8.57	4.492	0.511
(c) Amendments		10.41	7.40	10.81	7.33	0.482	0.492
'F'test		**	**	**	*	NS	**
S.Em±	(a)	0.33	0.31	0.36	0.39	0.008	0.008
	(b)	0.33	0.31	0.36	0.39	0.008	0.008
	(c)	0.10	0.09	0.10	0.11	0.002	0.002
C.D. at 5%	(a) & (b)	0.97	0.91	1.04	1.12	-	0.024
	(a) & (c)	0.71	0.67	0.77	0.83	-	0.017
	(b) & (c)	0.71	0.67	0.77	0.83	-	0.017
2. Within amendments							
(a) Type of amendments							
Maize stover		10.64	7.41	10.83	7.19	0.484	0.496
Paddy straw		10.15	7.63	10.53	7.50	0.485	0.494
Lime		10.43	7.17	11.05	7.30	0.475	0.486
'F'test		NS	NS	NS	NS	NS	*
S.Em±		0.17	0.16	0.18	0.19	0.004	0.004
C.D. at 5%		-	-	-	-	-	0.012
(b) Time of application							
20 days before sowing		10.34	7.67	10.90	8.09	0.474	0.477
At sowing		8.36	6.47	8.82	6.55	0.475	0.485
20 days after sowing		11.51	7.74	11.67	7.35	0.489	0.504
40 days after sowing		11.42	7.73	11.83	7.33	0.488	0.503
'F'test		**	**	**	**	*	**
S.Em±		0.19	0.18	0.21	0.22	0.005	0.005
C.D. at 5%		0.27	0.13	0.60	0.65	0.014	0.014
C.V.(%)		5.5	7.2	5.7	9.0	2.9	2.9

significant increase in yield (9.28 q/ha) over control (7.25 q/ha), whereas the increase in yield due to amendments (7.40 q/ha) was statistically not significant. Comparison between CO_2 and amendments showed that the effect of CO_2 treatment was significantly more during both the years.

Application of three types of amendments did not result in significant variations of seed yield during both the years (10.15 to 10.64 q/ha in 1989 and 7.17 to 7.63 q/ha in 1990). Among the different times of application, lowest seed yields of soybean (8.36 q/ha in 1989 and 6.47 q/ha in 1990) were recorded when amendments were applied along with sowing and they were significantly inferior to all the remaining times of application viz., 20 days before sowing (10.34 and 7.67 q/ha), 20 DAS (11.51 and 7.74 q/ha) and 40 DAS (11.42 and 7.73 q/ha) which were all statistically on par.

Stover yield of soybean (Table 4.58): The CO_2 enrichment significantly enhanced the stover yield of soybean (12.90 q/ha in 1989 and 8.57 q/ha in 1990) as compared to control (10.37 and 7.54 q/ha) and amended treatments (10.81 and 7.33 q/ha). However, amendments did not show significant effect on stover yield over control. Application of three types of soil amendments did not result in significant variations of stover yield during both the years (10.53 to 11.05 q/ha in 1989 and 7.19 to 7.50 q/ha in 1990). Among the different times of application, lowest stover yield of soybean (8.82 and 6.55 q/ha in 1989 and 1990) was recorded when amendments were applied at sowing during both the years and they were significantly inferior to rest (10.90 to 11.83 q/ha in 1989 and 7.33 to 8.09 q/ha in 1990). Further, application of amendments at 20 days before sowing was found statistically inferior (10.90 q/ha) to application either at 20 (11.67 q/ha) or 40 (11.83 q/ha) DAS during 1989. However, during 1990 it was found statistically superior (8.09 q/ha) to application at 20 (7.35 q/ha) or 40 (7.33 q/ha) DAS.

Harvest index of soybean (Table 4.58): The CO_2 fertilization improved the HI of soybean (0.492 in 1989 and 0.511 in 1990) compared to amendments (0.482 and 0.492) and control (0.471 and 0.484) however being significant only during second year. Amendments too improved the HI of soybean over control but the differences were not significant during both the years. Maize stover and paddy straw improved the HI (0.484 and 0.485 in 1989 and 0.496 and 0.494 in 1990, respectively) of soybean as compared to lime application (0.475 and 0.486), however being significant only during 1990. Amendments incorporated either during 20 or 40 DAS improved the HI significantly (0.489 and 0.488 in 1989 and 0.504 and 0.503 in 1990, respectively) when compared to the incorporation either at sowing (0.475 in 1989 and 0.485 in 1990) or 20 days in advance to sowing (0.474 and 0.477).

4.4.3.3 Nutrient uptake studies in soybean

Total nutrient uptake viz., N,P and K by intercropped soybean were estimated and the results are presented in Table 4.59.

The nitrogen uptake by soybean: Nitrogen uptake of soybean was significantly increased by CO_2 (101.9 kg/ha) and amended (81.9 kg/ha) treatments as compared to control (75.2 kg/ha) during first year. Whereas during second year, the increased uptake over control (57.3 kg/ha) was significant only for CO_2 treatment (73.6 kg/ha) and not for amendments (58.3 kg/ha). Types of amendments did not bring significant variations in nitrogen uptake during both the years. Amendments applied at 20 days before, 20 and 40 DAS were statistically on par with regards to nitrogen uptake (81.8 to 91.0 kg/ha in 1989 and 60.5 to 61.5 kg/ha 1990) and all of them were statistically superior to the amendments applied at sowing which gave the lowest

Table 4.59: Total uptake of nitrogen, phosphorus and potassium by soybean as influenced by CO2 fertilization, amendments and time of their application in sunflower-soybean intercropping system

Treatments	Nutrient uptake (kg/ha)					
	Nitrogen		Phosphorus		Potassium	
	1989	1990	1989	1990	1989	1990
1. (a) Control	75.2	57.3	17.1	12.9	40.9	30.7
(b) + CO_2	101.9	73.6	23.0	16.2	54.2	38.3
(c) Amendments	81.9	58.3	18.7	13.1	44.2	31.0
'F'test	**	**	*	**	**	**
S.Em± (a)	2.8	3.6	1.5	0.7	1.9	1.6
(b)	2.8	3.6	1.5	0.7	1.9	1.6
(c)	0.8	1.0	0.4	0.2	0.5	0.5
C.D. at 5% (a) & (b)	8.0	10.4	4.3	2.0	5.5	4.7
(a) & (c)	5.9	7.7	3.2	1.5	4.1	3.5
(b) & (c	5.9	7.7	3.2	1.5	4.1	3.5
2. Within amendments						
(a) Type of amendments						
Maize stover	83.1	58.2	19.0	13.1	44.8	30.9
Paddy straw	80.7	60.0	18.4	13.5	43.6	31.9
Lime	81.9	56.7	18.6	12.7	44.3	30.2
'F'test	NS	NS	NS	NS	NS	NS
S.Em±	1.4	1.8	0.7	0.3	0.9	0.8
C.D. at 5%	-	-	-	-	-	-
(b) Time of application						
20 days before sowing	81.8	61.5	18.4	13.7	43.9	32.5
At sowing	65.0	50.7	15.0	11.5	35.5	27.2
20 days after sowing	89.7	60.6	20.5	13.7	48.5	32.2
40 days after sowing	91.0	60.5	20.7	13.6	49.2	32.1
'F'test	**	**	**	**	**	**
S.Em±	1.6	2.1	0.8	0.4	1.1	0.9
C.D. at 5%	4.6	6.0	2.5	1.1	3.2	2.7
C.V.(%)	5.8	10.5	13.6	8.9	7.4	8.9

nitrogen uptake (65.0 and 50.7 kg/ha) during both the years.

The phosphorous uptake in soybean: The CO_2 enrichment significantly enhanced the phosphorus uptake of soybean (23.0 kg/ha in 1989 and 16.2 kg/ha in 1990) as compared to control (17.1 and 12.9 kg/ha) and amended treatments (18.7 and 13.1 kg/ha). However, amendments did not show significant effect on phosphorus uptake over control. Within amendments, statistical differences in uptake were not seen during both the years. However, lime application slightly decreased the uptake during second year. Amendments applied at the time of sowing gave lowest phosphorus uptake (15.0 kg/ha in 1989 and 11.5 kg/ha in 1990) and was statistically inferior to rest of treatments (18.4 to 20.7 kg/ha in 1989 and 13.6 to 13.7 kg/ha in 1990) which were all on par.

Potassium uptake in soybean: Potassium uptake also was significantly higher in CO_2 treatments (54.2 and 38.3 kg/ha in 1989 and 1990) as compared to control (40.9 and 30.7 kg/ha) and amendments (44.2 and 31.0 kg/ha) and both of which were statistically on par. Amendments viz., maize stover, paddy straw and lime incorporations did not influence the total potassium uptake of soybean significantly (43.6 to 44.8 in 1989 and 30.2 to 31.9 in 1991). Application of amendments along with sowing brought down the total potassium uptake significantly to least values (35.5 kg/ha in 1989 and 27.2 kg/ha in 1990) as compared to the rest of treatments during both the years. Amendments applied at 20 and 40 DAS resulted in higher potassium uptake (48.5 and 49.2 kg/ha, respectively) as against application at 20 days before sowing (43.9 kg/ha) during first year. However, such differences were not observed in second year.

4.4.3.4 Crude protein content of soybean seeds (Table 4.60)

CO_2 treatments improved the crude protein content of seeds (41.90% in 1989 and 42.60%). However, the increase was not statistically significant during second year. Amendments also showed the trends of improved protein content although statistically nonsignificant. Within different types of amendments, the variations were not significant during both the years. Highest per cent crude protein was recorded in treatment where the amendments were applied 20 days in advance (41.67%) followed by application at 20 DAS (41.23%) and 40 DAS (41.20%) and was lowest in treatment applied with amendments at the time of sowing (40.87%) during first year. However, the 20 and 40 DAS treatments were statistically on par. During second

Table 4.60 Crude protein content of soybean seeds as influenced by CO2 fertilization, amendments and time of their application in sunflower-soybean intercropping system.

Treatments	Crude protein per cent 1989	1990	Mean
1. (a) Control	41.10	41.70	41.40
(b) + CO_2	41.90	42.60	42.25
(c) Amendments	41.24	41.94	41.59
'F'test	**	NS	
S.Em± (a)	0.19	0.34	
(b)	0.19	0.34	
(c)	0.05	0.10	
C.D. at 5% (a) & (b	0.54	-	
(a) & (c)	0.40	-	
(b) & (c)	0.40	-	
2. Within amendments			
(a) Type of amendments			
Maize stover	41.25	41.95	41.60
Paddy straw	41.27	41.95	41.61
Lime	41.20	41.92	41.56
'F'test	NS	NS	
S.Em±	0.09	0.17	
C.D. at 5%	0.31	-	
(b) Time of application			
20 days before sowing	41.67	42.33	42.00
At sowing	40.87	41.57	41.22
20 days after sowing	41.23	41.97	41.60
40 days after sowing	41.20	41.90	41.55
'F'test	**	NS	
S.Em±	0.11	0.19	
C.D. at 5%	0.31	-	
C.V.(%)	0.8	1.4	

year, the differences were nonsignificant although the trends were similar to first year.

4.4.4 Combined growth, yield and income of sunflower-soybean intercropping

4.4.4.1 Total leaf area duration (LAD)

The data on the sum of total LAD of component crops in intercropping as influenced by CO_2 fertilization, amendments and time of their application are presented in Table 4.61. CO_2 fertilization brought significant increase in the total LAD (259.6 days in 1989 and 241.1 days in 1990) of the system as compared to either control (210.5 and 211.4 days) or amended treatments (227.4 and 212.6 days). Between control and amendments, significant increase in LAD was observed due to amendments during first year only.

Among the types of amendments, there were no statistical differences in LAD during both the years. Incorporation of amendments 20 days in advance of sowing resulted in highest LAD (241.9 days in 1989 and 227.4 days in 1990) followed by incorporation at 40 DAS (234.4 and 215.3 days), 20 DAS (230.6 and 205. 5 days) and was lowest when incorporation was done at the time of sowing (202.9 and 202.4 days), during both first and second years. However, 20 and 40 DAS treatments during

Table 4.61 Total leaf area duration and total biomass yield of sunflower-soybean intercropping system as influenced by CO_2 fertilization, amendments and time of their application.

Treatments		Total LAD (days)			Total biomass(q/ha)		
		1989	1990	Mean	1989	1990	Mean
1. (a) Control		210.5	211.4	210.4	76.1	64.1	70.1
(b) + CO_2		259.6	241.1	250.3	83.7	70.9	77.3
(c) Amendments		227.4	212.6	220.0	79.0	68.1	73.5
'F'test		**	**		*	**	
S.Em±	(a)	4.3	3.7		1.8	1.5	
	(b)	4.3	3.7		1.8	1.5	
	(c)	1.2	1.1		0.5	0.4	
C.D. at 5%	(a) & (b	12.5	10.9		5.1	4.3	
	(a) & (c)	9.2	8.0		3.8	3.2	
	(b) & (c)	9.2	8.0		3.8	3.2	
2. Within amendments							
(a) Type of amendments							
Maize stover		229.8	212.8	221.3	79.8	68.5	74.1
Paddy straw		224.9	215.1	220.0	78.2	69.7	73.9
Lime		227.6	210.0	218.8	79.0	66.1	72.5
'F'test		NS	NS		NS	*	
S.Em±		2.1	1.9		0.9	0.7	
C.D. at 5%		-	-		-	2.1	
(b) Time of application							
20 days before sowing		241.9	227.4	234.6	81.3	73.7	77.5
At sowing		202.9	202.4	202.6	77.0	70.1	73.5
20 days after sowing		230.6	205.5	218.0	77.2	62.8	70.0
40 days after sowing		234.4	215.3	224.8	80.5	65.9	73.2
'F'test		**	**		*	**	
S.Em±		2.5	2.2		1.0	0.8	
C.D. at 5%		7.2	6.3		3.0	2.5	
C.V.(%)		3.3	3.0		3.9	3.8	

first year and at sowing and 20 DAS treatments during second year were statistically on par.

4.4.4..2 Total biomass yield of sunflower-soybean intercropping

The total biomass of the intercropping system was increased substantially by CO_2 treatment (83.7 q/ha in 1989 and 70.9 q/ha in 1990) and significantly higher than control (76.1 and 64.1 q/ha) and amendments (79.0 and 68.1 q/ha) (Table 4.61). Amendments also improved the biomass production, however being significant only during second year.

Among the three types of amendments tried, maize stover and paddy straw were found statistically superior (68.5 and 69.7 q/ha, respectively) to lime (66.1 q/ha) during second year. However, no such differences were noticed during first year. Time of application of amendment affected the total biomass production, significantly. During first year, application of amendments 20 days before sowing was superior (81.3 q/ha) to application at the time of sowing (77.0 q/ha) or 20 DAS (77.2 q/ha) but on par with application at 40 DAS (80.5 q/ha). During second year also application of amendments 20 days in advance of sowing was found superior (73.7 q/ha) to application at sowing (70.1 q/ha), 20 DAS (62.8 q/ha) and also to the application of amendments at 40 DAS (65.9 q/ha). Further amendments applied at sowing was found statistically superior (70.1 q/ha) to application at 20 DAS (62.8 q/ha) during second year, however statistically being on par during first year (77.0 and 77.2 q/ha).

Interaction effect between amendments and times of their application was found significant during 1990 (Table 4.61a). Incorporation of organic amendments like maize stover and paddy straw at 20 days before sowing was found statistically superior (74.5 and 77.5 q/ha) to lime (69.0 q/ha) in terms of total biomass yield. Further, organic amendments applied at 20 DAS gave lowest biomass yield (60.7 and 61.4 q/ha for maize stover and paddy straw, respectively) followed by 40 DAS (66.6and 66.5 q/ha) and at sowing (72.4 and 73.3 q/ha) which were statistically differing with each other. While the lime application either at sowing, 20 or 40 DAS did not bring any significant variations in the total biomass yields (64.5 to 66.2 q/ha).

4.4.4.3 Total oil yield

The results on total oil yield of sunflower-soybean intercrop are presented in Table 4.62. Oil yield of the system was not varied significantly among control, CO_2 fertilization and amendments during both

Table 4.61(a) Total biomass yield (q/ha) of sunflower-soybean intercropping system as influenced by the interaction between amendments and time of application during 1990 summer season.

Time of application	Amendments		
	Maize stover	Paddy stover	Lime
20 days before sowing	74.5	77.5	69.0
At sowing	72.4	73.3	64.5
20 days after sowing	60.7	61.4	66.2
40 days after sowing	66.6	66.5	64.7
'F'test		*	
S.Em±		1.5	
C.D. at 5%		4.3	

Table 4.62 Total oil yield and gross income from sunflower-soybean intercropping system as influenced by CO_2 fertilization, amendments and time of their application

Treatments	Total oil yield (q/ha) 1989	1990	Mean	Gross income (Rs./ha) 1989	1990	Mean
1. (a) Control	10.70	8.69	9.69	12428	10081	11254
(b) + CO_2	11.34	9.29	10.31	13517	10992	12254
(c) Amendments	11.23	9.42	10.32	13076	10858	11967
'F'test	NS	NS		*	NS	
S.Em± (a)	0.34	0.44		328	445	
(b)	0.34	0.44		328	445	
(c)	0.10	0.13		95	128	
C.D. at 5% (a) & (b)	-	-		955	1294	
(a) & (c)	-	-		703	952	
(b) & (c)	-	-		703	952	
2. Within amendments						
(a) Type of amendments						
Maize stover	11.35	9.56	10.45	13217	10983	12100
Paddy straw	11.21	9.66	10.43	13031	11142	12086
Lime	11.14	9.05	10.09	12980	10450	11715
'F'test	NS	NS		NS	*	
S.Em±	0.17	0.22		164	222	
C.D. at 5%	-	-		-	647	
(b) Time of application						
20 days before sowing	11.64	10.20	10.92	13522	11719	12620
At sowing	11.55	10.14	10.84	13110	11474	12292
20 days after sowing	10.69	8.56	9.62	12635	9968	11301
40 days after sowing	11.06	8.79	9.92	13037	10272	11654
'F'test	*	**		**	**	
S.Em±	0.20	0.25		190	257	
C.D. at 5%	0.58	0.74		551	747	
C.V.(%)	5.3	8.1		4.3	7.1	

the years. However, CO_2 fertilization and amendments marginally improved the oil yields during 1989 (11.34 and 11.23 q/ha, respectively) and also 1990 (9.29 and 9.42 q/ha) over control (10.70 q/ha in 1989 and 8.69 q/ha in 1990).

Types of amendments also brought no significant differences in total oil yield of the intercropping system during both first and second years. Amendments applied at 20 DAS resulted in lowest oil yields (10.69 q/ha in 1989 and 8.56 q/ha in 1990) and were significantly inferior to rest of treatments. Further during first year, the treatments like application of amendments at 20 days before sowing (11.64 q/ha), at sowing (11.55 q/ha) and 40 DAS (11.06 q/ha) were statistically on par. While during second year the treatments like application of amendments at 20 days before sowing (10.20 q/ha)and at sowing (10.14 q/ha) were on par and both were statistically superior to treatments like application at 20 and 40 DAS (8.56 and 8.79 q/ha, respectively).

4.4.4.4 Gross income

The data on the gross income derived from sunflower-soybean intercropping are presented in Table 4.62. The gross income of intercropping improved due to CO_2 treatment (RS. 13517 and 10992/ha during 1989 and 1990) and also due to amendments (Rs. 13076 and 10858 /ha). However, the increase in income was significant only during first year for CO_2 treatment only.

With regard to types of amendments, no significant variations were observed during first year (Rs. 12980 to 13217/ha), while during second year paddy straw incorporation was found superior (Rs. 11142/ha) to lime (Rs. 10450/ha). In general, organic amendments were better than lime during both the years. Times of application of amendments revealed that amendments incorporated at 20 days before sowing gave highest income (Rs. 13,522 and 11,719/ha during 1989 and 1990), while that at 20 DAS gave lowest income (Rs. 12635 and 9968/ha) both during first and second years. However, the treatment which gave the highest income (incorporation at 20 days before sowing) was on par with incorporation at sowing (Rs. 13110/ha) and 40 DAS (Rs. 13037/ha) during first year and only with incorporation at sowing (Rs. 11474/ha) during second year.

Significant interaction between amendments and times of their application during 1989 (Table 4.62a) showed that maize stover and paddy straw applied at 20 DAS resulted in lowest income (Rs. 12,299 and 12,420/ha, respectively) and were significantly

Table 4.62(a) Gross income (Rs. /ha) from sunflower-soybean intercropping system as influenced by the interaction between amendments and time of their application during 1989 summer season

Time of application	Amendments		
	Maize stover	Paddy stover	Lime
20 days before sowing	13981	13568	13016
At sowing	13397	13201	12734
20 days after sowing	12299	12420	13185
40 days after sowing	13191	12936	12986
'F'test		*	
S.Em±		328	
C.D. at 5%		955	

inferior to their application either at 20 days before sowing, at sowing or 20 days after which were all statistically on par (Rs. 13191 to 13981 for maize stover and Rs. 12936 to 13568 for paddy straw incorporation) whereas lime application, irrespective of sowing time gave income with nonsignificant variations (Rs. 12734 to Rs. 13185 /ha).

DISCUSSION

V. DISCUSSION

Discussion of the salient features of these investigations is centred around the questions as to how best and how soon can we augment our oilseed production. The objectives of enhancing productivity by choosing the intercropping system in the first instance and by optimising the canopy architecture by identifying the best suited plant populations and planting pattern for the system as a whole in the second place, are further strenthened by exploring the possible benefits that could be accrued through factors of enhanced carbon dioxide, light and triacontanol in one set and use of amendments such as paddy straw, maize stover and lime in another set. The discussion on the results of these studies on sunflower and soybean would therefore be focussed around these objectives to sort out the practical aspects that can be transferred to the farmers from those that need further research.

