EVALUATION OF THE INTERACTIONS OF SOWING DATE, FERTILITY, SHOOT FLY PROTECTION LEVEL AND CULTIVAR IN *RABI* SORGHUM

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CERTIFICATE

Mr. Elasha Abdel Hay Elasha Abu Elbashir has satisfactorily prosecuted the course of research and that the thesis entitled **"EVALUATION OF THE INTERACTIONS OF SOWING DATE, FERTILITY, SHOOT FLY PROTECTION LEVEL AND CULTIVAR IN *RABI* SORGHUM"** submitted is the result of original research work and is of sufficiently high standard to warrant it's presentation to the examination. I also certify that the thesis or part thereof has not been previously submitted by him for a degree of any university.

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This is to certify that the thesis entitled "**Evaluation of the interactions of sowing date, fertility, shoot fly protection level and cultivar in *rabi* sorghum**" submitted in partial fulfillment of the requirements for the degree of '**Doctor of Philosophy in Agriculture**' of the Acharya N.G Ranga Agricultural University, Hyderabad, is a record of the bona fide research work carried out by **Mr. Elasha Abdel Hay Elasha Abu Elbashir** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee.

No part of the thesis has been submitted for any other degree or diploma. The published part has been fully acknowledged. All assistance and help received during the course of the investigations have been duly acknowledged by the author of the thesis.

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I declare that the thesis entitled **"EVALUATION OF THE INTERACTIONS OF SOWING DATE, FERTILITY, SHOOT FLY PROTECTION LEVEL AND CULTIVAR IN *RABI* SORGHUM"** submitted to Acharya N.G Ranga Agricultural University for the degree of **Doctor of Philosophy** is a bona fide record of work done by me during the period of research at ICRISAT Asia Center, ICRISAT, Patancheru. This thesis has not formed in whole or in part the basis for the award of any degree or diploma.

Date: 3 - 9 - 1997

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ABSTRACT

The effects of individual management practices (planting date, fertility, shoot fly control and cultivar) on *rabi* sorghum productivity was well documented; however, the interactions and the impact of three or more practices studied together is lacking. The present study was carried to measure the magnitude of the effects of individual management variables and to identify important interactions among them to be exploited for increased grain and fodder sorghum yields under *rabi* conditions.

The direct and interaction effects of planting date, fertility, shoot fly control and cultivar on growth and development ((leaf area index (LAI), total dry weight (TDW)), resource use ((radiation interception, water and nutrients)), crop use efficiency ((radiation use efficiency (RUE), water use efficiency (WUE) and nitrogen use efficiency (NUE)), grain, fodder, and biomass yields were investigated at ICRISAT Asia Center (IAC) during *rabi* 1995 and 1996 at deep and shallow Vertisol sites.

The results from both seasons in both sites showed that early planting of sorghum had smaller effects on growth and development parameters and resource use, but had significantly larger effects on crop use efficiency (RUE, WUE, NUE), % intact (%IN), and % affected and not recovered plants

;AN) compared to normal planting. There were more %IN plants with larger panicles and greater ain number per unit area and per panicle in early than normal planting. This resulted in significantly eater stover, grain, biomass yields and net benefit returns in early than normal planting.

Differences between the crop fertilized with FYM+20kgN (F2) and FYM+66kgN (F3) in owth and development parameters, resource use and use efficiency, yield and yield components and t benefit returns were small and accordingly, there was no point to fertilize *rabi* sorghum at doses yond F2. However, the crop under either F2 or F3 recorded significantly greater values for the oresaid attributes compared to that under FYM (F1) (10 t/ha every alternate year). There was 25- % greater LAI and 27-35% TDW in the crop fertilized with F2 and/or F3 than in the F1 crop. The diation use was 9-16% (interception), 7-15% (accumulation) greater and the use efficiency (RUE) flowering was 24% more in the crop under F2 and/or F3 than in the F1. In the study, there was 12 5% greater stover, 14 - 23% grain yield and 27 - 46% net benefit in the crop fertilized with either or F3 than with F1. Fertilization had greater effects on NUE (grain) and WUE (grain) than total JE and total WUE.