5.1 Seasonal and other effects on overall productivity of sunflower and soybean

The overall productivity of oilseed crops is determined by the timeliness and the amount of rainfall received in a particular season. Intercropping system is recognized as an insurance against large scale fluctuations in yield and crops under limited moisture availability. In the intercropping system of sunflower and soybean, besides moisture, several other agronomic factors like optimum plant population and planting geometry, adequate nutrient supplying capacity of the soil and favourable canopy environment of light and carbon dioxide would all go a long way in increasing the productivity.

In the current studies, yields of pure kharif sunflower under rainfed conditions in Experiment I, were 8.2 q per ha in 1988 and 13.1 q per ha in 1989. The corresponding figures of the intercropped sunflower were 6.2 and 10.2 q per ha. Thus, the year 1989 was favourable for both pure and intercrops of sunflower giving higher yields of about 4 to 5 q per ha compared to 1988. These were largely caused by a lack of adequate sunshine hours during 1988 for the 30 days with only 4.2 bright hours per day compared to an improved lighting with about 6.0 hours per day during 1989 (Fig. 3.2). Besides light, during 1988, there was heavy downpour of rains three times ranging from 114 to 203 mm during pre-flowering stage followed by a dry spell of about 15 days particularly at flowering stage, whereas in 1989, there was well distributed rainfall throughout the crop growth period (Fig 3.3). Thus, the yields in general, were lower in the first year compared to second year. These results also make an interesting comparison with the results of the irrigated intercrop sunflower of the Experiment II where the yields were 8.5 and 13.3 q per ha in first and second year, respectively. This in effect suggests that with irrigation the yields of intercropped sunflower could be on par with those of the pure crop of kharif sunflower in rainfed situations as obtained in the first experiment. (8.2 and 13.1 q/ha).

Compared to these yield levels reaching a maximum of about 13 q per ha under favourable conditions in kharif, the yields in summer were found to go up to an average of 21 q per ha in Experiment III (Fig. 5.11). Thus a summer irrigated sunflower crop seems to have a high yield potentials (Plates 9, 10 and 11). Higher yield in summer than kharif was also observed by Chhabra et al. (1982) and Krishnegowda (1983). It is mainly because of higher light intensity (540 cal/cm^2/day) and bright sunshine hours (8.8 to 9.9) in summer as against kharif season (365 ca./cm^2/day and 5.3 to 7.2 hrs; Veeraraja Urs, 1977; Appendix 1). Factors like additional CO_2 and light enhanced the yield of sunflower slightly, whereas organic amendments were found to raise the yields of intercropped sunflower up to a maximum of about 24.5 q per ha. Thus in general, the productivity of sunflower

Plate 9. A view of the part of <u>kharif</u> Experiments I and II

Plate 10. A view of the part of summer Experiment III

Plate 11. A close view of sunflower and soybean intercropping in summer experiment

Plate 9

Plate 10

Plate 11

could be manipulated depending on various factors of production like season, irrigation and other agronomic practices.

The overall productivity of soybean was around 15.6 q per ha in 1988 and 13.1 q per ha in 1989 in Experiment I under pure cropping system. When intercropped with sunflower, the corresponding figures were 9.8 and 8.2 q per ha for the two years. In the second experiment, the intercrop soybean yields under <u>kharif</u> irrigated conditions were 10.4 q per ha in 1988 and 8.8 in 1989 registering only a small increase in yields due to irrigation. However, it is observed that there was a general reduction in the yield levels of soybean during the second year. This is largely attributable to seasonal effects that in October month of second year which coincided with pod filling stage of soybean, there was a lower sunshine of 6.0 bright hours compared to previous year of the same month with 8.5 hours. Further, unlike in principal crop of sunflower, intercropping brought down the soybean yields compared to the pure crop which could not be made up either with irrigation or any other factors of crop production. The maximum productivity of 11.5 q per ha under intercrop situations was seen with CO_2 enrichment. It is thus seen that sunflower could manage to overcome the reduction in yields when taken in intercropping system through some agronomic means, whereas soybean yields were masked by severe competition by sunflower in general (CR of sunflower was 1.96 as against 0.54 of soybean) as observed by reduction in LAI from 4.0 to 2.13 and in DM from 14.28 to 9.87 g per plant on an average of two years (Table 4.8 and 4.10). These results are in confirmity with those of other workers (Shanthamallaiah et al., 1978; Robinson, 1984). The reduced growth and yield of intercropped soybean was attributed to shading effect of tall growing crop, the sunflower (Dalal, 1977; Srivastava, et al., 1980). Further, Roquib et al. (1973) reported that the height of companion crop will determine the amount of yield reduction in soybean.

5.2 Experiment I: Performance of sunflower and soybean in intercropping with varied plant populations and planting patterns

The question of maximizing yield in an intercropping system is dependent on an understanding on either the complementarity or the ill effects that the component crops exert on each other. It is well known that there would be generally a reduction in the yield of one crop or at times of both the crops, but the overall productivity and advantages are maintained by adopting intercropping of two or more crops than growing them as pure crops. In the present investigation, the optimizing of plant densities coupled with locating the right planting pattern to modify the canopy architecture have been studied in greater details than mere comparing pure and intercrops with one or two given set of combinations.

5.2.1 Response of sunflower to intercropping at different plant populations and planting patterns

A reduction in sunflower yield by about 23 per cent on an average of two years when intercropped with soybean, compared to pure crop was observed to be a direct reflection of a similar nature in the expression of growth and yield attributes. The sole sunflower crop was well built as indicated by a lower height to stem girth ratio (17.9 and 15.5) compared to that of intercrop (21.1 and 18.5) in the two years. Besides a thin stem, LA, LAI and the vertical canopy area were all higher in pure crop (13.99 and 25.94 dm^2/plant, 1.16 and 2.16, 4049 cm^2/plant) compared to intercrop (10.55 and 19.72 dm^2/plant, 0.76 and 1.42, 2731 cm^2/plant) resulting in higher DM production (36 and 30 %) in the two years. The yield attributes like filled seeds (368 and 598), seed filling per cent (70.2 and 69.3) and seed weight per plant (13.50 and 20.08 g) were also significantly higher in pure crop which resulted in better performance of pure crop compared to intercropped sunflower (294 and 498, 65.9 and 65.6, 10.85 and 16.38 g, respectively). The stalk yields were also higher with those of grain yields in pure crop (Table 4.6). Observations of Shanthamallaiah _et al_. (1978) and Shafshak _et al_. (1986) were also similar to these results.

On a further examination, it is observed that maintaining 100 per cent plant population of sunflower even under intercropping system (83,333 plants/ha) resulted in fairly high yields of sunflower. At 75 per cent of its sole crop population (62,500 plants/ha) the yield level was 7.82 q per ha on an average of two years and at 100 per cent it increased to 8.51 q per ha (Fig. 5.1) registering around 9 per cent increase. The increased yield at 100 per cent was effected by additional 25 per cent plant population which enhanced the mean LAI from 1.02 at 75 per cent to 1.16, and its competitive ability (CR, 1.72 to 2.15) but not due to individual plant growth and yield attributes which were all affected by competition. It was observed that there were reduction due to 100 per cent population compared to 75 per cent in parameters like LA (16.33 to 13.94 dm^2/plant), vertical conopy area (2849 to 2612 cm^2/plant), the total DM (43.7 to 35.8 g/plant), number of filled seeds (429 to 364), seed filling per cent (66.9 to 64.5) and seed weight per plant (14.8 to 12.4 g). The increased yield of sunflower of higher plant population in intercropping was also observed by Shafshak _et al_. (1986). However, Robinson (1984) reported no significant reduction in yield of sunflower intercrop when plant population was reduced from 52,000 to 22,000 per ha in an intercropping with soybean.

The yields of intercropped sunflower were slightly reduced with increasing plant population of soybean from 50 to 75 or 100 per cent. The reduction was from 8.47 q per ha at 50 per cent population to 8.02 q per ha at 75 per cent (5%) while further increase to 100 per cent population of soybean did not affect the yield (8.01 q/ha) (Fig. 5.1). The marginal reductions in yield of sunflower even by doubling the soybean population was due to the fact that competitive ability of sunflower was increased with increase in soybean population (1.53 at 50% to 1.98 at 75% and 2.42 at 100%). This reduction in yield at 75 per cent of soybean although marginal, was attributed to an integrated effect of lower LA per plant, LAI, DM per plant, number of filled seeds, filling per cent and seed weight per plant. Again the reduction in most of the above growth and yield parameters were statistically nonsignificant during both the years.

Further examination of the intercropping systems from the angle of planting pattern adopted, it was observed that the seed yield was significantly higher in sunflower uniform rows (6.4 and 10.4 q/ha) than in paired rows (5.9 and 9.9 q/ha in the two year, respectively). The stalk yields were also similar. This is attributable to better growth and yield parameters in uniform rows as observed from such increases in LA (15.0 to 15.3 dm^2/plant), LAI (1.07 to 1.10), total DM (39.1 to 40.49 g/plant), number of filled seeds (394 to 399 g/plant) and seed weight (13.41 to 13.82 g/plant), although the improvements in all these parameters were nonsignificant. Singh and Singh (1977) also observed a slight reduction in seed yield of sunflower due to pairing compared to uniform rows. Similarly in finger millet, Kumaraswamy (1981) observed a considerable reduction in yield due to its paired row planting to introduce soybean in between. However these studies are in variance with observations of Umapathi et al. (1980) who have indicated that planting of sunflower in paired rows is better which may be due to the fact that the plant population of sunflower was around 75 per cent of sole crop and that of intercrops were ranging from 50-75 per cent only.

Pairing of rows by definition means reducing the spacing between two rows of a pair to accommodate an intercrop, which was not found conducive for better growth and yield of nonbranching crop like sunflower as observed in the experiment (Plates 12 and 13) because of localization of the same plant species in a restricted area of the land. Thus, localization resulted in poor light availability for the lower leaves present in between the two rows of a pair (Fig 4.5) although there was better distribution towards the centre of two pairs. Hence, pairing may not suit for nonbranching crops unlike the crops of branching nature (eg-pigeonpea), which can direct their branching towards the wider space created between the pairs. Further, localization might have resulted in competition for nutrients and moisture between same plant species restricted in a particular area since the feeding zone of plants of a given species is same. This can be seen from lower CR values of sunflower under paired rows (2.60) compared to uniform rows (2.22) which indicates that its competitive ability with soybean was reduced due to pairing.

From the stand point of lower monetary value of the crop, the proportionately small area occupied by it in the intercropping system and the shorter canopy it exhibits, tolerating some shade, soybean could be

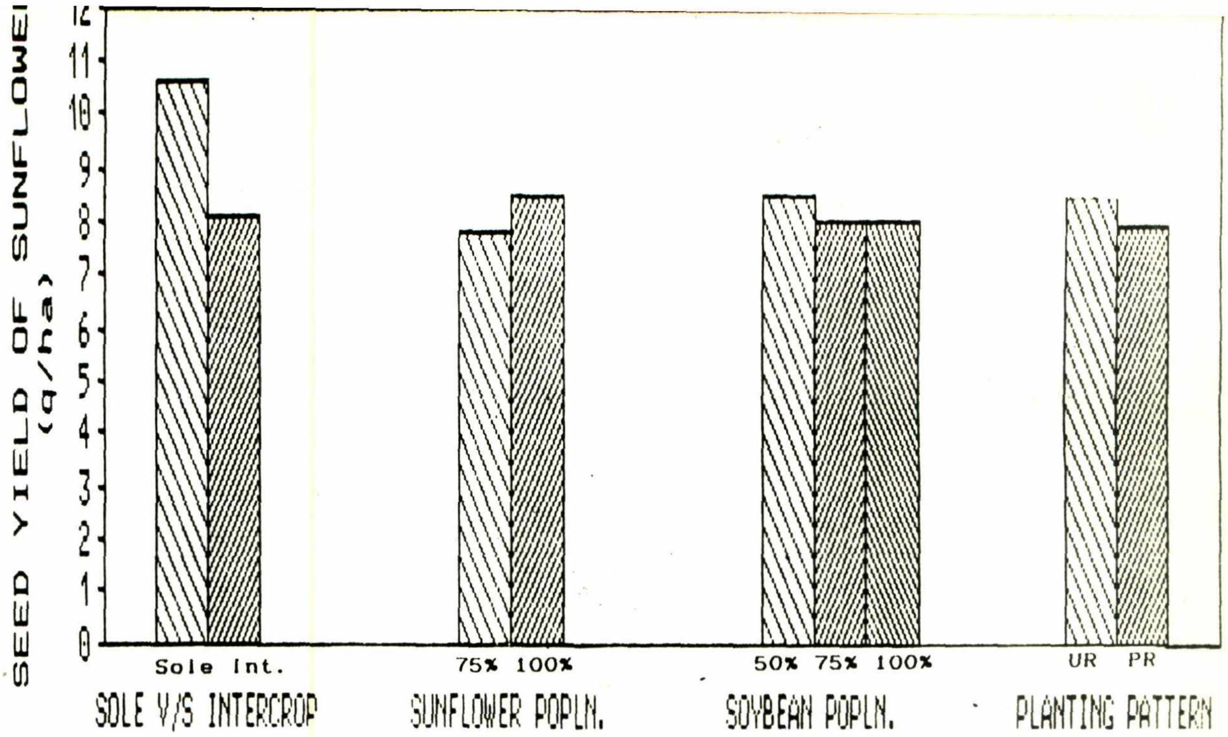


Fig 5.1 Seed yield of sunflower as influenced by intercropping of soybean, plant populations and planting patterns (UR = uniform rows, PR = paired rows) of intercrops

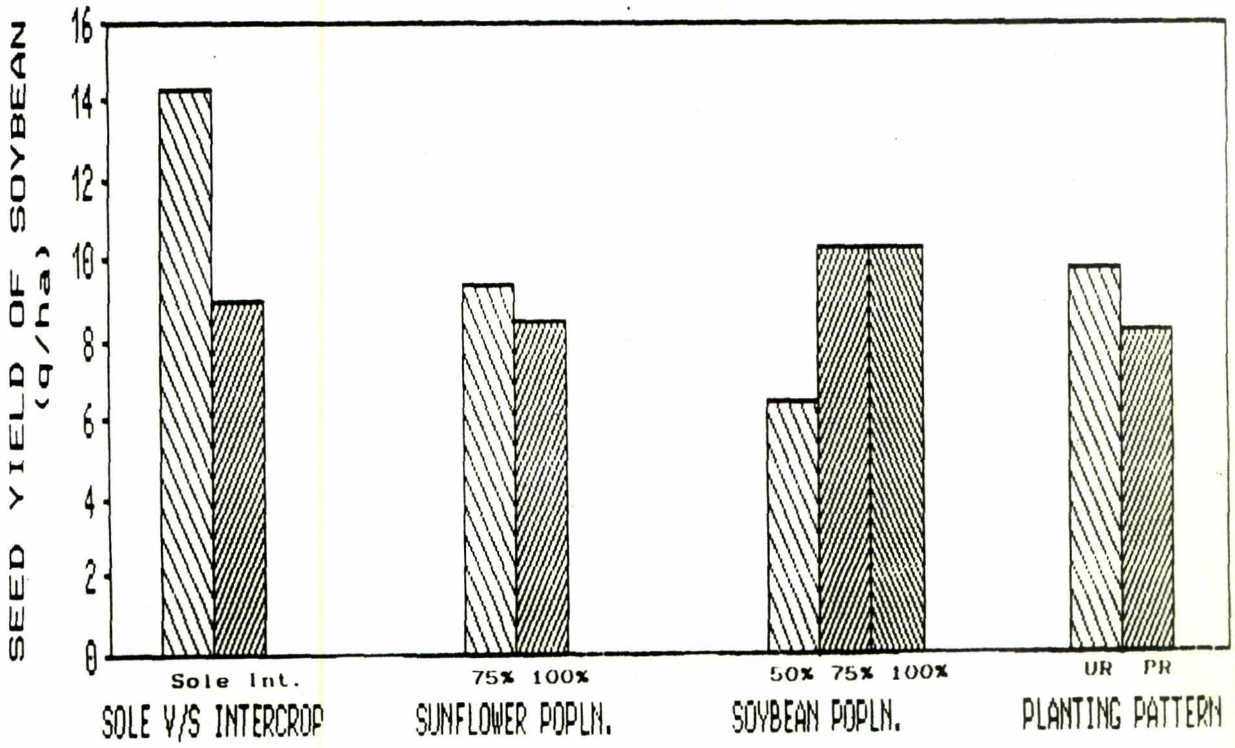


Fig 5.2 Seed yield of soybean as influenced by intercropping with sunflower, plant populations and planting patterns (UR = uniform rows, PR = paired rows of intercrops

Plate 12. The growth of sunflower under uniform row planting

Plate 13. The growth of sunflower under paired row planting

Plate 12

Plate 13

regarded as a secondary crop compared to the principal crop of sunflower. Its response to alterations in its population and planting pattern of the system in relation to sunflower in the intercropping system presents an interesting picture of comparison.

5.2.2 Response of soybean to intercropping with sunflower at different plant populations and planting pattern

As it was brought out earlier, intercropping with sunflower reduced the yield of soybean to an extent of 37 per cent in each year. In intercropping, increase in sunflower population from 75 to 100 per cent brought down the yield levels of soybean further (9.46 to 8.58 q/ha, Fig. 5.2) due to its adverse effects on LA (9.11 to 8.42 dm^2/plant), LAI (2.23 to 2.03), total DM production (10.57 to 9.17 g/plant) and seed weight per plant (5.34 to 4.58) on an average of two years. The CR of soybean was also reduced (0.59 to 0.48) by increasing of sunflower population. Robinson (1984) also observed the adverse effect of increased sunflower population on soybean.

The yields were improved with increasing population of intercropped soybean from 50 to 75 or 100 per cent. The average improvement of two years was from 6.48 q per ha of intercropped soybean at 50 per cent population (1,66,666 plant/ha) to 10.26 q per ha at 75 per cent population (2,50,000 plants/ha). Further increase in level to 100 per cent (3,33,333 plants/ha) did not affect the yield considerably (10.32 q/ha, Fig. 5.2). The improvement in seed yield at 75 per cent was effected purely by the additional 25 per cent population which enhanced the canopy cover to a greater extent (increase in mean LAI of 1.61 to 2.23) without significantly affecting per plant growth and yield attributes in general (LA, 9.68 to 8.94 dm^2/plant; total DM, 11.21 to 10.28 g/plant; number of pods, 16.35 to 14.35 /plant; seed weight, 5.69 to 5.13 g/plant, all mean of two years). Whereas, further increase in population from 75 to 100 per cent significantly reduced the per plant characters (7.68 dm^2 g/plant, 8.12 g/plant, 9.8 /plant and 3.53 g/plant at 100%, respectively) which compensated for the extra yield obtained by the additional 25 per cent population. Such observations of reduction in growth and yield with increased population of soybean upto 100 per cent in the intercropping system with sunflower are wanting. However, in maize-soybean intercropping it was observed that 100 per cent maize with 50 per cent of soybean was optimum (Venugopal, 1988).

Planting pattern adopted in intercropping was also effective in altering the growth and yield of soybean. Soybean under uniform single rows of sunflower performed better (9.75 q/ha, mean of two years) than under paired rows (8.29 q/ha, Fig. 5.2). The better performance under uniform rows can also be verified from the growth and yield attributes viz., LA (9.22 dm^2/plant), LAI (2.24), total DM production (10.56 g/plant), number of pods (14.5/plant) and seed weight (5.29 g/plant) as compared to paired rows (8.31 dm^2/plant, 2.03, 9.18 g/plant, 13.6/plant and 4.63 g/plant, respectively) on an average of two years. Shafshak et al. (1986) also observed higher pods per plant, seed weight per plant and seed yield of soybean under uniform rows of sunflower with 1:1 row proportion as compared to 2:4 row proportion. Further examination of the canopy architecture, revealed that the vertical canopy area of individual soybean plants were higher (1261 cm^2/plant, Fig. 4.5) under sunflower uniform row planting as compared to paired row planting (950 cm^2/plant, Fig. 4.6). And also the canopy overlapping was higher in paired row planting (14.48%) as compared to uniform row planting (12.60%). The vertical canopy shape of the individual soybean plant under sunflower paired rows was like an inverted pyramid with longer basal stem height with out any leaves and overcrowded leaves at the top 20 cm of the canopy profile (Fig 4.6) indicating the poor distribution of leaves for better light utilization. Whereas, under uniform rows, there was a well distributed leaves throughout the canopy height of soybean with comparitively short basal stem height with no leaves (Fig. 4.5).

5.2.3 The intercropping advantages: Combined growth, yield and income as influenced by plant populations and planting patterns

Sole v/s Intercropping: Intercropping has long been considered an extremely important practice in many parts of the world, especially in the developing countries of the tropics like India. This is because, higher economic yields are obtainable from the intercropping system as a whole bringing in greater stability of income in different seasons, in addition to meeting the domestic needs of staple food crops. In India, its importance was highlighted nearly 40 years back itself in a very comphrehensive review by Yagnanarayana Aiyer (1949).

In the present study on sunflower-soybean intercropping, a higher income of Rs. 5974 per ha was derived from intercropping as against Rs. 4309 and 4261 from pure crops of soybean and sunflower, respectively, on an average of two years (Fig. 5.4). Between pure crops, in the first year, soybean provided higher income (Rs. 4680/ha) as compared to sunflower (Rs. 3278/ha), whereas in second year, pure sunflower provided higher income (Rs. 5244) than pure soybean (Rs. 3938) indicating their instability in their performance as pure crops when compared to a stable higher income from this intercropping system of sunflower and soybean over two years (Rs. 5410/ha in first year and Rs 6539/ha in second year). The data on land equivalent ratios also revealed the advantages of going for sunflower-soybean intercropping (1.38 and 1.40 in 1988 and 1989) compared to either of the two component crops under sole cropping (1.00). The total oil yield on an average of two years from the intercropping was 4.8 q per ha as compared to 4.1 q per ha from pure sunflower and only 2.1 q per ha from pure soybean crop (Fig. 5.3). The bright possibility of increasing the total oil production in the state by mere intercropping of these two oil seed crops and by monitoring their populations and planting patterns is a strong case for further research and extension. Intercropping was superior to sole cropping due to better performance of combined growth attributes like total LAI (3.23) and total biomass production (40.94 q/ha) in intercropping as compared to pure crops of sunflower (LAI, 1.66 and biomass yield, 32.55 q/ha) and soybean (LAI 4.00 and biomass yield, 28.92 q/ha). However, the LAI of pure soybean was higher than intercropping because of greater suppression of soybean by the principal crop sunflower, whereas the pure and intercropped crops of sunflower did not show such extreme variations in LAI. Generally, it is observed that the intercropped space between two adjacent rows of sunflower was utilized well especially in the bottom canopy compared to sole crop of sunflower (Fig 4.1 and 4.3). Thus, the improvements in better use of natural resource of light paved way for a better expression of the combined growth attributes of both the component crops in the intercropping system as observed by 18 to 26 per cent total solar radiation (TSR) left unused in the bottom interspace betwen two adjacent rows of sole sunflower compared to less than 10 per cent of TSR available at the bottom canopy in the intercropping system (Fig. 4.4 to 4.6). Besides, the canopy surface area exposed to the Sun in intercropping over that of pure cropping revealed that the surface area was increased by 1.16 to 1.51 times (Fig. 4.3 to 4.6) the surface area of pure cropping.

Effect of plant population and planting pattern on combined growth, yield and income of intercropping

In the preceding section it has been highlighted that intercropping of sunflower and soybean afforded a greater utilization of light resources and this resulted in better complementarity between the two component crops resulting in higher economic returns.

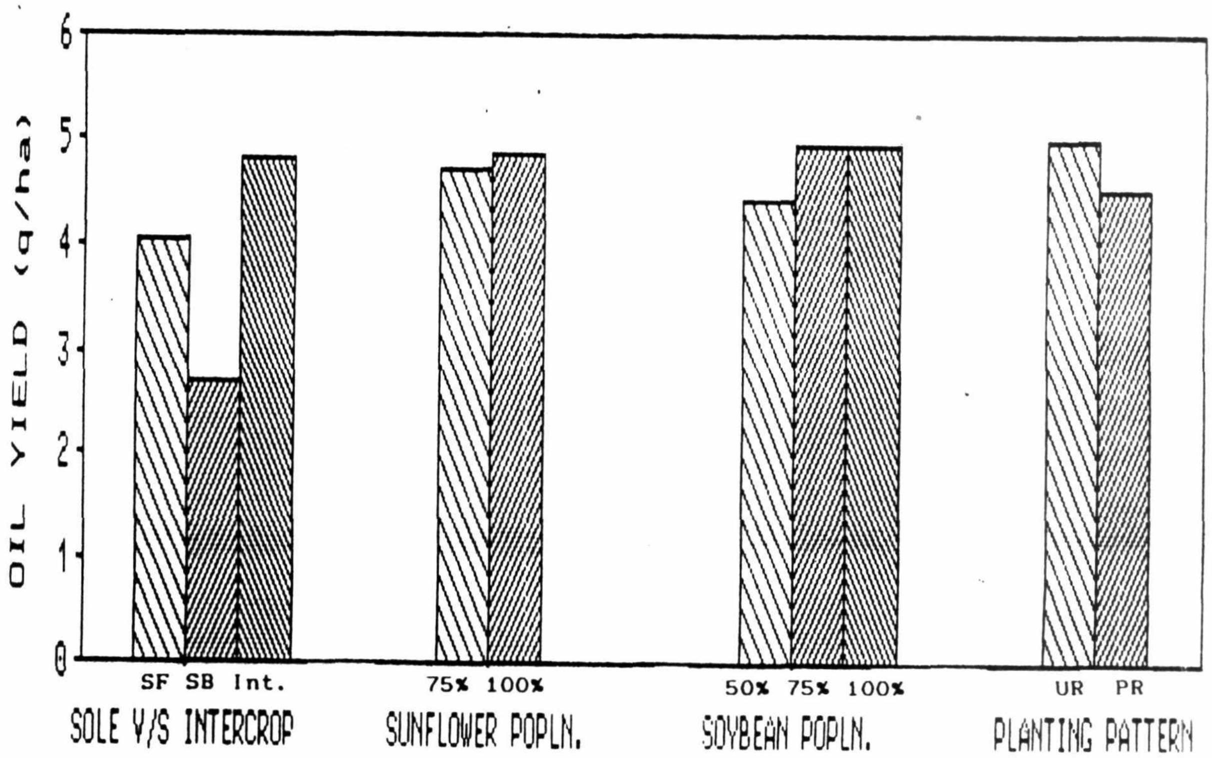


Fig 5.3 Total oil yield from sunflower-soybean intercropping system as influenced by plant populations of component crops and planting patterns (UR = uniform rows, PR = paired rows

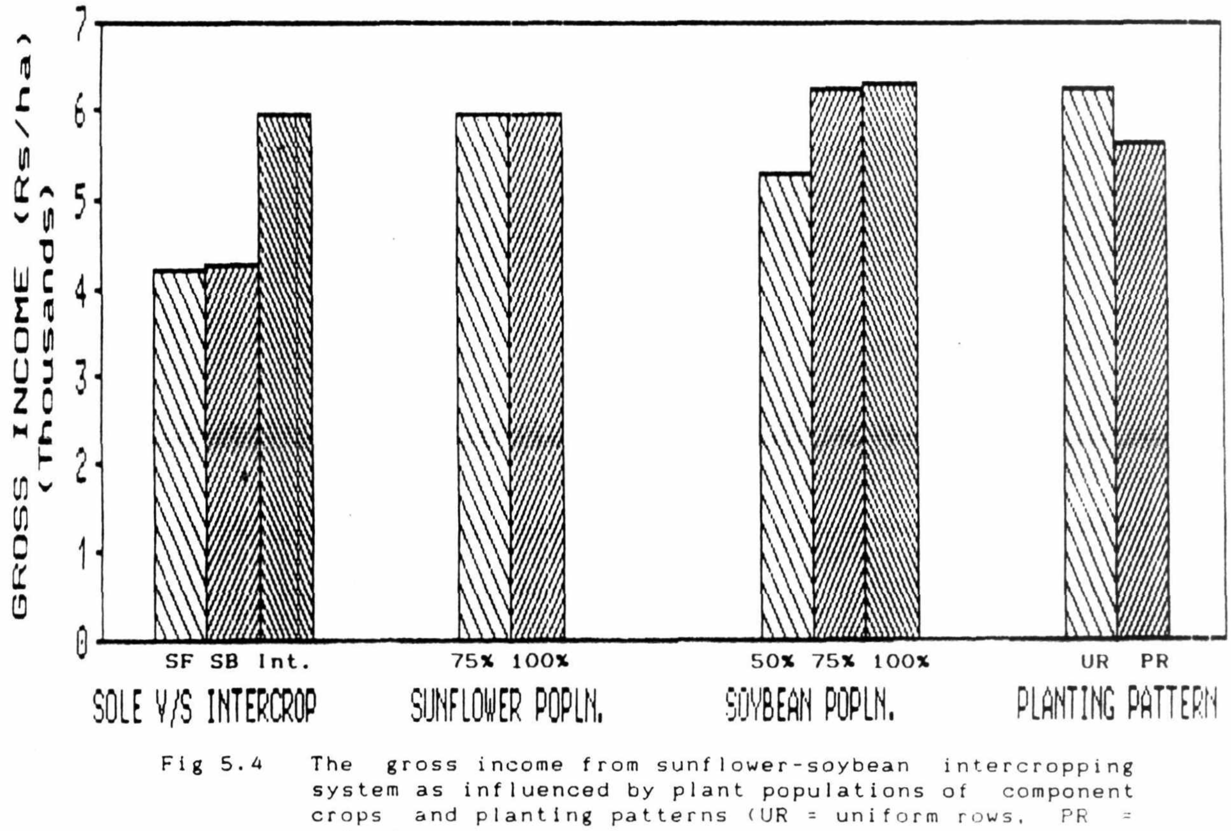


Fig 5.4 The gross income from sunflower-soybean intercropping system as influenced by plant populations of component crops and planting patterns (UR = uniform rows, PR = paired rows

Dwelling further into these aspects, it is necessary to ascertain the right mix of the two component crops as well as to know the optimum planting pattern so that the complementarity effects are enlarged and greater economic returns are achievable. It is in this context that the six plant population combinations were compared amongst themselves and these were studied under two planting patterns of raising soybean with sunflower in the uniform rows or in paired rows thus attempting to study the performance of the intercropping system under modified canopy architecture. The results of two years indicated that gross income of around Rs. 6300 could be obtained in the intercropping system of sunflower as the principal crop in uniform rows compared to paired row system with Rs. 5654 (Fig 5.4). With respect to plant population levels of component crops, sunflower population did not affect the gross income of intercropping. While increase in soybean population from 50 to 75 or 100 per cent increased the mean gross income from Rs. 5332 to 6287 or 6303 per ha, respectively. Thus, in uniform row planting with 75 per cent of sunflower with either 75 or 100 per cent soybean and 100 per cent of sunflower with either 75 or 100 per cent soybean, the gross returns were comparable among themselves (Rs. 5964 to 6303, on an average of two years, Fig. 5.4) and were considerably higher than their combinations with paired row planting (Rs. 5654/ha) or any combinations with 50 per cent soybean irrespective of sunflower populations and planting patterns (Rs. 5332/ha). The data on total oil yield of intercropping (Table 4.15 and Fig. 5.3) also support the above interpretation drawn based on the gross income. Similarly, the LER was maximum with uniform row planting (Table 4.17) as with gross returns. Even with plant population levels, the gross returns and LER were found to be highly associated. The high gross returns obtained with combinations viz., 75:75, 75:100, 100:75 and 100:100 of sunflower and soybean, respectively, all with uniform row planting also had high LER's of 1.51 to 1.55.

Further analysis of these treatments (75:75, 75:100, 100:75 and 100:100 of sunflower:soybean with uniform row planting) from the angle of canopy architecture (Fig 4.4 and 4.5) over that of other treatment combinations (having either planting pattern of paired row system, Fig. 4.6 or 50 per cent soybean component, Fig. 4.3) in the intercropping revealed the following points to support their superiority.

1. Better utilization of light as observed by <10 per cent of TSR at the bottom interspace (Fig. 4.4 and 4.5) as against 18 to 23 per cent TSR in

treatments having 50 per cent soybean component (Fig 4.3);

2. Per cent canopy overlapping was less (Figs. 4.4 and 4.5) as compared to the treatment having paired row planting pattern (Fig. 4.6) and

3. The canopy surface area exposed to the Sun was more (Figs. 4.4 and 4.5) as compared to treatments having paired row planting pattern (Fig 4.6).

Further, the treatment combination of 75:75 with uniform row planting was found superior in terms of least canopy overlapping (0.94%, Fig. 4.4) and highest canopy surface area exposed to the Sun (1.51 times the canopy surface area of pure crop) as compared to 100:100 treatment combination with uniform row planting (Fig. 4.5, 12.6%, 1.33 times).

Thus, it is the canopy architecture which was exhibited by each set of treatment combinations that markedly influenced the utilization of natural resources of light, soil and other microclimatic factors so as to enhance all the growth attributes of the two component crops together leading higher DM, seed yields and oil yields. It is thus the build up of the canopy architecture for high yields in these treatments which was responsible for reaping maximum yield advantages and monetary returns.

Further, considering the cost of certain high value inputs viz., seeds and fertilizers, the treatment combination of 75 per cent each of sunflower and soybean component with uniform row planting was found most economical, since it consumed only 75 per cent of their recommended seed rate and fertilizer dosage as compared to other treatment combinations viz., 75:100, 100:75 and 100:100 with uniform row planting which were observed to be on par with the above treatment in terms of yield levels and gross income. Under rainfed conditions with limited moisture availability 75+75 per cent populations thus seems to be appropriate.

5.3 Experiment II: Effect of CO_2 fertilization, light enrichment and triacontanol sprays in sunflower-soybean intercropping

The overall productivity of an intercropping system can only be statisfactory if all growth factors are optimum and if managment practices are such as to minimize certain ill effects of competition among the component crops. In this investigation with sunflower as the principal crop, additional aspects of managment had to be thought of as seed filling in sunflower is a major agronomic constraint for obtaining maximum yields. And for soybean the competitive effect from sunflower is generally higher because of a fairly fast growth of sunflower reaching greater heights early thus limiting the normal potentials of nitrogen fixation and thus masking the growth and yield of soybean. This is particularly true when the intercropping system is taken up in the kharif season on a large scale. It is often observed that light is a limiting factor in the season with many cloudy days besides uncertainty in good distribution of rainfall. At the same time, seed setting of sunflower is hampered and the growth and yield of soybean is minimized. In this context, the present investigation was framed to explore the posibilities of improving the seed setting in sunflower by CO_2 fertilization and light enrichment as well as through the sprays of a growth promoter triacontanol, in the formulation of Grinit. These three factors were also tested simultaneously on soybean as an intercrop. Thus, it was an attempt to enhance the whole productivity of the intercropping system of sunflower and soybean. The discussion on these results are made sequentially on individual crops first and on the system later.

5.3.1 Response of intercropped sunflower to CO_2

The growth parameters like LAI and DM in intercropped sunflower was significantly improved with additional CO_2 at around 800$\pm$75 ppm. The CO_2 improved the *LAI of sunflower crop from* 1.07 to 1.18 in the first and 1.76 to 1.99 in the second years as observed at 68 days after sowing. Though CO_2 was not effective in improving the stem girth and chlorophyll content of intercropped sunflower, the DM per plant was significantly improved from 25.9 to 30.1 g at 68 DAS and from 38.2 to 41.4 g at maturity in the first year and the corresponding values in second year were 43.0 to 49.4 and 59.4 to 64.9 g. In spite of improvements in the LAI and DM, there were no improvements in the yield of sunflower with CO_2 fertilization (8.50 to 8.58 q/ha in 1988 and 13.28 to 13.39 q/ha in 1989). This must have been because of an inadequate translocation of metabolites in to the sink. For one thing, there was no improvement in the chlorophyll content per se. The other observations were that though there were some marginal improvements in the *yield* attributes like head diameter, number of seeds per head and seed weight per plant, these did not help in improving the yields significantly. It is interesting to observe that there was a slight decrease in the test weight when CO_2 was provided (48.8 to 47.1 g/1000 seeds in 1988 and 44.7 to 42.8 g/1000 seeds in 1989) and significant reduction in seed filling per cent from 74.02 to 69.4 in 1988 and from 72.3 to 69.4 in 1989. These two factors were responsible for not improving the yield over and above those obtained in controls, whereas the total DM production favourably and significantly increased with CO_2, with the result that the harvest index was brought down from 0.383 to 0.353 in first year and from 0.396 to 0.337 in second year. The chief cause for such results of improvements of growth attributes and reductions in the yield attributes could be that duration was shortened and maturity was abrubtly hastened when CO_2 was provided. This could be seen from the data on the duration of sunflower (Table 4.32). With CO_2 there was a reduction in duration by about five days. Similar result of reduced duration of sunflower by ten days due to CO_2 fertilization were observed by Mauney et al. (1978) in pure crop of sunflower and they opined that this phenomenon was common in determinate types where the entire stem apex is ended with an inflorescence unlike in indeterminate types like soybean. Yet another cause of a low response of CO_2 by sunflower might be because of the nature of CO_2 trying to sink to the ground level being heavier than air. Thus it is the component crop of soybean which must have made use of this additional CO_2 for its growth and development.

5.3.2 Response of intercropped soybean to CO_2

In contrast to improved growth and no yield response with CO_2 in the principal component of sunflower of this intercropping system, soybean responded very well both in growth and yield attributes to CO_2 enrichment for the intercropping system at around 800±75 ppm. Soybean being a legume is known to respond to CO_2 by improvements in growth, nodulation and yield (Hardy and Havelka, 1973; Shivashankar *et al*., 1976; Shivashankar and Vlassak, 1978). This was also particularly so in intercropping situations with a taller crop than soybean (eg. with fingermillet, Geetha Kumari, 1989). On a thorough examination of the data the following salient points emerge.

The yield of intercropped soybean was increased from 9.42 to 11.46 q per ha in first year and 7.54 to 10.00 q per ha in second year. Thus CO_2 enrichment registered an yield increase of 26 per cent over ambient level on an average of two years. The stover yield also followed similar pattern by CO_2 enrichment. The growth parameters like plant height, LAI, chlorophyll content and total DM production were improved by CO_2 enrichment resulting in higher number of pods per plant (19.9 & 18.2), seeds per pod (2.66 & 2.70), test weight (16.91 & 15.97 g/100 seeds), harvest index (0.502 & 0.545) and seed weight per plant

(6.81 & 5.41 g) as compared to no CO_2 treatment (16.3 & 15.0, 2.46 & 2.44, 16.00 & 14.99 g/100 seeds, 0.475 & 0.518 and 5.36 & 4.21 g, respectively during first and second year). Consequently, there were significant increases in seed and stover yields of intercropped soybean confirming that photosynthates are the limiting factors for higher biological nitrogen fixation and the yield of soybean. Thus additional CO_2 as was available to this lower statured soybean compared to taller component of sunflower in this intercropping system was responsible for enhanced growth and increased yield of soybean.

5.3.3 Response of intercropped sunflower to light enrichment

Along with inadequacy of the photosynthates, light is also an important deciding factor in allowing a crop to reach its maximum potential yields. As this intercropping system was taken up in kharif season, under the prevailing low light intensities and duration the effect of enhanced light through reflections offered by aluminium foils at the borders of these treatment have been considerable as is seen from the growth and yield of sunflower component (Tables 4.20 to 4.21). The seed yield of sunflower was increased from 7.86 to 9.22 q per ha in 1988 and 12.69 to 13.98 q per

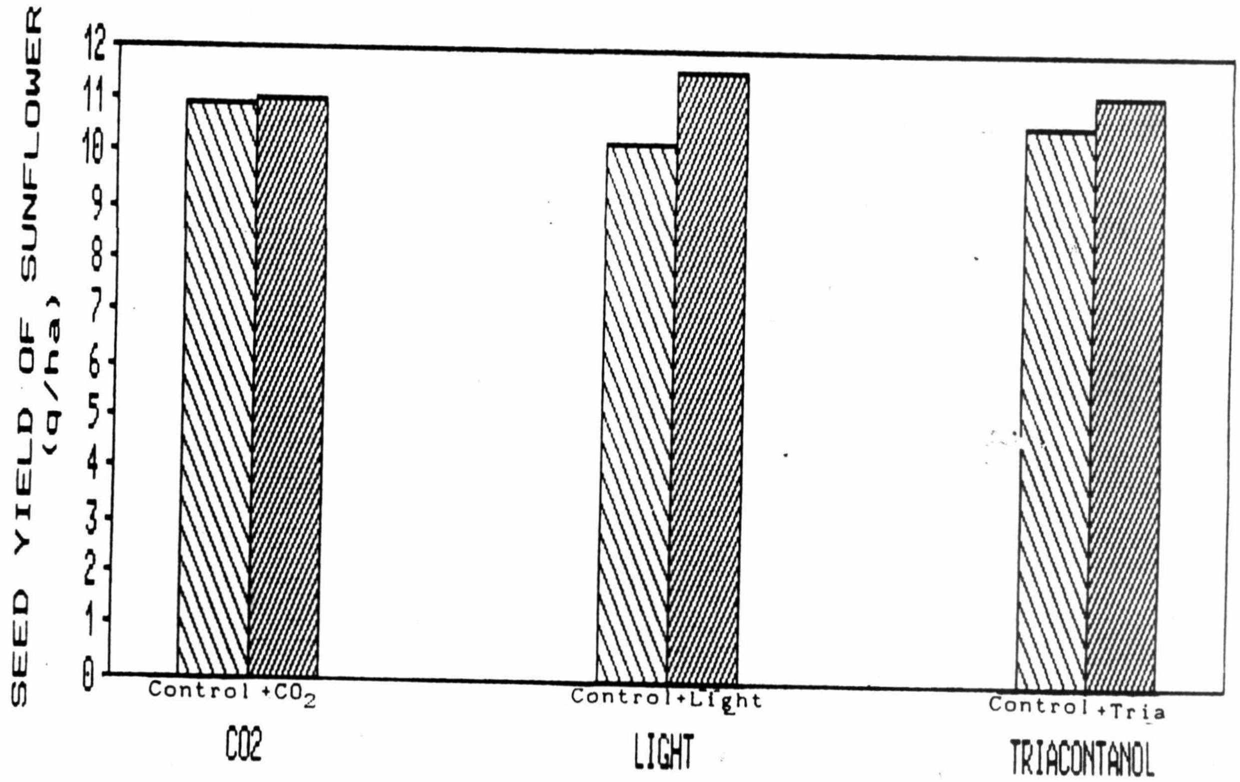


Fig 5.5 Seed yield of sunflower as influenced by CO_2 fertilization, light enrichment and triacontanol application