Shoot fly protection (PR) resulted in 24% and 22% greater LAI and TDW than non protected op (NP). Radiation and nitrogen use were 16% and 7% greater in PR than NP crop. Shoot fly ntrol had smaller effects on grain NUE and grain WUE, but significantly larger effects on total JE and total WUE of *rabi* sorghum. Among yield components, grain number per unit area was the gle yield attribute positively responded to protection as a result of more productive plants per unit ea in PR than NP crop. Grain number and weight per panicle decreased with shoot fly protection, obably due to a greater percentage of productive plants and therefore more competition resulting smaller panicles having fewer seed number and lesser weight than NP crop. By harvest, stover and omass yields of *rabi* sorghum were 27% and 20% greater in PR than NP crop, but their grain yield ere similar and accordingly NP and PR crop had similar net benefits.

The study showed that the interactions of sowing date x genotype, fertility x genotype and otection x genotype were important considerations for increased *rabi* sorghum productivity. This is true since the three genotypes had different response across management treatments in that ferences in LAI, TDW, resource use and use efficiency as well as yield and yield components in 35-1 and Swathi were small at early and normal planting, but these parameters were significantly hanced in IC 94004 when it was sown early. On the otherhand, yield and yield components in IC 004 and M35-1 significantly responded to increased fertility levels (to F3) than in Swathi (to F2). e response of genotypes to protection when normally sown was significantly greater in IC 94004 n either genotypes, indicating that when sowing was delayed to normal, protection was necessary IC 94004, but not necessarily so with M35-1 or Swathi.

The path coefficient analysis indicated that *rabi* sorghum grain yield was highly correlated to direct effect of total N uptake, total WUE, panicle number per unit area, grain number per panicle l harvest index. The direct effect of cumulative radiation accumulation and evapotranspiration on *ri* sorghum grain yield was not strong.

LIST OF ABBREVIATIONS

Abbreviation	Meaning
%AN	Per cent affected and not recovered.
%AR	Per cent affected and recovered.
%IN	Per cent intact.
%LI	Per cent radiation interception.
%SFDH	Per cent shoot fly dead heart.
CUM	Cumulative light.
DAE	Days after emergence.
DAS	Days after sowing.
DFL	Days to flowering.
F1	FYM (farm yard manure at 10 t/ha every alternate year).
F2	FYM + 20 kgN + 9 kgP /ha.
F3	FYM + 66 kgN + 9 kgP /ha.
FL	Flowering.
G1	M35-1.
G2	Swathi.
G3	IC 94004.
GRM	Grain mass.
GRNO	Grain number.
GRWT	Grain weight.
HAR	Harvest.
LAI	Leaf area index.
LFDW	Leaf dry weight.
LS	Lodge score.
Mj	Mega joule.
NP	Not protected against shoot fly.
NUE	Nitrogen use efficiency.
PLH	Plant height.
PNDW	Panicle dry weight.
PNLN	Panicle length.
PNNO	Panicle number.
PR	Protected against shoot fly.
RUE	Radiation use efficiency.
SD1	Early planting (third week of September).
SD2	Normal planting (third week of October).
STDW	Stem dry weight.
t/ha	Tonne per hectare.
TDW	Total dry weight.
WUE	Water use efficiency.