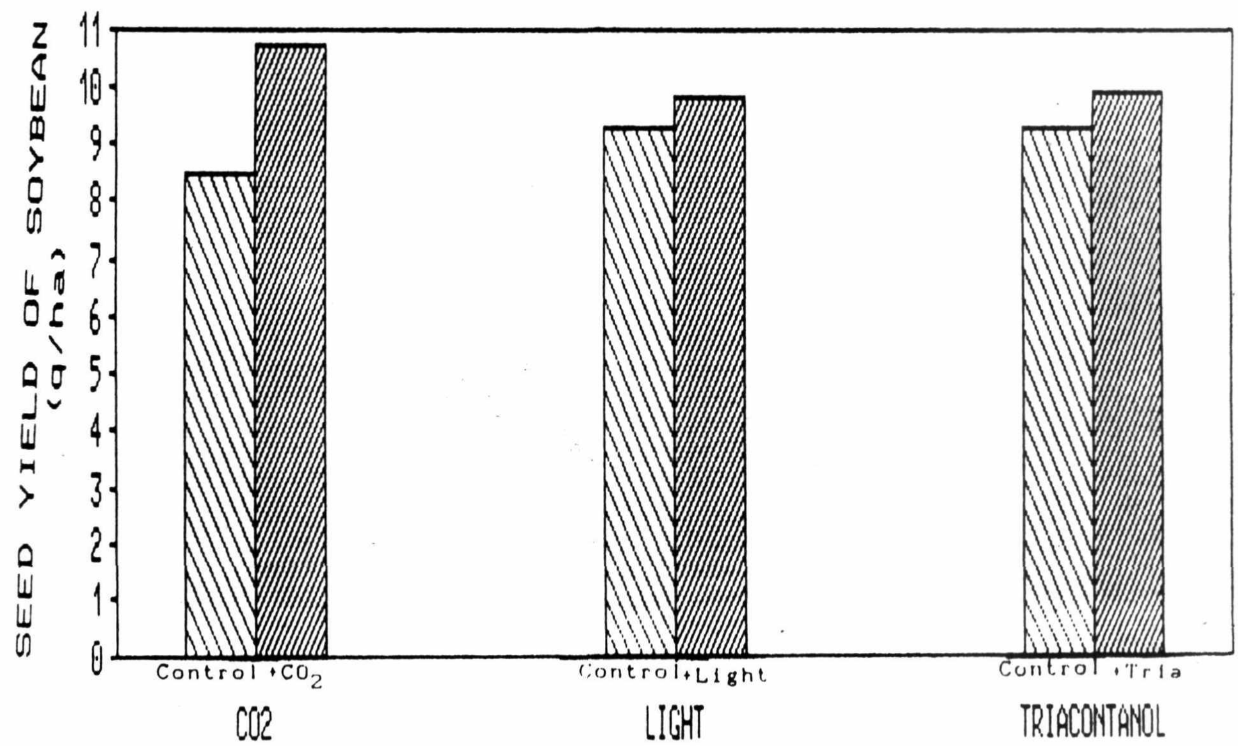


Fig 5.6 Seed yield of soybean as influenced by CO_2 fertilization, light enrichment and triacontanol application

ha in 1989. Stalk yield too improved from 14.24 to 16.31 q per ha in first year and 24.97 to 26.60 q per ha in second year. Such observations of increased seed and stalk yield at higher light intensity was also observed by other workers (Rawson and Hindmarsh, 1983). Further, the favourable effect of additional light on sunflower was witnessed from increased LAI (1.44 to 1.56), stem girth (6.03 to 7.9 cm), total DM (48.8 to 53.1 g/plant) and consequently the head diameter (12.15 to 13.38 cm), number of filled seed per head (454.7 to 503.2), filling per cent (70.3 to 72.1) and seed weight per plant (17.40 to 19.27 g) on an average of two years. Rawson et al. (1984) also observed that an increase in light intensity from 9.5 to 25.5 MJ per day resulted in very high improvement in LAI, total seed number and filled seed number per head.

5.3.4 Response of intercropped soybean to light enrichment

Soybean also responded to light enrichment by significantly increasing its number of primary branches (3.16 to 3.88 in 1988 and 2.96 to 3.60 in 1989), total DM production (8.60 to 9.25 during 1989), number of pods per plant (17.6 to 18.6 and 16.02 to 17.3) and thereby the seed weight per plant (5.89 to 6.27 g and 4.59 to 5.02 g). Such responses of soybean to light enrichment was seen by other workers only in pure crops (Johnston *et al.*, 1969 and Schou *et al.*, 1978). However, the effect of light enrichment to the level of improving seed yield per ha was marginal (10.17 to 10.75 q/ha and 8.50 to 9.04 q/ha).

It is known that the light intensity decides the rate of CO_2 assimilation in plants. Thus, in general the response of crops to CO_2 enrichment increases with increase in light intensity. In intercropping, the light enrichment and CO_2 fertilization individually increased the seed weight per plant of soybean from 4.17 g in control to 4.24 and 5.00 g per plant, respectively and it was further increased to 5.80 g per plant when light enrichment was combined with CO_2 fertilization. The additive effect of increased seed weight was attributable to increased total DM production (8.01 g/plant in control to 10.54 g/plant in light plus CO_2 enriched treatment). Cooper and Brun (1967) observed positive interaction of light intensity and CO_2 leading to four fold increase in photosynthesis of pure soybean. Hence, in this study the increase in photosynthesis might be responsible for increased total DM production and seed weight per plant of intercropped soybean.

5.3.5 Response of sunflower to triacontanol application

Seed setting and seed filling are the two common prominent problems encountered in sunflower, bringing down its potential yields. Apart from hand pollination and nutritional management, growth promoters like NAA and GA have all been tried with some success but they are not in vogue in common practice. Triacontanol is one recently introduced growth promoter which holds bright promise in stepping up agricultural production of several crops. Being readily available in several liquid formulations, one of them viz., Grinit was taken up for this study to explore the possiblities of improving seed setting and seed filling in sunflower. The salient findings on these aspects are discussed further.

Application of triacontanol at three stages during the crop growth period viz., button stage, mid flowering and mid seed filling stages of sunflower brought significant improvement in the seed yields from 8.27 to 8.82 q per ha in first year and from 12.95 to 13.71 q per ha in second year. The improvment in growth and yield attributes like total chlorophyll content of leaves (2.18to 2.29 mg/g fresh leaf in 1989), stem girth (6.39 to 6.73 cm), total DM production (49.6 to 52.4 g/plant), number of filled seeds per head (465.4 to 492.4), seed filling per cent (70.2 to 72.3) and ultimatly seed weight per plant (17.63 to 19.05 g) were observed to be responsible for increased seed yield of sunflower. Inspite of improvement in several growth and yield attributes, the increases in seed yields of sunflower were not high as reported by Jadhav et al. (1987) in mustard with 156 per cent increase in yield and by Shivashankar (1986) in maize with 76 per cent increase over controls. These results can also be compared with those of Patil and Bangal (1985) and Prasanna (1987) who found low or no yield responses with pigeonpea, sunflower and groundnut. Thus, there are some inconsistencies in the magnitude of response to triacontanol. In the present studies though there were significant improvements in seed yields of sunflower with an average of 7 per cent in two years over control caused mainly due to improvement in chlorophyll content and filling per cent, full potentials might not have been reached because of only marginal improvements effected by tricontanol in parameters like LAI, stem girth (in 1989 only), total DM production (in 1988 only), harvest index and stalk yields. Further studies on method of spraying, timing, concentration and on different formulations are therefore needed.

5.3.6 Response of intercropped soybean to triacontanol application

Spraying of triacontanol at three stages viz., vegetative, midflowering and early pod filling stages, significantly enhanced the LAI (1.96 to 2.12), chlorophyll content (4.07 to 4.34 mg/g fresh leaf in 1989) and total DM production (8.3 to 9.35 g/plant in 1989) which inturn increased the yield attributes like number of pods per plant (17.0 to 17.8) and seed weight per plant (5.35 and 5.52 g) although the improvements were marginal and nonsignificant. Because of poor influence of triacontanol on yield attributes, the increase in seed yield per ha (9.33 to 9.90 q, mean of 1988 and 1989, Fig. 5.6) and stover yield per ha (9.22 to 9.84 q) were not statistically significant in both the years. Compared to these, the observations of Shivashankar (1986) indicated 42 per cent increase in soybean yields by triacontanol application at two stages. In studies by Steffens and Worley (1980) and Jourdan and Oplinger (1983) no response of soybean to triacontanol have been reported. It is probable that triacontanol would fare better in pure soybean with no limitations of light.

5.3.7 Effect of CO_2 fertilization, light enrichment and triacontanol application on overall growth, yield and income of intercropping

The results on the effect of three factors viz., CO_2, light and triacontanol independently but on both the component crops of sunflower and soybean in the intercropping system as a whole revealed significant beneficial effects from each of these factors though on individual crops the effects were a little inconsistent. It is in the intercropping system as a whole that all these factors independently have emphatically improved the growth and yield attributes.

With regard to CO_2, the combined LAI of sunflower and soybean improved from 3.27 to 3.81 and the total biomass yield from 47.3 to 53.9 q per ha. Thus the total oil yield improved from 6.67 to 7.19 q per ha in first year and from 5.02 to 5.41 q per ha in second year. The gross income realized from intercropping was thus substantial with a raise from Rs. 6631 to 7334 per ha in first year and Rs. 8126 to 9076 per ha in second year. Geetha Kumari (1989) also observed higher yield and income from intercropped <u>ragi</u> and soybean through CO_2 fertilization.

Light was also equally beneficial as that of CO_2 in improving the combined LAI and total biomass.

The total oil yields increased from 6.63 to 7.24 q per ha in 1988 and from 4.89 to 5.53 during 1989. The gross income also followed the same pattern (Fig. 5.8).

The effect of triacontanol was significant in producing total LAI and total biomass yield, but to a slightly lower extent than the other two factors. The oil yield on an average improved from 5.79 to 6.25 q per ha (Fig. 5.7). The gross income realised also improved from Rs. 6757 to 7208 in first year and from Rs. 8427 to 8775 per ha in second year. Shivashankar (1986) obtained very high enhancement in the total biomass and seed yields of maize and soybean under intercropping sprayed with triacontanol over control.

Looking at all these factors independently the CO_2 fertilization gave the maximum gross income but considering its cost and effectiveness, the other two factors of light and triacontanol could be regarded as useful. Both of them were identical in their total effects on the intercropping system as a whole. Because CO_2 fertilization is an expensive tool for increasing crop productivity, alternate sources of providing CO_2 to the crop canopy have been explored earlier through the use of straw and other cheap organic sources (Shivashankar et al., 1975; Geetha Kumari, 1989). The results on the use of organic amendments of Experiment III are discussed further.

5.4 Experiment III: Studies on CO_2 fertilization and time of application of lime and organic amendments in sunflower - soybean intercropping

Sustainability in agriculture with respect to maintenance of soil fertility and stabilized crop production year after year is the main concern of all agronomists and soil scientists in the present day alaraming situation of degradation and loss of soil and declining yields and pollution of the soil, ground water and atmosphere. One of the major agents in maintaining soil physical, chemical and biological health and in augmenting a steady production is the time old honoured practice of providing organic matter in some form or the other to the soil periodically. In this context the present experiment envisaged increasing the total oil productivity of the intercropping system to fetch higher monetary return and to build and leave a richer soil for the succeeding crops. Simultaneously the release of CO_2 through decomposition of organic amendments applied at different timings was also planned to study the beneficial effects on the photosynthesis and productivity of sunflower and soybean.

5.4.1 Response of sunflower to CO_2

Intercropped sunflower was not favourably influenced with respect to the yield of crop though there were some improvements to the tune of around 2.5 q per ha in stalk yields. The marginal increase observed in seed yield was 19.96 to 20.29 q per ha, stalk yield was 32.80 to 35.19 q per ha although the seed filling per cent and harvest index showed negative response to CO_2 treatment (76.8 to 74.6 per cent and 0.365 to 0.350, respectively). There were some initial responses of sunflower to CO_2 with regard to leaf area index (4.38), the leaf area duration (Table 4.39) and total DM production with significant improvements from 57.5 to 63.0 g per plant at 55 days and from 69.4 to 75.0 g per plant at 75 days. These did not effect any significant improvements in oilseed and oil yields. This was largely because of the nature of the sunflower crop with a determinate habit. It was observed that the LAD between 55 days and maturity of the crop was reduced by almost 2.5 days and the duration of the crop when treated with 800 $\pm$ 75 ppm of CO_2 was reduced by about 6 days on an average of two years. This reduced the seed filling percentage by about two per cent and the HI marginally. Thus, at the expense of higher stalk yields particularly in the second year as supported by higher DM, the seed yield was not influenced by CO_2. Such low or no response to CO_2 in sunflower was noticed by Mauney et al. (1978) with increase in DM in vegetative stage and decrease in duration of crop by about 10 days. It is these reasons which were attributed to lack of response in yield in sunflower largely because of the determinate type of the crop with the apex of the stem ending with an inflorescence. However, Morison and Gifford (1984) also observed increases in DM and specific leaf weight in sunflower due to CO_2 fertilization. Besides in the current studies, sunflower in the intercropping must not have had the full benefit of CO_2 as the gas must have settled down to lower canopy with soybean trapping it to a large extent.

5.4.2 Response of soybean to CO_2

Intercrop soybean was fairly well influenced by CO_2. The seed yields significantly influenced from 8.41 to 11.09 q per ha (Fig. 5.13) and stalk yields from 8.95 to 10.73 q per ha. These improvements were caused by increase in total DM production from 9.34 to 11.64 g per plant. The yield and biomass production data have been substantiated by improvement in the growth attributes. The LAI of soybean treated with CO_2 was significantly higher at all four stages reaching a maximum of 2.54 at 90 days compared to the maximum of 1.93 reached by control, on an average of two years.

Similarly, the DM production was improved significantly with CO_2 at all the stages reaching a maximum 11.64 g per plant at maturity compared to 9.34 g per plant obtained in control. Thus higher yield with CO_2 was caused by higher total LAI and DM which helped in improving yield attributes. The number of pods increased from 14.6 to 17.5 per plant and the 100 seed weight from 15.05 to 16.02 g and seed weight per plant was from 4.45 to. 5.81 g, with CO_2 enrichment at 800 $\pm$ 75 ppm. The reasons for higher productivity of intercropped soybean with CO_2 fertilization could also be that more number of primary branches were induced besides improving the seed weight and test weight. Nutrient uptake studies also showed the superiority of treatment with CO_2 enrichment. Such improvements caused by CO_2 in soybean were also observed by Hardy and Havelka (1973), Shivashankar et al. (1976) and Geetha Kumari (1989). One of the main reasons for such good responses in all these studies have been because of improvement in nodulation and nitrogen fixation by leguminous soybean. However, in the current studies, nodulation characteristics were not significantly influenced by CO_2. Therefore, the effect of CO_2 in this study could be detected by marked increase in average plant height from 70.4 cm in control to 90.6 cm which can be regarded as an advantage in trying to reach out for light in this intercropping system (Plate 14).

5.4.3 Influence of amendments on soil properties

Organic amendments are generally known to improve the soil physical, chemical and biological properties of soil and also to conserve and imporve the moisture holding capacity of soil and thus cause for improvements in yield. The B.D. of soil was decreased from 1.62 to 1.57 g per cc (Appendix 5), as was also observed by Havangi and Mann (1979) due to application of organic residues. In this study, organic amendments applied at 4 and 8 t per ha improved the organic matter content from around 0.80 to 0.87 and 1.00 per cent (Table 4.33), available nitrogen from 352.1 to 383.6 and 402. 8 kg per ha (Table 4.34), available P_2O_5 from 47.3 to 59.4 and 68.7 kg per ha (Table 4.35), available K_2O from 321.5 to 367.9 and 385.6 kg per ha (Table 4.36). Such observations of improved soil fertility by organic amendments were also made by Shivashankar (1986) and Venugopal and Shivashankar (1989). The biological activity measured in terms of activity of dehydrogenase enzyeme was markedly increased from the initial 0.39 to 0.68 mg TPF per g of soil per ha as observed at 10 days after incorporation (Fig. 4.8). This was also observed by Venugopal and Shivashankar (1989) and Geetha Kumari

Plate 14. A close view of a CO_2 fertilized plot

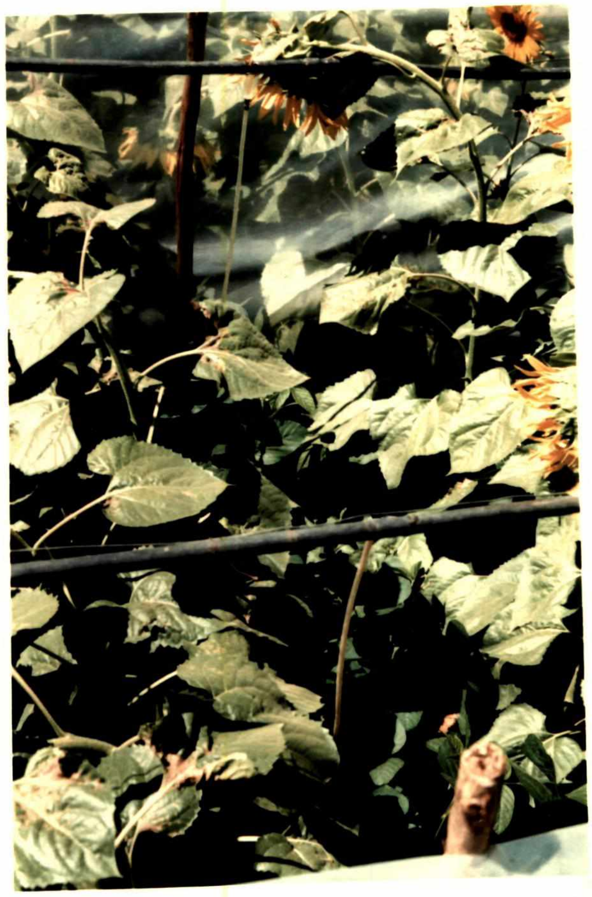


Plate 14

(1989). Further organic amendments improved the soil moisture content and maintained it at fairly higher level without wide fluctuations between two irrigation cycles as compared to control (Fig. 5.9). Whereas, application of unburnt lime was not found to be beneficial in terms of improving the above physical, chemical and biological properties of soil, but increased the soil pH from 7.0 to as high as 7.8 at 4t and to 8.0 at 8t per ha as observed after 40 days of incorporation. Further, application of amendments increased the CO_2 evolution rate of soil. Organic amendment at 4 and 8 t per ha improved the CO_2 evolution rate from 10.20 to 17.75 and 22.8 kg CO_2 per ha per hour, respectively during the first 6 days of incorporation and gradually declined there after. Whereas lime incorporation started increasing the CO_2 evolution after 6 days of application (8.3 to 10.2 and 14.0 kg/ha/hr during 7 to 12 days and from 6.8 to 12.1 and 14.0 kg CO_2 /ha/hr during 13 to 18 days at 4 and 8 t, respectively). The increased CO_2 evolution through organic amendements was observed by many workers viz., Shivashankar (1976), Shivashankar and Krishnaiah (1986) and Geetha Kumari (1989).

With these improvements in soil properties as well as in the micro climate of the plant atmosphere through release of CO_2, the overall growth and yield

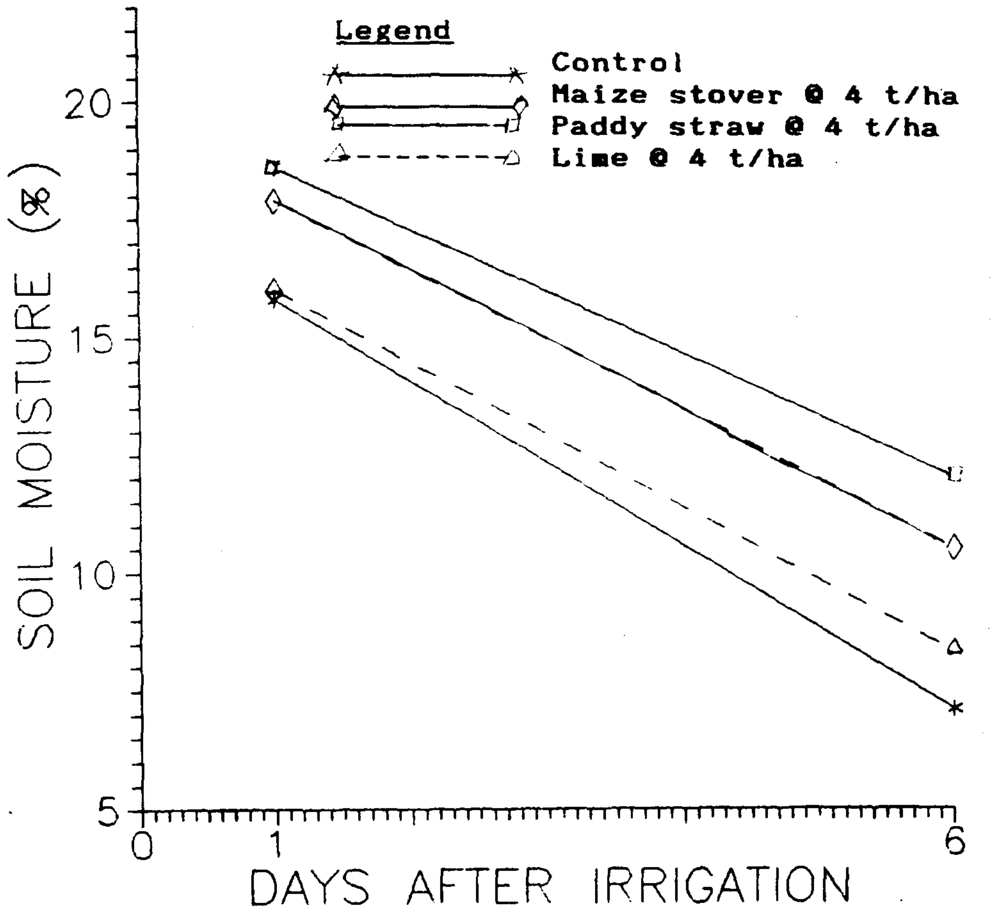


Fig 5.9 Soil moisture status of summer field experiment between two irrigation cycles as influenced by the incorporation of amendments a month before

attributes were improved depending less on nature of the amendments and more on the time of their application.

5.4.4 Response of sunflower to amendments and their time of application

Amendments applied either at 20 days before or at sowing were found to be superior in elucidating good responses in the seed yields of sunflower (22.75 and 23.21 q/ha, respectively) compared to application at 20 and 40 days after sowing (19.24 and 20.01 q/ha, respectively) on an average of two years (Fig. 5.11). Stalk yields of sunflower also improved by application of amendments at 20 days in advance to sowing (36.26 and 35.22 q/ha) as compared to application at 20 days after sowing (31.62 q/ha) and 40 days after sowing (34.08 q/ha). It is seen that the improvements caused by organic amendments applied 20 days before sowing or at the time of sowing were governed by improvements in the soil properties as well as in the release of CO_2 without large scale effect of immobilization.

By the time sowing was taken up, amendments applied 20 days before sowing were able to be of some help through release of CO_2 by decomposition as observed in the controlled supplementary experiment in the lysimeters conducted simultaneously seasonwise and datewise (Table 4.30). In the treatment with application of organic amendments and lime 20 days before sowing, the CO_2 releases were still remarkably higher than control when observed at 20, 40 and 60 days after incorporation (Table 4.30), thus benefitting the crop. Further, the improvements in soil fertility status like organic matter, available N, P_2O_5, K_2O contents and less fluctuation in soil moisture status between two irrigation cycles (Fig. 5.9) due to application of amendments at 20 days before sowing was taken advantage by the crop right from the seedling stage.

Thus the treatments with early incorporation of amendments must have derived some benefit of improved nutrient status and CO_2 evolution for enhanced photosynthesis and growth and yield attributes. Such beneficial effects of organic residue incorporation at 3 weeks before sowing on growth and yield have been well documented in crops like soybean (Shivashankar *et al*., 1975), in maize (Venugopal and Shivashankar, 1989) and in *ragi* with soybean intercrop (Geetha Kumari, 1989). Besides, with the recommended doses of fertilizers at sowing, the immobilization effect of N would have been overcome in treatment with early incorporation of 20 days before sowing.

In treatments with amendments applied at sowing, the initial growth at seedling stage was slightly affected due to immobilization effect (Fig. 4.10). But this effect was completely nullified by the suceeding beneficial effects of amendments in terms of improved soil nutrients and CO_2 evolution which brought enhancement in the growth to become on par with the treatment applied with 20 days before sowing (Fig. 5.10). Besides the duration of sunflower was also lengthened with delays in maturity by an average of around 3.5 days due to incorporation of amendments in general at sowing and organic amendments in particular enhanced the duration by more than 5 days which resulted in increased LAD during the seed filling stage and hence highest seed filling per cent (83.2 and 77.2) and seed yield of sunflower during both the years. Further beneficial effects of improved soil properties with organic amendments remaining almost identical, it is the quantity and time of their application that matters. This can be seen by supportive data on the improved growth and yield attributes of sunflower when amendments were applied 20 days before or at sowing compared to 20 days after and 40 days after sowing. The course of LAI, chlorophyll content, LAD and total DM production were superior in treatments which received the amendments at 20 days before and at sowing (Tables 4.38 to 4.42, Fig. 5.10)

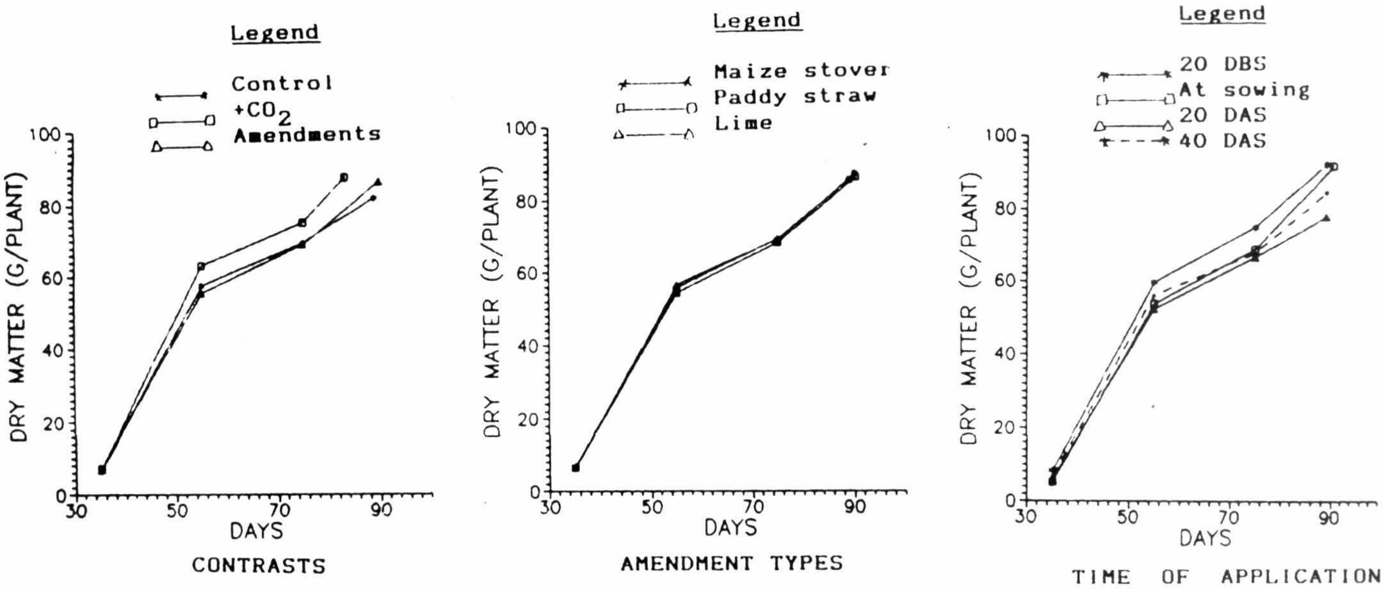


Fig 5.10 Course of dry matter production of sunflower as influenced by CO_2 fertilization, soil amendments and time of their application in sunflower-soybean intercropping system

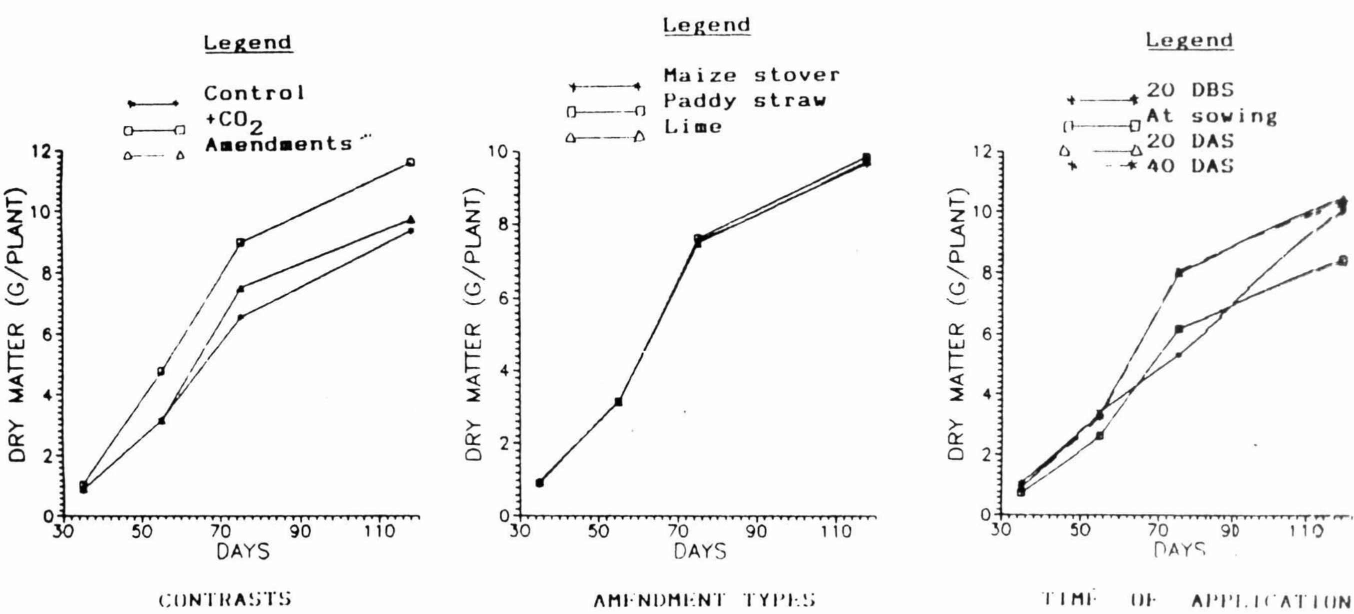


Fig 5.12 Course of dry matter production of soybean as influenced by CO_2 fertilization, amendments and time of their application in sunflower-soybean intercropping system

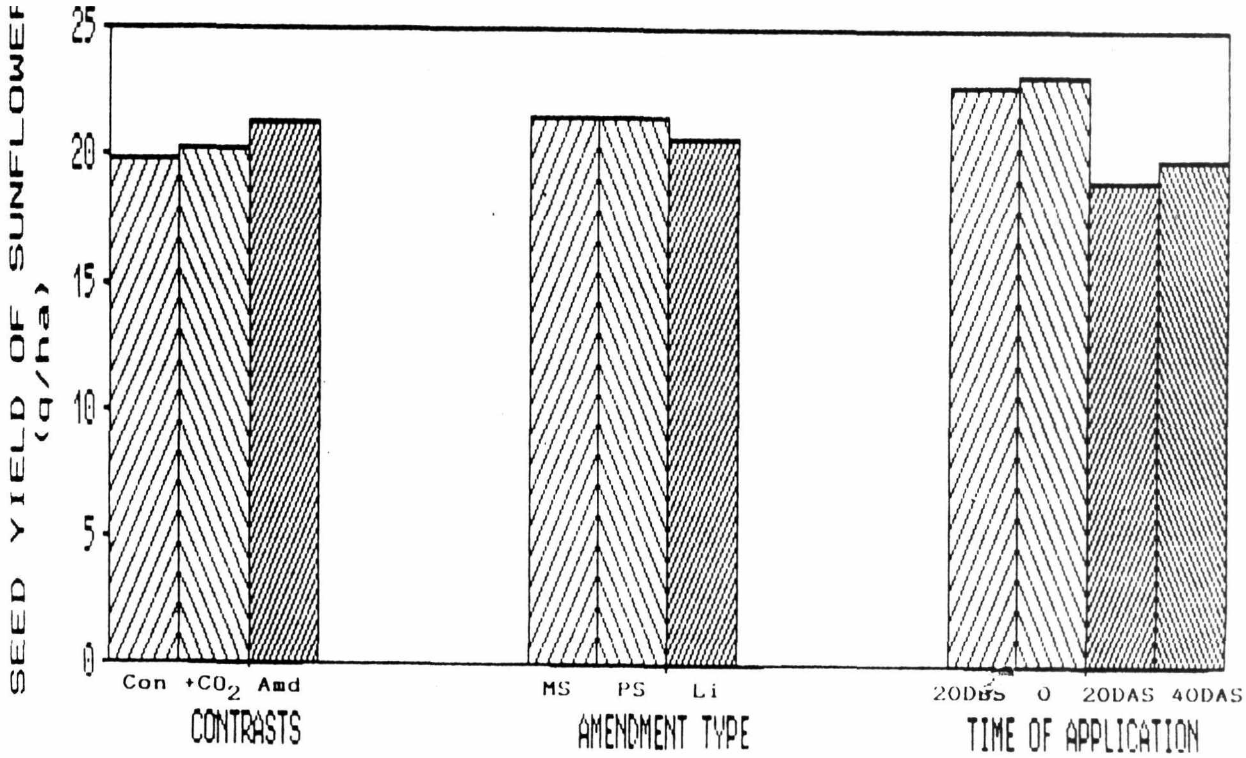


Fig 5.11 Seed yield of sunflower as influenced by CO_2 fertilization, amendments and time of their application in sunflower-soybean intercropping system (Con:Control, Amd:amendments, MS:maize stover, PS:paddy straw, Li:Lime, DBS:days before sowing and DAS:Days after sowing)

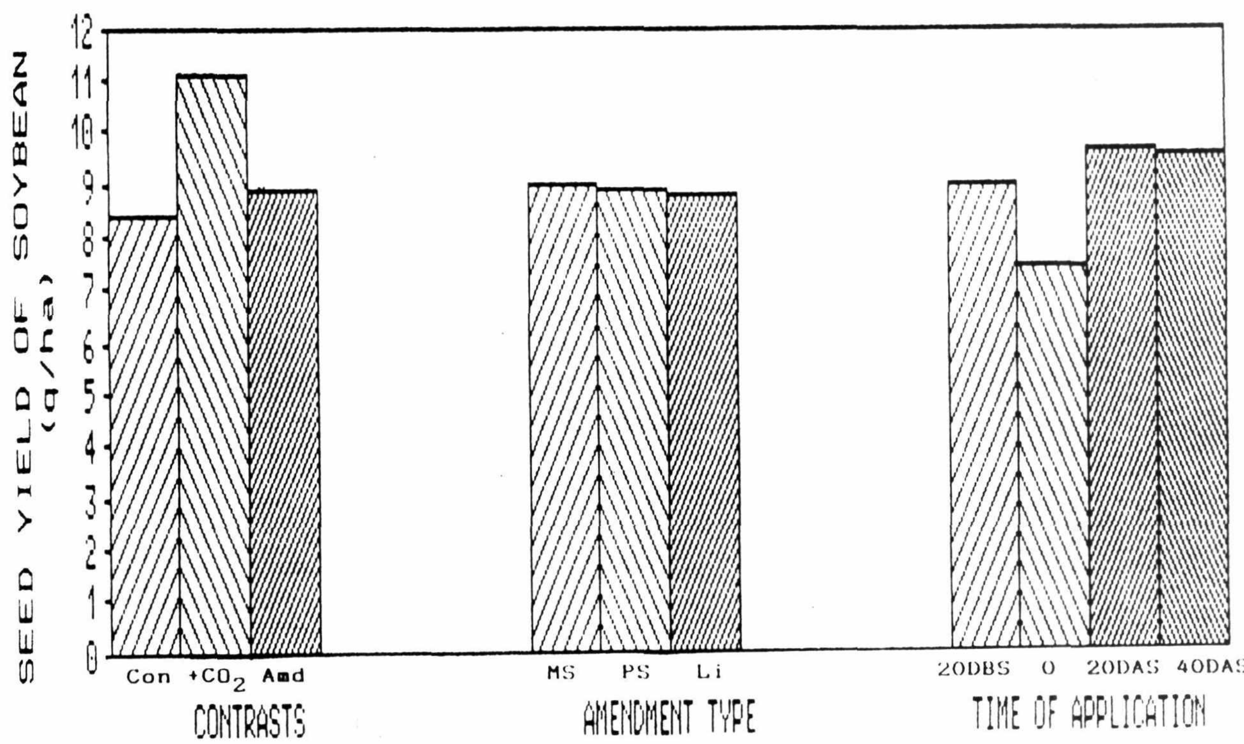


Fig 5.13 Seed yield of soybean as influenced by CO_2 fertilization, amendments and time of their application in sunflower-soybean intercropping system (Con:Control, Amd:amendments, MS:maize stover, PS:paddy straw, Li:Lime, DBS:days before sowing and DAS:Days after sowing)

which resulted in significant improvements in yield attributes like head diameter (14.59 and 14.30 cm), number of filled seeds (704 and 708 /head), seed filling per cent (78.45 and 80.20), test weight (52.68 and 53.88 g/1000 seeds), harvest index (0.370 and 0.384) and seed weight (34.26 and 35.32 g/plant), respectively as compared to 20 and 40 days after sowing (head diameter, 13.10 and 13.30 cm; filled seed number, 595 and 627; seed filling per cent, 75.1 and 74.9; test weight, 52.00 and 51.26 g/1000 seeds; harvest index, 0.364 and 0.354; seed weight, 28.44 and 29.4 g/plant, respectively) on an average of two years.

5.4.5 Response of soybean to amendments and their time of application

Soybean being a legume with rich potentials for high yields under good agronomic practices is found to respond very well to organic amendments. The question of time of application of amendments seems to be dependent on the performance of the component crop also so that the total productivity could be manipulated. From the yield data (Table 4.58) it can be observed that organic amendments exhibited high responses from soybean during both the years when applied at 20 (mean = 9.62 q/ha) or 40 (9.57 q/ha) days after sowing followed by the application of amendments at 20 days before sowing (9.00 q/ha) (Fig. 5.13). There was a depression in yield when organic amendments applied at the time of sowing (7.41 q/ha). The reduced yield due to incorporation of organic residues at sowing was also observed by Prihar et al. (1972) in wheat and Geetha Kumari (1989) in ragi. This depression in yield must have come about from the fact that the germination was improper and delayed when soybean was sown after application of organic amendments which might be because of the hindrance from certain organic acids and compounds released by the initiation of the process of decomposition which aspects need further examination. The second reason for such a depression was the immobilization effect for the initial growth period as could be observed from a lower nitrogen availability in the controlled lysimeter experiment (Table 4.34). A reduction in the availability by 100 to 150 kg N per ha was observed in the study with 4 and 8 t of either maize stover and paddy straw. Such immobilization effect from soil affecting growth and yield of crops have been documented by Allison (1955) and Prihar et al. (1972). It was also observed that this treatment had less vigourous shoot growth (75 and 66 cm of plant height and 1.41 and 1.09 of primary branches), root growth and hence nodulation was affected providing the lowest number of root nodules of 38.3 and 24.3 per plant in the first and second years, respectively.

Compared to this, the other three treatments of times application (20 days before sowing, 20 and 40 DAS) had higher root nodules of 45 and 25 with application 20 days before sowing, 52 and 32 with 20 DAS, 50 and 36 with 40 DAS during first and second years, respectively. Thus, these three treatments gave a high yields because of nodulation efficiency and enhanced growth like plant height (80 to 88 cm in 1989 and 71 to 72 cm in 1990), number of primary branches (1.70 in 1989 and 1.16 to 1.20 in 1990), course of LAI (Table 4.51), total LAD (138.7 to 143.5 and 97.8 to 99.3), chlorophyll content (3.91 to 3.99 mg/g fresh leaf), course of DM production (Fig. 5.12) and consequently higher number of pods (17.2 to 18.0 and 13.9 to 14.3), test weight (15.02 to 15.75 and 15.04 to 15.66 g/100 seeds) and seed weight (5.51 to 6.05 and 4.08 to 4.16 g/plant) as compared to the treatments with application of amendments at sowing (LAI, Table 4.51; LAD, 107.8 and 82.5; total chlorophyll, 3.90 mg/g fresh leaf; DM production, Fig. 5.12; pod number per plant, 14.5 and 12.7; Test weight, 15.00 and 14.89 g/100 seeds; seed weight, 4.50 and 3.62 g/plant). The nutrient uptake of N, P and K also showed the weakness of soybean plants in treatments which received amendments at sowing. The increased duration of sunflower due to application of organic amendments at sowing is also one of the reasons for reduced performance of associated soybean in the same treatment.

The treatment with application of organic amendments 20 days before sowing had the advantage of providing better physical (Appendix 5 and Fig. 5.9), chemical (Table 4.33 to 4.36) and biological (Fig. 4.8) conditions for the establishment of soybean crop as well as by releasing CO_2 steadily. The immobilization eff/ect in this treatment appeared to be just optimum to provide an impetus to initiate good nodulation. In the treatments with 20 days after application of organic amendments, the immobilization effect was masked because of supply of fertilizers at sowing as well as providing some effect of immobilization to favour good nodulation as is seen by highest nodulation compared to other treaments. This finding of increased nodulation due to organic amendments is in confirmity with that of Shivashankar and Shantharam (1980). And the treatment with organic amendments applied 40 days after sowing had no such inhibition effect as nodulation was fairly well initiated by that time. Further, the CO_2 released from incorporation of these amendments at 20 and 40 days after sowing was efficiently utilized by the soybean intercrop, since the peak evolution of CO_2 from the soil coincided with well established canopy.

Thus each of these three treatmemts with different timings of their application provided favourable response in improving the nodulation, growth and yield of soybean as has been discussed earlier.

5.4.6 Response of intercropping system to CO_2 fertilization and time of application of amendments

The intercropping system of sunflower and soybean as a whole responded very favourably to CO_2 with a mean total LAD of 250 days compared to 211 of the control and a mean total biomass of 77 q per ha compared to 70 of the control. The mean total oil yield increased from 9.69 to 10.31 q per ha (Fig. 5.14). Thus there was an increase in average gross income by about Rs. 1000 with CO_2 application (Fig. 5.15). However, considering the expensive treatment of CO_2, application of amendments of either maize stover or paddy straw was found to increase the gross income by about Rs. 800 per ha over control irrespective of time of application. When amendments applied either at 20 days before sowing or at sowing, the gross income were Rs. 12620 and 12292 per ha (Fig. 5.15), whereas the control provided a gross income of Rs. 11250. This high gross income with these two timings was because of higher total oil yield of 10.9 and 10.8 q per ha

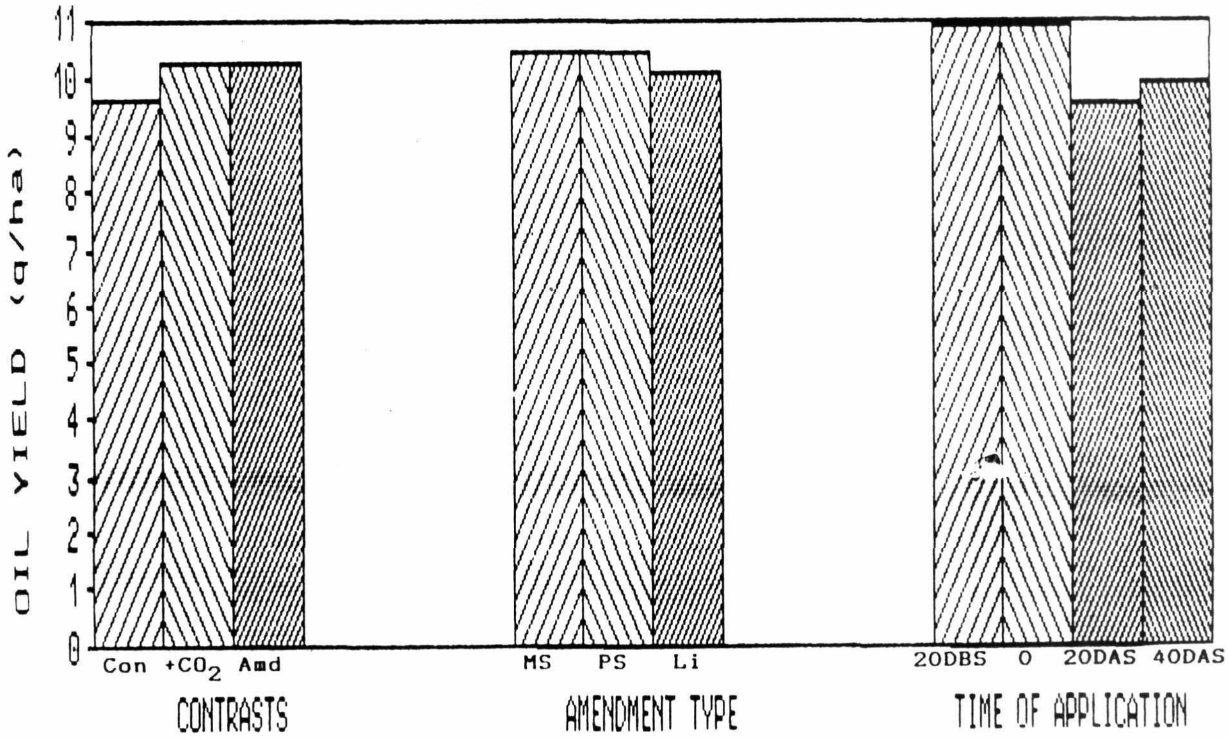


Fig 5.14 Total oil yield from sunflower-soybean intercropping system as influenced by CO_2 fertilization, amendments and time of their application (Con:Control, Amd:amendments, MS:maize stover, PS:paddy straw, Li:Lime, DBS:days before sowing and DAS:Days after sowing)

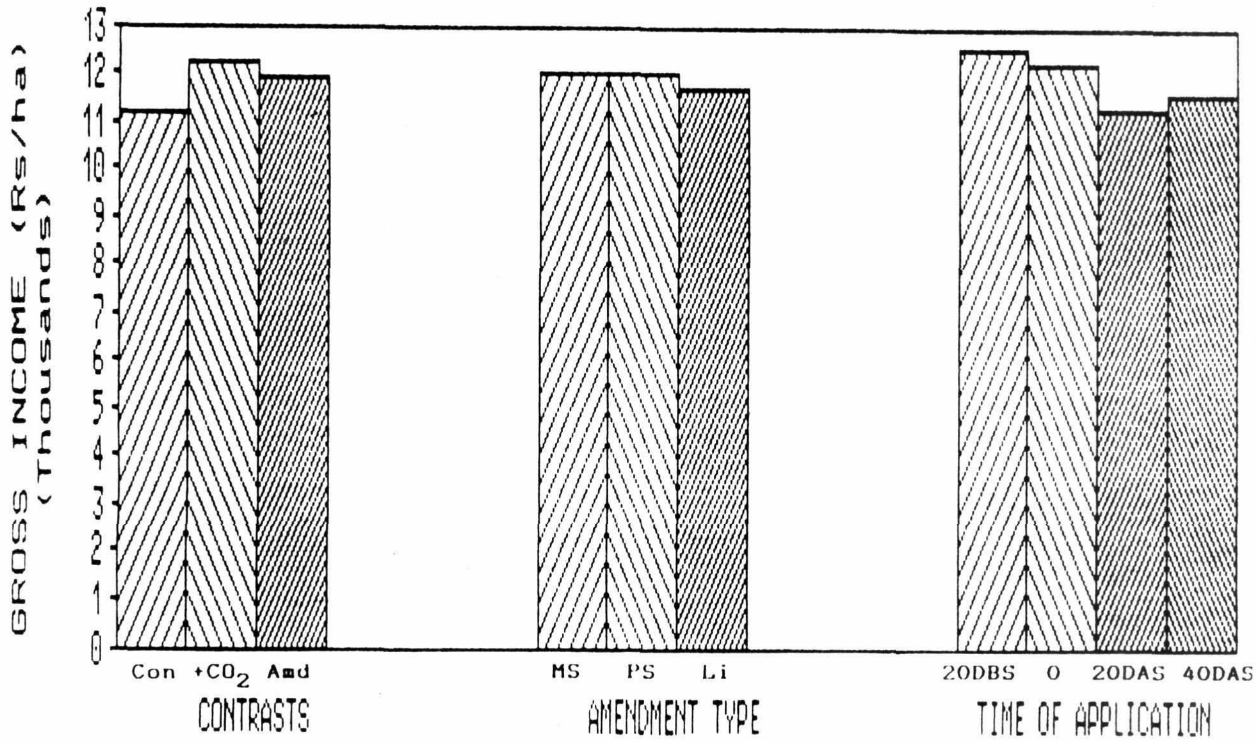


Fig 5.15 Gross income from sunflower-soybean intercropping system as influenced by CO_2 fertilization, amendments and time of their application (Con:Control, Amd:amendments, MS:maize stover, PS:paddy straw, Li:Lime, DBS:days before sowing and DAS:Days after sowing)

compared to 9.6 and 9.9 q per ha with the application at 20 and 40 days after sowing, respectively (Fig. 5.14).

The combined response of sunflower and soybean (Interaction Table 4.62a) indicated that the organic amendments of maize and paddy when applied at 20 days before or at sowing were superior to lime irrespective of the time of application. Total biomass yield of the two crops also indicated that application of organic amendments like maize stover or paddy straw, 20 days before or at sowing were superior to application of lime at any of the four timings.

The inference of these three field experiments is that sunflower-soybean intercropping system with 75 per cent plant population of each component (around 63,000 plants of sunflower and 2,50,000 plants of soybean per ha) with a planting pattern of uniform rows of sunflower at 0.9 m apart (with 17.5 cms between plants in a row) and two rows of soybean introduced in between (with 8.75 cm in between plants in a row) would be the most optimum combination from the points of view of complementarity between the components in effecient utilization of natural resources leading to the stabilized higher oil yield and income under rainfed conditions.

Further the advantages of this sunflower-soybean intercropping can be stepped up by CO_2 fertilization, light enrichment and triacontanol sprays to the intercropped canopy. Being an expensive technology, that too effective only for soybean, CO_2 fertilization can be substituted by using organic amendments like maize stover or paddy straw incorporated three weeks in advance of sowing to augment edible oil productivity.

Results of practical applicability:

1. Intercropping of sunflower and soybean, in general is better than pure cropping under rainfed conditions for getting higher oil yield and income.

2. The productivity of intercropping can be further improved by planting sunflower in uniform rows having 75 per cent of sole crop population (0.9 m x 17.50 cm, around 63,000 plants/ha) and introducing two rows of soybean (with 8.75 cm between plants, i.e 2,50,000 plants/ha which is 75% of sole crop) in between sunflower rows.

3. Incorporation of organic residues at 3 weeks before sowing is as good as CO_2 fertilization.

4. Application of triacontanol with not less than three sprayings coinciding mid vegetative,

flowering and seed filling stages helps in further improving the yields of sunflower and soybean.

Future line of work

1. Research on intercropping of three oil seed crops viz., sunflower, soybean and groundnut with appropriate planting pattern and planting geometry to develop a three storied canopy profile is urgently needed as an attempt towards intensive oil production.

2. Application of tricontanol needs standardisation with respect to number of applications, formulations, concentration and stages of application for exploring its full potential of increasing the yeild.

3. Cheaper ways of light enrichment needs to be foundout since it is a sound technology under kharif conditions.

4. Split application of organic amendments need to be tried for getting a steady and continuous release of CO_2 to the crop canopy.

SUMMARY

VI. SUMMARY

The investigations entitled "Productivity of sunflower-soybean intercropping system as influenced by canopy architecture, CO_2 fertilization, triacontanol, light enrichment, lime and organic amendments" were taken up from 1988 to 1990 at Main Research Station, Hebbal, U.A.S., Bangalore in a red sandy loam soil. Three field experiments and one lysimeter cum pot experiment were carried out to elucidate informations on the compatibility of sunflower and soybean in intercropping at varied plant population levels and planting patterns; the effect of CO_2 fertilization, light enrichment and triacontanol sprays on growth and yield of sunflower and soybean in intercropping and to evaluate the benefits of soil amendments in terms of CO_2 enrichment of the intercrop canopy, improvements in soil physico-chemical and biological properties and thus on the productivity of the intercropping system.

The first experiment consisted of 14 treatments with two pure crops and 12 intercrop combinations from out of three factors viz., two plant population levels of sunflower, three plant population levels of soybean and two planting patterns of sunflower. The experiment was laid out in RBD design with three replications with the treatments superimposed in the second year in the same location plotwise.

The second field experiment had eight treatment combinations from out of three factors of two levels each (ambient CO_2 & $+CO_2$, normal light & +light, and triacontonal & +triacontanol) with the treatments superimposed in the same plots during second year.

A lysimeter cum pot experiment to study the CO_2 evolution rate and changes in physical, chemical and biological properties of soil by organic and lime amendments consisted of seven treatments having one control and two levels each (4 and 8 t/ha) of maize stover, paddy straw and lime. There were two replications. The experiment was carried out during 1990 summer season for about two months coinciding the third field experiment.

The third field experiment had fourteen treatments with one control and CO_2 fertilization and the remaining twelve derived from combinations of three amendments (maize stover, paddy straw and lime) and four times of application (20 days before sowing, at sowing, 20 and 40 days after sowing). The treatments were superimposed in the second year in the same location plot wise.

The salient findings of these four experiments are presented further.

Experiment I: "Performance of sunflower and soybean in intercropping with varied plant populations and planting patterns"

1. **Sunflower:** Sunflower yields were reduced by intercropping from 8.20 to 6.17 q and from 13.11 to 10.17 q per ha in two years. The LAI , the total DM, number of filled seeds, seed filling per cent and seed weight were higher in pure crop while HI increased by intercropping.

Seed yield of sunflower was significantly lower with 75 per cent (5.87 and 9.77 q/ha) than with 100 per cent population (6.46 and 10.57 q/ha). However, 75 per cent sunflower population was found superiror in terms of total DM, number of filled seeds, seed filling per cent and seed weight as compared to 100 per cent. The increased yield in 100 per cent plant population was mainly because of increased LAI and the extra 25 per cent plant population which surpassed the superiority of per plant characters of 75 per cent treatment. Among the three population levels of soybean, only 50 per cent of its sole crop population resulted in higher yield of sunflower (6.44 q/ha in 1988 and 10.50 q/ha in 1989) as compared to 75 per cent (6.04 and 10.00 q/ha) or 100 per cent (6.01 and 10.01 q/ha). Cumulative effect of DM, seed fillig and seed weight per plant resulted in higher yield of sunflower at 50 per cent soybean populations as compared to 75 or 100 per cent.

Sunflower in uniform rows was superior (6.14 and 10.44 q/ha) to paired rows (5.92 and 9.90 q/ha) due to higher LAI, total DM, better seedfilling and seed weight.

2. **Soybean:** Intercropped soybean yielded lower (9.81 and 8.24 q/ha) than sole soybean (15.60 and 13.13 q/ha). The stover yield also decreased due to intercropping from 17.61 to 10.51 and from 11.51 to 7.31 q per ha during the two years.

In intercropping, soybean yield was higher with 75 per cent sunflower population (10.27 and 8.65 q/ha) as compared to 100 per cent (9.35 and 7.82 q/ha) during both the years. Whereas, stover yield did not vary between plant poulations of sunflower. Higher soybean yields in pure crop was effected by higher branches, LAI, total DM, number of pods per plant, test weight of seeds and HI. Soybean yields increased with increase in soybean population from 50 to 75 per cent (6.66 to 11.26 q/ha in 1988 and 6.30 to 9.27 q/ha in 1989). Stover yield also followed the same trend. However, 50 per cent of soybean population resulted in improved growth and yield parameters of individual plants, but these were not enough to compensate for the decreased yield due to lower plant population per ha as compared to 75 per cent which had higher LAI.

Between planting patterns in intercropping, soybean in between sunflower uniform rows yielded significantly higher (10.34 and 9.16 q/ha) as compared to soybean in between the sunflower paired rows (9.28 and 7.31 q/ha). The former had more number of branches, LAI, total DM, pods, test weight and seed weight per plant compared to soybean under paired rows of sunflower.

3. Combined growth, yield and income from intercropping: Sunflower-soybean intercrop gave significantly higher gross income (Rs. 5410 and 6539 /ha), total oil yield (4.22 and 5.43 q/ha), total biomass (36.92 and 44.96 q/ha) compared to sole cropping of either sunflower (Rs. 3278 and 5244 /ha, 3.19 and 4.98 q/ha, 24.13 and 40.98 q/ha) or soybean (Rs 4680 and 3938 /ha, 2.89 and 2.49 q/ha, 33.21 and 24.64 q/ha). Total LAI of intercrop was higher (3.16 and 3.30) than LAI of sunflower (1.16 and 2.16), but LAI of soybean was highest (4.28 and 3.73). Solar radiation was efficiently utilized by intercrop through greater interception and also due to increased top canopy surface area.

Sunflower population did not alter the growth, yield and income of intercropping, whereas increased soybean population from 50 to 75 per cent increased income (by Rs. 1219 and 691 /ha), the total oil yield (by 0.40 and 0.37 q/ha), the total biomass production (by 8.86 and 3.49 q/ha) and the total LAI (by 0.78 and 0.35) of the system during 1988 and 1989, respectively. Increased light interception and better distribution was due to increased top canopy surface area at 75 per cent. Further increase in population to 100 per cent brought no changes.

In sunflower-soybean intercropping, uniform rows of sunflower gave an additional gross income of Rs. 511 and 770 per ha, total oil yield of 0.39 and 0.55 q/ha, total biomass yield of 3.64 and 5.12 q per ha and total LAI of 0.23 and 0.25 over paired rows. Paired row planting resulted in increased overlapping in canopy, decreased canopy surface area exposed to the Sun with poor distribution of the leaf area in the canopy profile and with localization of the feeding zone of same plant species and hence less growth, yield and income over uniform row planting.

4. Competition functions: Land equivalent ratio (LER) values showed that sunflower-soybean intercropping system gave an yield advantage of 38 and 40 per cent. Uniform row planting with 75+75, 75+100, 100+75, 100+100 per cent combinations of sunflower and soybean were found superior with an LER of 1.51 to 1.55 than other treatment combinations. Among the above four treatments, 75+75 combination with uniform row planting was most economical because of reduced seed rate and fertilizer dosage by 25 per cent.

The competitive abilitiy of sunflower was found to be very high as shown by CR values (1.96) when compared to soybean (0.54). Higher plant populations of sunflower or soybean in intercropping further increased the competitive ability of sunflower. Sunflower in uniform rows was found better competitive than in paired rows. The CR of soybean decreased with its increased plant populations of sunflower. Whereas, planting pattern showed poor influence on the competitive ability of soybean.

Experiment II: Effect of CO_2 fertilization, light enrichment and triacontanol sprays in sunflower - soybean intercropping.

5. **Sunflower:** The seed yield of sunflower in CO_2 treatment (8.58 and 13.39 q/ha) was on par with no CO_2 treatment (8.50 and 13.28 q/ha). Whereas, the stalk yield was significantly increased due to CO_2 enrichment from 14.07 to 16.47 q and from 24.09 to 27.48 q per ha. The LAI and total DM increased significantly with CO_2

enrichment. The seed filling per cent and HI were significantly lower in CO_2 fertilized treatements. The duration of sunflower was reduced by CO_2 fertilization by 4.5 to 4.9 days. Light enrichment improved seed yields from 7.86 to 9.22 q and from 12.69 to 13.98 q per ha. Stalk yield was also significantly increased due to CO_2 enrichment. Triacontanol sprays thrice during crop growth period improved the seed yield by 0.55 and 0.76 q per ha over no sprays, because of increased LAI, chlorophyll content, stem girth, total DM, number of filled seeds, seed filling per cent, test weight, seed wight per plant and HI.

6. **Soybean:** The seed yield of soybean enhanced due to CO_2 fertilization by 2.04 and 2.46 q per ha. Stover yield too increased during second year. Improved plant height, LAI and total DM resulted in increased number of pods, seeds per pod, test weight, HI and seed weight per plant. The seed and stalk yields of soybean were affected neither by light enrichment nor by tricontanol sprays, although some improvements were seen in certain growth and yield attributes.

7. **Combined growth, yield and income of intercrops:** Gross income from intercroping increased by CO_2 treatment (Rs. 6631 to 7334 /ha and from Rs. 8126 to 9076 /ha) due to enhanced the total LAI, total

biomass production, seed yield of intercrops and total oil yield. Supplemental light to the intercropped canopy also raised the income by Rs. 685 and 630 per ha due to favourable effects on total LAI, total biomass yield, seed yields of intercrops and total oil yield of the system. Tricontanol application thrice during the crop growth period enhanced the gross income by Rs. 551 and Rs. 348 per ha due to increased total LAI, total biomass yield, seed yields and oil yield of intercrops.

8. Studies on CO_2 evolution rate and changes in physical, chemical and biological properties of soil by organic and lime amendments

Organic amendments largely enhanced the soil respiration through increased biological activity of the soil. Whereas lime application increased the CO_2 evolution rate of soil but decreased the dehydrogenase activity. Organic amendments at 4 and 8 t per ha markedly improved the soil fertility status by improving the organic matter content (0.87 and 1.00%), available N (383.6 and 402.8 kg/ha), P_2O_5 (59.4 and 68.7 kg/ha) and K_2O (367.9 and 385.6 kg/ha) contents of soil as compared to control (0.80% org. matter, 352.1, 47.3 and 321.5 kg available N, P_2O_5 and K_2O /ha) at 60 days after incorporation. Bulk density of soil decreased by organic amendments (1.62 to 1.57 g/cc, Appendix 5). Lime application did not improve physical and chemical properties of soil except of soil pH from 7.0 to 7.8 and 8.0 at 4 and 8 t per ha by 40 days of incorporation.

Experiment III: Studies on CO_2 fertilization and time of application of lime and organic amendments in sunflower-soybean intercropping system

9. **Sunflower:** Compared to control, CO_2 fertilization and soil amendments brought no marked differences in seed yield and stalk yield of sunflower. However, marginal improvements due to CO_2 and soil amendments were noticed. The duration of sunflower was shortened by 5.7 days by CO_2 treatment. Maize stover and paddy straw were superior to lime in improving the growth and yield of sunflower. Application of amendments either at 20 days before sowing or at sowing showed no differences in seed yield (23.97 and 24.52 q/ha and 21.53 and 21.91 q/ha) and both were significantly superior to application either at 20 days after sowing (21.01 and 17.48 q/ha) or 40 days after sowing (21.97 and 18.06 q/ha). The growth parameters viz., LAI, LAD, chlorophyll content, total DM at all stages and yield parameters like head size, number of filled seeds, filling per cent, test weight, HI and seed weight per plant were superior in treatments which received the amendments 20 days in advance to sowing.

Application of amendments at sowing was on par with application at 20 days before sowing except an intial set back on seedling growth due to immobilization effect. Test weight, HI and filling per cent of treatment which received amendments at sowing were found even statistically superior to treatment which received 20 days in advance. Application of amendments at 20 days after sowing had an adverse effect on growth and yield parameters of sunflower, some times more than the effect of 40 days after incorporation.

Organic amendments applied at sowing enhanced the duration of sunflower by around 5 days as compared to other times of their application. Lime application did not change the duration irrespective of the time of application.

10 Soybean: CO_2 fertilization improved seed (12.90 and 9.28 q/ha) and stover yield (12.90 and 8.57 q/ha) as compared to control (seed yield, 9.57 and 7.25 q/ha; stover yield, 10.37 and 7.54 q/ha) and amended treatments (10.41 and 7.40 q/ha; 10.81 and 7.33 q/ha) during the two years, respectively. The CO_2 enrichment improved plant height, branching, nodulation, course of LAI, LAD and total DM production resulting in increased number of pods per plant, seeds per pod, test weight, HI and seed weight per plant. There was increased uptake of N, P and K by CO_2 fertilization. Crude protein content of seeds was also improved by CO_2 fertilization.

Generally, types of amendments did not vary the growth and yield attributes and hence the seed and stalk yield of soybean. However, nodulation and NPK uptake were enhanced by application of organic amendments while lime application suppressed these. Application of ammendments at sowing reduced the seed and stover yields to lowest level (seed yields, 8.36 and 6.47 q/ha; stover yields, 8.82 and 6.55 q/ha in 1988 and 1989, respectively) as compared to other time of applications viz., application at 20 days before, 20 and 40 days after sowing (seed yeilds, 10.34 to 11.51 q/ha and 7.67 to 7.74 q/ha; stover yields, 10.90 to 11.83 q/ha and 7.33 to 8.09 q/ha). Application of amendments at 20 days before sowing, 20 days after sowing and 40 days after sowing, by and large were statistically on par in influencing the growth and yield of soybean. Application at 20 and 40 days after sowing were superior to application at 20 days before sowing in test weight, HI and seed weight per plant. Crude protein content of seeds were improved by application of amendments at 20 days in advance to sowing and significantly reduced due to application at sowing.

11. Combined growth, yield and income of intercrops: The total LAD, total biomass yield, total oil yield were improved by CO_2 fertilization when compared to control and amendments and thus the gross income (Control, Rs. 12428; soil amendments, Rs. 13076 and CO_2 treatment, Rs. 13517 /ha, during first year).

Maize stover and paddy straw were superior in influencing the total growth, yield and income of intercropping as compared to lime. Amendments incorporated at 20 days in advance to sowing were found superior to other treatments in terms of total LAD, total biomass production, total oil yield and the gross income (Rs. 13522 and 11719 /ha) and it was closely followed by application at sowing (Rs. 13110 and 11474 /ha). Whereas, application of amendments at 20 days after sowing gave the lowest yield and income (Rs. 12635 and 9968 /ha) followed by 40 days after sowing (Rs. 10272 and 11654 /ha). Organic amendments viz., maize stover and paddy straw incorporated at 20 days in advance to sowing gave highest income of Rs. 13,981 and 13,568 per ha during first year as against the lowest income of Rs. 12,299 and 12,420 per ha, respectively when incorporated at 20 days after sowing. However, the time of application of lime gave no such differences (Rs. 12734 to 13185 /ha).

REFERENCES

VII. REFERENCES

Allison. F.E., 1955, The enigma of soil nitrogen balance sheets. Adv. agron., 7: 213-250.

*Ackerson, R.C., Witenbach, V.A. and Havelka, V.D., 1980, Effect of atmospheric CO_2 concentration on physiological processes of soybeans. Agron. Abst., 72nd annual meeting, American Society.

Ackerson, R.C., Havelka, V.D. and Boyle, M.G., 1984, CO_2 enrichment effects on soybean physiology. II effect of stage specific CO_2 exposure. Crop Sci., 24(6): 1150-1154.

Anonymous, 1973, Ann. Prog. Rep., All India Coordinated Rice Improvement project, Hyderabad, 253-255.

Anonymous, 1979, Ann. Prog. Rep. All India Coordinated Research Project on Dryland Agriculture, Bangalore.

Anonymous, 1986, Souvenir. 15 years of Dryland Agricultural Research, Central Research

Institute for Dryland Agriculture, Hyderabad, p.31.

*Anonymous, 1988, Results of sunflower intercropping; fewer diseases and higher yield Shanxi agric. Sci., No.6, Institute plant protection, Shanxi Academy Agricultural Science, Taiyuan, Shanxi, China, p. 15-16, (In) Field Crop Abstr., 42(5): 447.

Balasubramanian, A., Siddaramappa, R. and Rangaswamy, G., 1972, Effect of organic manuring on the activities of the enzyme hydrolysis of sucrose and urea in soil aggregation.Plant and soil, 37:319-328.

*Benendetti, A., Carvallari, L. and Nigro, C., 1982, Some aspects of humus balance in soil Annali dell Instituto Sperumental per in nutrizione plante, 11(5): 1911,

Beuerlein, J.E. and Pendleton, J.W., 1971, Photosynthetic rates and light saturation curves of individual soybean leaves under field conditions. Crop Sci., 11:217-219.

Biswas, T.D., Roy, M.R. and Sahu, B.N., 1970, Effect of different sources of organic manures and soil growing rice. J. Indian Soc. Soil Sci., 18(3): 233-242.

Biswas, T.D., Jain, B.L. and Mandal, S.C., 1971, Cumulative effect of different levels of mannures on the physical properties of soil. J. Indian Soc. Soil Sci., 19(1): 31-7.

Bohning, R.H. and Burnside, C.A., 1956, The effect of light intensity on the rate of apparent photosynthesis in leaves of sun and shade plants. American J. Bot., 43:557-561.

Bosland, J.M., Hughes, D.L., Yamaguchi, M., 1979, Effect of glyphosine and triacontanol on growth, yield and soluble solids content of 'PMR-45' Muskmelons. Hort. Sci., 14(6): 729-730.

Bouwkamp, J.C., McArdle, R.N., 1980, Effect of triacontanol on sweet potatoes. Hort. Sci., 15(1):69.

Briggs, G.E., Kidd, F. and West, C., 1920, quantitative analysis of plant growth. Part and II. Ann. Appl. Biol., 7:103-23.

Bruggunik, G.T., 1984, Effects of CO_2 concentration on growth and photosynthesis of young tomato and carnation plants. Acta Horticulturae, 162:279.

Burnside, C.A. and Bohning, R.H., 1957, The effect of prolonged shading on the light saturation curves of apparent photosynthesis in such plants. Plant physiol., 32:61-63.

Calvert, A. and Slack, G., 1975, Effects of CO_2 enrichment on growth, development and yield of green house tomatoes. I Response to controlled conditions. J. Hort. Sci., 50:61-71.

Carlson, R.W. and Bazzas, F.A., 1982, Photosynthetic and growth response to fumigation with SO_2 at elevated CO_2 for C_3 and C_4 plants. Oecologia, 54:50-54.

Casida, L.E., Klein, D.A. and Santon, J., 1964, Soil dehydrogenase activity estimation. Soil Sci., 98: 371-376.

Chandel, A.A., Pandey, K.N., Saxena, S.C. and Tiwari, S.K., 1988, Symbiotic nitrogen contribution by nodulated soybean to non-nodulated soybean and ragi. Indian J. Agron., 33(4): 393-395.

Chandrasekar, V.P. and Morachan, Y.B., 1979, Effect of advanced sowing of intercrops and nitrogen levels on yield components of rainfed sunflower. Madras agric. J., Chapman, H.W. and Loomis, W.E., 1953, Photosnthesis in potato under field conditions. Plant physiol., 28:703-716.

Chaudhary, M.L., Singh, J.P. and Narval, R.P., 1981, Effect of long term application of phosphorus, potash and and farm yard manure. J. Indian Soc. Soil Sci., 29(3): 81-85.

*Chen, J-X., Ye, X-F., Wang, W-G. and Zheng, Z.R., 1982, Effect of highly purfied 1-triacontanol in controlling the abscission of cotton bolls and its physiological basis. Acta Agronomica Sinica., 8(1): 33-39.

Chhabra, M.L., Yadav, T.P. and Gupta, S.C., 1982, Effect of season of sowing on the productivity of sunflower. Indian J. Agric. Sci., 52(2): 107-112.

Chibnall. A.C. Williams, E.F., Latner., A.L. and Piper, S.H., 1933, The isolation of n--triacontanol from lucerne wax. Biochem. J., 27: 1885-1888.

Cooper, R.L. and Brun, W.A., 1967, Response of soybean to a CO_2 enriched atmosphere. Crop Sci., 7: 455-457.

Crizaldo, E.N., Amatorio, M.Q., Lansigan, A.A., 1979, Effect of triacontanol on seedlings of Molucean

San (Albizia falcataria (L.) Back). Sylvatrop., 4(4):261-267.

Crookston, R.K. and Kent, R., 1976, Intercropping a new version of an old idea. Crop and Soils, 28(9): 7-9.

Dahlman, R.C., Strain, B.R. and Rogers, H.H., 1985, Research on the response of vegetation to elevated atmospheoric carbondioxide J. Environ. Quality, 14(1): 1-8.

Dalal, R.C., 1974, Effect of intercropping of maize with pigeonpea on grain yield and nutrient uptake. Expt. Agric., 10:219-224.

Dalal, R.C., 1977, Effect of intercropping of maize and soybean on grain yield. Trop. Agric., 54(2): 189-191.

Daniel, G.H., 1955, Dredge corn trials. J. National Inst. Agric. Bot., 7:309-317.

Dayal, R., Singh, G. and Sharma, R.C., 1967, Growing of legume and cereal mixture under dryfarming conditions. Indian J. agron., 12:126-131.

De, P.K. and Sulaiman, M., 1950, Fixation of nitrogen in rice soils by algae as influenced by crop,

CO_2, and inorganic substances. Soil Sci., **70**: 137-151.

Debata, A., Murthy, K.S., 1981, Effect of growth regulator on photosynthetic efficiency, translocation and senescence in rice. Indian J. Expt. Biol., **19**: 986-987.

*De saussure, 1804, Thesis-Recherches chemiquies Sur la vogetation, paris.

Dhawan, K.R., Bassi, P,K. and Spencer, M.S., 1981, Effects of CO_2 on ethylene production and action in intact sunflower plants. Plant physiol., **68**(4): 831-834.

Donald, C.M., 1961, Competition for light in crops and pastures. Symp. Soc. Expt. Biol., **15**:282-313.

Donald, C.M., 1982, In search of yield. J. Australian Inst. Agric. Sci., **28**: 171-178.

Donald, C.M., 1963, Competition among crops and pasture plants. Adv. Agron., **15**:1-114.

Dormaar, J.F. and Summerfeldt, T.G., 1986, Effect of excess feed lot manure on chemical constituents of soil under non-irrigated and irrigated managment. Canadian J. Soil Sci., **66**:303-313.

Downton, W.J.S., Grant, W. J.R. and Loveys, B.R., 1987, CO_2 enrichment increases yield of valencia orange. Aust. J. plant physiol., 14:493-501.

English, S.D., Mc William, J.R., Smith, R.C. G. and Davidson, J.L., 1979, Photosynthesis and partitioning of drymatter in sunflowers. Aust. J. Plant physiol., 6(2): 149-164.

*Finlay, R.C., 1975, Intercropping soybean with cereals. (In) Soybean Production, Protection and Utilization. International Agrciultural publications, INT SOY Series No. 6, University of Illinois, Urbanachampaign.

Foch, H., Klug, K. and Canvin, D.T., 1979, Effect of carbondioxide and temperature on photosynthetic CO_2 uptake and photosrespiratory CO_2 evolution in sunflower leaves. Planta, 145: 21-23.

Frayman, S. and Venkateswaralu, J., 1977, Intercropping of rainfed red soils of Deccan plateau, India. Can. J. Plant Sci., 57: 697-705.

Gaastra, P., 1963, Climatic control of photosynthesis and respiration,(In) Evans, L.T., Environmental control of plant growth. Academic press, New York, p. 113-140.

Gattani, P.D., Jain, J.V. and Seth, S.P., 1976, Effect of continuous use of chemical fertilizers and manures on soil physical and chemical properties. J. Indian Sco. Sci., 24: 284.

Gaur, A.C., Mathur, R.S. and Varshney, T.N., 1970, Decomposition of different types of organic matter added to soil. Agrochimica, 14: 524-532.

Ge, X-H. and Zhang, C-X., 1984, Effects of triacontanol on the seedlings of Poncirus trifoliate in water culture. Plant physiol., Comm., 6: 26-27.

Geetha Kumari, V.L., 1989, Effect of intercropping, organic amendment, carbon dioxide enrichment, molybdenum and phosphorus nutrition on ragi and soybean. Ph. D. Thesis, University of Agricultural Sciences, Bangalore.

Gifford, R.M., 1970, Aspects of variability and control of CO_2 exchange in maize leaves. Ph. D. Thesis, Cornell University, Dissertation Abstract, No. 70,140.

Gifford, R.M., 1979, Growth and yield of CO_2 enriched wheat under water limited conditions. Aust. J. plant physiol., 6:367-368.

Gifford, R.M., Lambers, H. and Morison, J.I.L., 1985, Respiration of crop species under CO_2 enrichment. Physiol. plantarum, 63:351-356.

Gregory, P.G., 1926, The effect of climatic conditions on the growth of barley. Ann. Bot., 40: 1-26.

Gupta, R.D. and Tripathi, B.R., 1986, Effect of organic materials on the carbon dioxide evolution and nitrogen mineralization in some soils of north-west Himalayas. J. Indian Soc. Soil Sci., 34: 38-42.

Habeebullah, B., Manickam, T.S., Malhavel, P. and Chamy, A., 1983, Effect of planting dates on the productivity of sunflower. Madras agric. J., 70(6): 382-384.

Hardman, L.L. and Brun, W.A., 1971, Effect of atmospheric carbon dioxide enrichment at different developmental stages on growth and yield components of soybean. Crop Sci., 11:886-888.

Hardy, R.W.F and Havelka, U.D., 1973, Symbiotic N_2 fixation: Multifold enhancement by CO_2 enrichment of field grown soybean. Plant physiol., 49: (Supplement), 35.

Hardy, R.W.F. and Havelka, U.D., 1975, Photosynthate as a major factor limiting nitrogen fixation by field grown legumes with emphasis on soybean. p. 421- 439, (In) P.S. Nutman (ed.) symbiotic nitrogen fixation in plants. International Biology program series, vol. 7, Cambridge University Press, London.

Haugstad, M., Ulsaker, L.K., Ruppel, A. and Nilsen, S., 1983, The effect of triacontalnol on growth, Photosynthesis and photorespiration in Chlamydomonas reinhardtii and Anacystis nidulans, physiol. plant., 58: 451-456.

Havangi, G.V. and Mann, H.S., 1979, Effect of rotation and continuous application of manures and fertilizers on soil properties under dryland conditions. J. Indian Soc. Soil Sci., 18:45-50.

Havelka, V.D., Ackerson, R.C., Boyle, M.G. and Wittenback, V.A., 1984, CO_2 enrichment effect on soybean physiology. Crop Sci., 24(6): 1146-1150.

*Hayashi, K., 11972, Current development and relating problems of rice varieties with high yielding potential. IRC Newsl., 21:18-29.

Heindle, C.G. and Brun, W.A., 1983. Light and shade effects on abscission and C^{14}-photoassimilate partitioning among reproductive structures in soybean. Plant Phsiol., 73: 434-439.

Heij, G., Uffelen, J.A.M. and Van, 1984. Effects of CO_2 concentration on growth of glass house cucumber. Acta Horticulturae, 162:29-36.

Hicklenton, P.R. and Jolliffe, P.A., 1980. Alterations in the physiology of CO_2 exchange in tomato plants grown in CO_2-enriched atmospheres. Canadian J. Bot., 58::2181-2189.

Hiremath, S.M., 1979. Effect of row proportions and nitrogen application on the growth and yield of soybean and pigeonpea in intercropping system. Mysore J. Agric. Sci., 14: 637-638.

Hiscox, J.D. and Isrealstam, G.F., 1979. A method for the extraction of chlorophyll from leaf tissue without maceration. Canadian J. Bot., 57: 1332-1334.

Hrubec, T.C., Robinson, J.M. and Donaldson, R.P., 1985. Effects of CO_2 enrichment and carbohydrate content on the dark respiration of soybean. Plant Phsiol., 79: 694-689.

*Huber, S.C., Rogers, H. and Isreal, D.W., 1984, Effects of CO_2 enrichment on photosynthesis and photosynthate partitioning in soybean leaves. Physiologia plantarum, **62**(1): 95-100.

Imai, K., Coleman, D.F., Yagagisava, T., 1984, Elevated atmospheric partial pressure of carbon dioxide and drymatter production of cassava (Manihot esculenta, Crantz.). Japanese J. Crop Sci., **53**: 479-485.

Jackson, M.L., 1973, Soil Chemical Analysis. Printice Hall of India Pvt. Ltd., New Delhi.

Jadhav, B.B., Patil, B.A. and Patil, V.H., 1987, Effects of triacontanol on lablab bean and Indian mustard. Indian J. Agric. Sci., **57**(1): 56-58.

Johnston, T.J., Pendleton, J.W., Peters, D.B. and Hicks, D.R., 1969, Influence of supplmental light on apperent photosynthesis, yield and yield components of soybeans. Crop Sci., **9**: 7577-7581.

Johnston, H.W., Sanderson, J.B. and Macleod, J.A., 1978, Cropping mixtures of field peas and cereals on prince Edward Island. Can. J. Plant Sci., **58**: 421-426.

Jones, P., Allen, L.H. Jr. and Jones, J.W., 1985, Responses of soybean conopy photosynthesis and transpiration to whole day temperature changes in different CO_2 enrichment. Agron. J., 77(2): 242-249.

Jourdan, S.W. and Oplinger, E.S., 1983, Evaluation of triacontanol as a potential soybean growth regulant. Plant Growth Regulatar Bull., **11**(4): 6-8

Kapland, D.I. and Ester, G.O., 1985, Organic matter relationship to soil nutrient status and aluminium toxicity in Alfalfa. Agron. J., **77**: 735-741.

Katyal, J.C., 1977, Influence of organic amendment on chemical and cation exchange properties of some flooded soils. Soil Biol. Biochem., **9**: 259-260.

Katyal, J.C. and Sharma, D.D., 1979, Role of micronutrients in crop production. Fert. News, **24**:33-50.

Kimball, B.A. and Idso, S.B., 1983, Increasing atmospheric CO_2 effect on crop yield, water use and climate. Agric. Water management, 7(113): 55-72.

Kriedeman, P.E., Neales, T.F. and Ashton, D.H., 1964, Photosynthesis in relation to leaf orientation and light interception. Aust. J. Biol. Sci., 17: 591-600.

Krishnegowda, K.T., 1983, Agronomic investigations on the problem of poor seed set and yield in sunflower (Helianthus annus L.). Ph. D. Thesis, University of Agricultural Sciences, Bangalore, Karnataka.

Ku, S.B. and Edwards, G.E., 1977, Oxygen inhibition of photosynthesis II. Kenetic characteristics as affected by temperature. Plant physiol, 59: 991-999.

*Kuduk, C., 1978, Effect of organic amendment with straw upon the chemical, physical and biological properties of a light soil. Glebozhawize, 29(2): 67-78.

*Ladha, K.C., Lavti, D.L. and Somani, L.L., 1984, Effect of organic amendment addition and phosphorus fertilization on physical properties of a sandy loam soil and yield of soybean. Desert Studies, 9(1): 61-62.

*Lakhani, D.A., 1976, A crop physiological study of mixtures of sunflower and fodder radish. Ph. D. Thesis, Reading University, England.

Mahendra Singh, Orgen, W.L. and Widholm, J.M., 1974, Photosynthetic characterstics of several C_3 and C_4 plant species grown under different light intensities. Crop Sci., 14:563.

Marks, S. and Strain, B.R., 1989, Effects of drought and CO_2 enrichment on competition between two old field perennials. New phytol., 111: 181-186.

Mauney, J.R., Fry, K.E., and Gruinn, G., 1978, Relationship of photosynthetic rate to growth and fruiting of cotton, soybean, sorghum and sunflower. Crop Sci., 18(2):259-263.

McKeown, A.W., 1983, Increasing the effectiveness of 1-triacontanol applied to plants. Dissertation Abstr. Int., 43(12): 3797-3798.

Mohan Kumar, R., 1989, Intercropping systems with oilseeds on flat bed, raised bed and ridges and furrows in wet land. M. Sc. Thesis, University of Agricultural Sciences, Bangalore, Karnataka.

Morison, J.I.L. and Gifford, R.M., 1983, Stomatal sensitivity to Co_2 and humidity. A comparison of two C_3 and two C_4 grass species. Plant physiol. **71**(4): 789-796.

Morison, J.I.L. and Gifford, R.M., 1984, Plant growth and water use with limited water supply in high CO_2 concentrations. II plant dry weight, partitioning and water use efficiency. Aust. J. Plant physiol., **11**(5): 375-384.

Mortenson, L.M., 1934, Photosynthetic adaptation in CO_2 enriched air and the effect of intermittent CO_2 application on green house plants. Acta Horticulturae, **162**:153-158.

Murthy, K.S., Nayak, S.K. and Sahu, G., 1975, Effect of low light stress on rice crop. A synopsis on crop plant response to environmental stress. Golden Jubliee of Vivekanada Laboratory for Hill Agriculture, Almora.

Myers, R.L., Brun, W.A. and Bremner, M.L., 1987, Effect of raceme-e- localized supplemental light on soybean reproductive abscission. Crop Sci., **27**: 273-277.

Narwal, S.S. and Malik. D.S., 1985, Influence of intercropping on the yield and food value of rainfed sunflower and companion legumes. Expt. Agric., **21**:395-401.

*Nichiporovich, A.A., 1962, Properties of plant crops as an optical system. Soviet plant physiol, 8:428-435.

Norman, A.G. and Krampitze, L.O. 1946, The nitrogen nutrition of soybeans. Soil Sci. Soc. American Proc., 10: 191-196.

Parsa, A.A., Wallace, A. and Martin, J.P., 1979, Enhancement of iron availability by some organic materials. J. agric. Sci., 93:115-120.

Patil, V.A. and Bangal, D.B., 1985, Effect of triacontanol (miraculon) on yield of pigeonpea. Curr. res. rep., 1(2): 169-170.

Patterson, D.T. and Flint, E.P., 1980, Potential effects of global atmospheric CO_2 enrichment on the growth and competitiveness of C_3 and C_4 weed and crop plants. Weed Sci., 28(1):71-75.

Peet, M.M., Huber, S.C. and Patterson, D.T., 1986, Acclimation to high CO_2 in monoecious cucumbers II carbon exchange concentations. Plant physiol., 80(1): 63-67.

Pearce, R.B., Brown, R.H. and Blaser, R.E., 1967, Photosynthesis in plant communities as influenced by leaf angle. Crop Sci., 7: 321-324.

Poorter, M., Pot, S. and Lambers, H., 1988, The effect of an elevated atmospheric CO_2 concentation on growth photosynthesis and respiration of Plantago major. Physiol. Planta., 73:553-559.

Potvin, C. and Strain, B.R., 1985, Photosynthetic response to growth temperature and carbon dioxide enrichment in two species of C_4 grasses. Can. J. Bot., **63**: 483-487.

Power, J.F., Willis W.O., Gruvens, D.L., and Reichman, G.A., 1967, Effect of soil temperature, phosphorus and plant age on growth analysis in Barley. Agron J., **59**:231-234.

Prasad, B.N. and Singh, R.P., 1981, Accumulation and decline of available nutrients with long term use of fertilizers, manure and lime on multiple cropped lands. Indian J. Agric., Sci., **51**(2): 108-111.

Prasanna, K.T., 1987, Influence of triacontanol on carbon exchange rate, growth and productivity in a few crop plants. Ph. D. Thesis, University of Agricultural Sciences, Bangalore, Karnataka.

Prasanna Kumar, 1978, Studies on the decomposition of ragi straw in soil. M. Sc. Thesis, University of Agricultural Sciences, Bangalore, Karnataka.

Prihar, S.S., Verma, K.S. and Bhajan Singh, 1972, Direct and residul effect of rice husk on crop growth on a sandy loam soil. Indian J. agron., 17(4): 344-347.

Radke, J.K. and Hagstrom, R.T., 1976, Strip intercropping for wind portection. (In) Multiple cropping. American Society of Agronomy, Special publication, No. 27, 201-222.

Rajendraprasad and Reddy, M.R., 1973, Note on the efficient use of solar energy through a mixed culture of wheat genotypes. Indian J. agric. Sci., 43(5): 528-529.

Rao, B.C., 1985, Physiological effects of triacontanol on first crop rice at its late growth stages under high temperature conditions. Plant physiol. Commu., 1: 28-29.

Rao, M.R. and Shetty, S.V.R., 1976, Some biological aspects of intercropping systems on crop weed balance. Indian J. Weed Sci., 8(1): 32-43.

Rawson, H.M. and Hindmarsh, J.H., 1983, Light, leaf expansion and seed yield in sunflower. Aust. J. Plant physiol, **10**: 25-30.

Rawson, H.M., Dustone, R.L., Long, M.S. and Begg, J.E., 1984, Canopy development, light interception and seed production in sunflower as influenced by temperature and radiation. Aust. J. Plant physiol., **14**(4): 255-265.

Raymond, C., Jewell, W.J., Novak, J.D., William, W., Gerald, S. and Friedman, 1977, Land application of wastes. Vol. II, V.N.R. Company, New York, p. 53.

Reinertsen, S.A., Elliott, L.F., Cochran, U.L. and Campbell, G.S., 1984, Role of available carbon and nitrogen in determining the rate of wheat straw decomposition. Soil Biol. Biochem., **16**:459-464.

Richie, H.L. and Evans, H.J., 1962, Carbon dioxide requirement for growth of legume nodule bacteria. Soil Sci., **94**(6): 351-356.

Ries, S.K., Richman, T.L. and Wert, V.F., 1978, Growth and yield of crop treated with triacontanol. J. American Sco. Hort. Sci., **103**(3): 361-364.

Ries, S.K., Wert, V.F. and Biernbaum, J.A., 1983, Factors altering response of plants to triacontanol. J. American Soc. Hort. Sci., **108**(6): 917-922.

Ries, S.K. and Wert, V.F., 1977, Triacontanol: A new naturally occurring plant growth regulator. Sci., **195**:1339-1341.

Robinson, R.G., 1984, Sunflower for strip, row and relay intercropping. Agron. J., **76**:43-47.

Rogers, H.H., Binghan, G.E., Cure, J.D., Smith, J.M. and Surano, K.A., 1983, Response of selected plant species to elevated CO_2 in the field. J. Environ. Qual., **12**(4): 569-574.

Roquib, A., Kundu, A.L. and Chatterjee, B.N., 1973, Possibility of growing soybean in association with other crops. Indian J. Agric. Sci., **43**(8):792-794.

Sasek, T.W., Delucia, E.V. and Strain, B.R., 1985, Reversibility of photosynthetic inhibition in cotton after long term exposure to elevated CO_2 concentrations. Plant physiol., **78**:619-622.

Schou J.B, Jeffers, D.L. and Streeter, J.G., 1978, Effects of reflectors, black boards or shades applied at different stages of plant development on yield of soybeans. Crop Sci., **18**: 29-34.

*Shafshak, S.E., Shokr, E.S., El-Ahmer, B.A. and Madakour, M.A., 1986, Studies on soybean and sunflowers intercrop. 2. Interspecific competition. Annals Agric. Sci, Moshtohor, **24**(4): 1795-1806. (In) Field Crop Abst., **42**(11):1071.

Shanthamallaiah, N.R., Purushotham, S. and Krishnappa, K.M., 1978, Studies on intercropping with sunflower. Mysore J. agric. Sci., **12**: 41-44.

*Shelke, V.B., 1977, Studies on crop geometry in dryland intercrop systems. Ph.D Thesis, Marathwada Agricultural University. Parbhani, Maharastra.

Shibles, R.M. and Weber, C.R., 1965, Leaf area, solar radiation interception and drymatter production of soybeans. Crop Sci., **5**: 575-578.

Shivaramu, H.S., 1987, Studies on intercropping of maize genotypes with pigeonpea, their harvesting time and fertility levels, under dryland conditions. M. Sc. Thesis, University of Agricultural Sciences, Bangalore, India.

Shivashankar, K., 1976, Studies on molybdenum seed treatment, straw incorporation, CO_2 enrichment and fertilization on N fixation, growth and yield of soybeans. Ph. D Thesis, katholieke Universiteit, Leuven.

Shivashankar, K., 1986, Agrobiological limitations in the productivity of cereals and pulses in mixed stands and cropping sequences. 3rd Ann. Prog. Rep., Dept. of Sci and Tech. Project, Dept. of Agronomy, University of Agricultural Sciences, Bangalore.

Shivashankar, K. and Krishnaiah, H.M., 1986, Agrobiological limitations in the productivity of cereals and pulses in mixed stands and cropping sequences. 3rd Ann. Prog. Rep., Dept. of Sci. and Tech Project, Dept. of Agronomy, University of Agricultural Sciences, Bangalore.

Shivashankar, K., and Shantaram, M. V., 1980, Nodulation growth and yield of soybeans as affected by paddy straw application to soil. Z. Pflanzen. Bodenk, 143: 168-173.

Shivashankar, K. and Vlassak, K., 1978, Influence of straw and CO_2 on N_2 fixation and yield of field grown soybeans. Plant and Soil, **49**:259-266.

*Shivashankar, K., Vlassak, K. and Livens, J., 1975, Influence of application de paille de molybdene sorla crocisance at randemont culture de Soja. Revue de L Agriculture, **3**: 675-681.

Shivashankar, K., Vlassak, K. and Livens, J., 1976, A comprison of the effect of straw incorporation on yield of soybeans. J. agric. Sci. Camb., **87**: 181-185.

Siddoway, F.H. and Barnett, A.P., 1976, Water and wind erosion control aspects of multiple cropping. (IN) Multiple cropping. American society of Agronomy, Special Publication number 27, 317-335.

Singh, K.C. and Singh, R.P., 1977, Intercropping of annual grain legumes with sunflower. Indian J. agric. Sci., **47**(11): 563-567.

Sionit, N., Strain. B.R., Hellmers, H. and Kramer, P.J., 1981, Effects of atmospheric CO_2 concentration and water stress on water relations of wheat. Bot. Gaz., **142**: 191-196.

Sionit, N., Hellmers, H. and Strain, B.R., 1981, Growth response of wheat to atmospheric CO_2 enrichment under different levels of nutrition. Agron. Abst., 72nd annual meeting, American Society of Agronomy.

Sionit, N., Hellmers, H. and Strain, B.R., 1982, Interaction of atmospheric CO_2 enrichment and irradiance on plant growth. Agron. J., 74(4): 721-725.

Sionit, N. and Patterson, D.T., 1985, Responses of C_4 grasses to atmospheric CO_2 enrichment II Effect of water stress. Crop Sci., 25(3):533-537.

Sivakumar, M.V.K. and Virmani, S.M., 1980, Growth and resource use of maize, pigeonpa and maize/pigeonpea intercropping in an operational research watershed. Expt. Agric., 16(4): 377-386.

Slack, C.R. and Hatch, M.D., 1967, Comparative studies on the activity and carboxylases and other enzymes in relation to the new pathway of photosynthetic CO_2 fixation in tropical grasses. Biochem. J., 103:606-665.

Slack, G. and Hand, D.W., 1985, The effect of water and summer CO_2 enrichment on the growth and fruit yield of glass house cucumber. J. Hort. Sci., 60(4): 507-516.

Snedecor, G.W. and Cochran, W.G., 1967, Statistical methods. 6th Edition, Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi, India.

Soundararajan, D., 1978, Studies on intercropping in pigeonpea under rainfed conditions. M. Sc. (Agri.) Thesis, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu.

Spenser, W. and Bowes, G., 1986, Photosynthesis and growth of water hyacinth under CO_2 enrichment. Plant physiol., 82: 528-533.

Srivastava, V.C., Soven, C. and Shahani, M.N., 1980, Performance of soybean in association with companion crop. Tropical Grain legume Bulletin, 20:11-14.

Steffens, G.L. and Worley, J.F., 1980, Triacontanol: evaluation in several plant assays. (In) Proc. Plant growth regulator working group.

Streeter, J.G. and Jeffers, D.L., 1979, Distribution of total non-structural carbohydrates in soybean plants having increased reproductive load. Crop Sci., 19(5):729-734.

Subbiah, B.V. and Asija, G.L., 1956, A rapid procedure for the estimation of available nitrogen in soils. Curr. Sci., **25**: 259-260.

Subbiah Mudaliar, V.T., 1979, Principles of Agronomy. The Bangalore Printing and publishing Co. Ltd., Bangalore, P. 417-420.

Sudha, B.G., 1990, Effect of CO_2 enrichment on gas exchange characteristics and seedling growth rates in a few tree species. M. Sc. Thesis, University of Agricultural Sciences, Bangalore.

Suri, V.K. and Goswamy, K.P., 1982, Influence of soil released CO_2 on field grown corn. Van Vigyan. **20**(1/2):5-12.

Tarhalkar, P.P. and Rao, N.G.P., 1975, Changing concepts and practices of cropping systems. Indian Fmg., **25**(3): 3-7 & 15.

Tenney, F.G. and Waksman, S.A., 1930, Composition of natural organic materials and their decomposition in the soil:V. Decomposition of various chemical constituents in plant materials, under anaerobic conditions. Soil Sci., **30**(2):143-160.

Thortan, H.G., 1929, The effect of fresh straw on growth of certain legumes. J. Agric. Sci. Camb. 19:563-570.

Trenbath, B.R., 1974, Biomass productivity of mixtures. Adv. Agron., 28:177-210.

Umapathy, P.N., Krishnegowda, K.T., Venkataramu, M.N., 1980, Intercropping in sunflower with groundnut, blackgram and green gram. Curr. Res., 9(5): 78-80.

Valle, R., Mishoe, J.W., Jones, J.W. and Allen, L.H.Jr., 1985, Transpiration rate and water use efficiency of soybean leaves adopted to differerent CO_2 environments. Crop Sci., 25: 477-482.

Veeraraja Urs, Y.S., 1977, Effect of Incident solar radiation on photosynthetic rate and growth and yield attributes in rice genotype. M. Sc. Thesis, University of Agricultural Sciences, Bangalore, Karnataka.

Venugopal, N., 1988, Maize stover residue management and nitrogen levels on sole maize and paired row system of maize - soybean intercropping. Ph. D. Thesis, University of Agricultural Sciences, Bangalore.

Venugopal, N. and Shivashankar, K., 1989, Direct and cumulatative effect of maize stover residue incorporation in conjunction with nitrogen on maize. Indian J. Dryland Agric. Res. Dev., 4(2):107-116.

Watson, D.J., 1952, The physiological basis for variation in yield. Adv. Agron., 4:101-144.

Watson, D.J. and Witts, K.J., 1959, The net assimilation rates of wild and cultivated beets. Ann. Bot., 23:431-439.

Whitehead, D.C., 1970, The role of nitrogen in grasland productivity. Commonwealth Agricultural Bureau, Bull., 48:14-18.

Willey, R.W., 1979, Intercropping-Its importance and Research needs. Part 1. Competition and yield advantages. Field crop abst., 32(1):1-10.

Willey, R.W. and Rao, M.R., 1977, Pearlmillet in intercropping. Int. Pearlmillet Workshop, 28th August-3rd September, ICRISAT, Hyderabad. Andhra Pradesh.

Willey, R.W. and Rao, M.R., 1980, A competitive ratio for quantifying competition between intercrops. Expt. Agric., 16:117-126.

*Wollny, E., 1880, Untersuchungen uber den Kohlensauregehatt der Bodenluft. Landw. Vers. Sta., **25**:375-391.

Wong, S.C., 1979, Elevated atmospheric partial presence of CO_2 and plant growth. Oecologia, **44**: 68-74.

Yagnanarayana Aiyer, A.K., 1949, Mixed cropping in India. Indian J. Agric. Sci., **19**: 439-543.

Yoshida, S., 1972, Physiological aspects of grain yield. Ann. Res. Plant Physiol., **23**:437-464.

Zimmerman, R.H., Krizek, D.T., Bailey, W.A. and Klueter, H.H., 1970, Growth of crab apple seedling in controlled environments: Influence of seedling age and CO_2 content of the atmosphere. J. American Soc. Hort. Sci., **95**(3): 323-325.

----
* Original not seen.

APPENDICES

Appendix 1 Normal, actual and their deviation (DM) of monthly weather data that prevailed during the crop growth period from August of November 1988, 1989 and January to May 1989, 1990 at Main Research Station, Hebbal, Bangalore.

Months	Total rainfall (mm)							Maximum temperature (^0C)						
	Normal*	Actual						Normal	Actual					
		1988	DM	1989	DM	1990	DM		1988	DM	1989	DM	1990	DM
January	3.4	--	--	0.0	-3.4	8.2	4.8	27.1	--	--	26.9	-0.2	27.6	0.5
February	10.1	--	--	0.0	-10.1	0.0	-10.1	29.6	--	--	30.5	0.9	30.7	1.1
March	14.3	--	--	0.0	-14.3	2.6	-11.7	32.4	--	--	31.8	-0.6	32.7	0.3
April	30.0	--	--	0.5	-29.5	8.8	-21.2	34.0	--	--	34.1	0.1	34.9	0.9
May	105.1	--	--	47.4	-57.7	67.6	-37.5	33.4	--	--	33.9	0.5	31.7	-1.7
June	71.3	--	--	--	--	--	--	30.3	--	--	--	--	--	--
July	92.8	--	--	--	--	--	--	29.3	--	--	--	--	--	--
August	97.3	278.3	181.0	47.1	-50.2	--	--	28.1	28.1	0.0	28.3	0.2	--	--
September	199.4	442.4	243.0	215.6	16.2	--	--	28.4	28.1	-0.3	28.7	0.3	--	--
October	103.4	68.6	-34.8	199.6	96.2	--	--	28.1	28.0	-0.1	28.9	0.8	--	--
November	68.1	10.0	-58.1	9.0	-59.1	--	--	26.7	27.5	0.8	27.7	0.4	--	--
December	9.6	--	--	--	--	--	--	26.2	--	--	--	--	--	--
Total/Mean	804.8	799.3	331.1	519.2	-111.9	87.2	-75.2	29.5	27.9	0.10	30.0	0.27	31.5	0.22

* Mean over 15 years from 1973 to 1987; DM = Deviation from mean

Appendix 1 (Continued).

Months	Minimum temperature (^0C)							Mean relative humidity (%)						
		Actual							Actual					
	Normal*	1988	DM	1989	DM	1990	DM	Normal	1988	DM	1989	DM	1990	DM
January	13.9	--	--	13.9	0.0	12.4	-1.5	65.2	--	--	66.0	0.8	64.0	-1.2
February	15.5	--	--	12.3	-3.2	15.0	-0.5	60.5	--	--	53.0	-7.5	64.0	3.5
March	17.9	--	--	17.3	-0.6	20.1	2.2	53.1	--	--	58.5	5.4	59.0	5.9
April	20.9	--	--	21.3	0.3	22.3	1.4	56.7	--	--	59.5	2.8	58.0	1.3
May	21.2	--	--	21.4	0.2	21.3	0.1	61.7	--	--	65.5	3.8	72.0	10.3
June	19.9	--	--	--	--	--	--	71.3	--	--	--	--	--	--
July	19.4	--	--	--	--	--	--	74.5	--	--	--	--	--	--
August	19.3	20.1	0.8	19.4	0.1	--	--	76.2	82.2	5.8	81.0	4.8	--	--
September	19.2	19.5	0.3	19.5	0.3	--	--	75.7	81.0	5.3	79.0	3.3	--	--
October	18.6	17.7	-0.9	18.6	0.0	--	--	73.2	68.0	-5.2	75.0	1.8	--	--
November	16.6	15.5	-1.1	16.0	-0.6	--	--	71.9	67.5	-4.4	72.5	0.6	--	--
December	15.0	--	--	--	--	--	--	69.4	--	--	--	--	--	--
Total/Mean	18.1	18.2	-0.22	17.7	-0.38	18.2	0.34	67.4	74.6	0.37	67.8	1.7	63.4	3.96

* Mean over 15 years from 1973 to 1987; DM = Deviation from mean

Appendix 1 (Continued).

Months	Evaporation (mm day^{-1})							Sunshine hours day^{-1}						
		Actual							Actual					
	Normal*	1988	DM	1989	DM	1990	DM	Normal	1988	DM	1989	DM	1990	DM
January	4.8	--	--	4.3	-0.5	4.7	-0.1	9.4	--	--	8.2	-1.2	8.9	-0.5
February	5.8	--	--	6.2	0.4	6.1	0.3	9.9	--	--	10.7	0.8	10.2	0.3
March	7.4	--	--	6.9	-0.5	6.9	-0.2	9.8	--	--	10.0	-0.5	9.6	-0.2
April	7.4	--	--	7.3	-0.1	7.6	-0.2	9.5	--	--	9.0	-0.5	9.4	-0.1
May	6.9	--	--	7.3	0.4	6.0	-0.9	8.8	--	--	9.0	0.2	7.4	-1.4
June	5.5	--	--	--	--	--	--	6.1	--	--	--	--	--	--
July	4.9	--	--	--	--	--	--	5.2	--	--	--	--	--	--
August	4.7	3.4	-1.3	4.3	-0.4	--	--	5.3	4.2	-1.1	5.9	0.6	--	--
September	4.6	3.4	-1.2	4.3	-0.3	--	--	5.9	6.3	0.4	6.7	0.8	--	--
October	4.2	4.8	0.6	3.5	-0.7	--	--	6.9	8.5	1.6	6.0	-0.9	--	--
November	3.7	3.7	0.0	4.1	0.4	--	--	7.2	8.4	1.2	8.2	1.0	--	--
December	3.8	--	--	--	--	--	--	7.8	--	--	--	--	--	--
Total/Mean	5.3	3.8	-0.47	5.3	-0.14	6.2	-0.20	7.6	6.8	0.52	8.2	0.11	9.1	-0.38

* Mean over 15 years from 1973 to 1987; DM = Deviation from mean

Appendix 2 Daily rainfall during the cropping seasons of experiment I (1-8-1988 to 11-11-1988 in the first season and 10-8-1989 to 17-11-1989 in the second season) at Main Research Station Hebbal, Bangalore.

1988				1989			
Date	Rainfall (mm)	Date	Rainfall (mm)	Date	Rainfall (mm)	Date	Rainfall (mm)
August		October		August		November	
4	10.9	1	1.8	13	0.3	13	8.8
5	11.9	3	39.5	15	2.5		
9	2.0	4	15.7	17	0.2	14	0.2
10	5.8	6	1.1	18	1.7		
12	10.9	7	5.2	25	8.2	Total	9.0
14	4.6	11	5.3	26	4.4		
17	8.6			28	1.6	Grand	
18	7.4	Total	68.6	29	0.4	Total	525.3
20	17.6			31	5.5		
22	4.3	Grand					
24	16.8	Total	789.3	Total	47.7		
25	15.8						
26	14.7			September			
27	114.3						
28	27.3			5	36.6		
29	5.3			6	1.7		
				17	103.0		
Total	278.3			18	8.0		
				19	8.5		
September				21	2.0		
1	1.3			22	13.5		
2	3.1			23	21.8		
3	12.7			26	1.6		
6	16.3			27	4.8		
7	8.4			28	9.4		
8	8.6			29	4.7		
10	203.2						
11	10.7			Total	215.6		
12	149.7						
13	2.5			October			
15	5.6			1	72.0		
16	1.8			6	5.6		
17	2.8			7	41.6		
18	0.5			8	20.3		
19	9.1			9	50.6		
24	1.5			21	60.0		
25	3.4			30	3.5		
26	1.6						
				Total	253.6		
Total	442.4						

Apendix 3 Carbon, nitrogen and phosphorus contents, C/N and C/P ratios of maize stover and paddy straw used in the experiment.

	% org. C	% N	% P	C : N	C : P
Maize stover	42	0.51	0.10	82:1	420:1
Paddy straw	39	0.42	0.11	93:1	354:1

Appendix 4 Fertilizer dosage (kg/ha) of sunflower and soybean used in experiments under rainfed and irrigated conditions.

	Sunflower			Soybean		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Experiment I (rainfed)	37.5	50.0	37.5	25.0	60.0	25.0
Experiment II and III	62.5	75.0	62.5	30.0	80.0	37.5

Appendix 5 Bulk density (g/cc) of soil as influenced by organic and lime amendments at different days after incorporation.

Days after incorporation	Maize stover	Paddy straw	Lime
0	1.62	1.62	1.62
20	1.58	1.60	1.61
40	1.57	1.57	1.61
60	1.57	1.57	1.62
80	1.59	1.59	1.62
100	1.60	1.59	1.61

Appendix 6 Soil moisture regime of summer field experiment between two irrigation cycles as influenced by the incorporation of amendments a month before (mean of two replications).

Treatments	Per cent soil moisture	
	A day after irrigation	On the day just before irrigation
Control	15.8	7.1
Maize stover @ 4 t/ha	17.9	10.5
Paddy straw @ 4 t/ha	18.6	12.0
Lime @ 4 t/ha	16.0	8.3
	17.1	9.5