CHAPTER I

INTRODUCTION

Globally, sorghum (*Sorghum bicolor (L) Moench)* ranks fifth in importance among cereals and sixth among important energy sources for the world's population. The world area of sorghum currently is about 45 million ha and the production is about 64 million tonne (ICRISAT and FAO 1996). Developing countries alone account for 90% of the world's sorghum area and 70% of the total output. Although about 19% of the world area of sorghum is in the Americas, this region produces 48% of the total grain produced; with Argentina and Mexico growing 90% of the sorghum in the Americas (Neild 1984). Semi - arid tropical Asia and semi - arid tropical sub - Saharan Africa are the world's major sorghum growing regions producing 65% of total semi-arid tropical crop, representing respectively about 33% and 25% of the total area worldwide. About 38% of the sorghum produced in the world comes from Asia, India alone produces 98% of the sorghum in South Asia and grows about half of the semi - arid tropics (SAT).

In India, sorghum ranks third among cereals accounting for about 13% of the gross cropped area in the semi - arid parts of the country (Tarhalkar 1986) and is grown on about 12.6 million ha (ICRISAT and FAO 1996) with 6.5 million ha under *rabi* sorghum (Soman and Seetharama 1992). The state of Maharashtra is the largest producer, Andhra Pradesh and Karnataka each producing one - third of Maharashtra and the three states together contribute about 77% of all the sorghum produced in India (Sivakumar et al. 1984). The *rabi* sorghum (with good grain and fodder qualities) contributes about 30% of the annual sorghum production in India (Tandon and Kanwar 1984), with average farmer's yield low at 0.5 t/ha. Efforts to improve the current productivity levels of the *rabi* sorghum have had little success compared to the yield increase achieved in the rainy season sorghum crop. It is true that the *rabi* sorghum environment has a multi - faceted problems requiring a thorough consideration of the physical environment to target specific set of management practices and/or recommendation(s) for individual environments.

There is an ample information on the effects of individual management practices (planting dates, fertilization, shoot fly management and cultivar type) on the *rabi* sorghum productivity studied separately (Tandon and Kanwar 1984), but information on the interactions impact of three or more practices studied together is lacking. Today, in a highly advanced agriculture, large increase in yield potential will mostly come from the careful consideration of the whole management package(s) and the positive interaction effects on these components as well as their integration in better understanding of crop processes and genotype x environment interactions (Seetharama 1986). There is particular need to understand genotype x water x nitrogen interactions in different production environments (Kamoshita et al. 1996, Onken et al. 1992).

With the targeting of higher yield levels, there is an increasing stress imposed on the plant and on the various processes contributing to those yields. Accordingly in the future, the recognition of interactions will be vital to significant progress towards maximum yields in research and maximum profit yields for farmers (Tisdale et al. 1985). It is believed that targeting individual *rabi* sorghum physical environments with a package of management practices and/or recommendations and identifying their positive interactions would have a significant effect on *rabi* sorghum productivity. This was proved to be so in a high corn and soybean yields (USA) when the technology was put together in a way that allowed the components to interact positively. In fact, the breakthroughs in genetic engineering, rhizosphere technology, plant growth regulators and other related areas can only succeed if the technology is integrated in a manner that allows the main effects and their interactions to be expressed (Tisdale et al. 1985).

The present study is part of a long term large experiment specifically designed to evaluate the main and the interaction effects of management factors (planting dates, fertilization, shoot fly management and cultivar type) on *rabi* sorghum productivity. It is an attempt to identify and explore the impact of various agronomic practices and their interactions on *rabi* sorghum growth and yield, particularly with reference to the crop's ability to use inputs and resources (light, water and nutrients) for grain and stover production. Keeping these aspects in view, the present investigation was taken up with the following objectives:

1) To measure the magnitude of the effects of individual management and genetic variables (planting dates, fertilization, shoot fly management and cultivar) on grain and fodder yields of *rabi* sorghum.

2) To identify the important interactions among these management and genetic variables that might be exploited for increasing productivity under *rabi* conditions.

The study would help in formulating priorities in both the research on and the production of the crop towards achieving the best attainable yields under a given set of technology and resource environments.

CHAPTER 11

REVIEW OF LITERATURE

2.1 EFFECT OF MANAGEMENT FACTORS (PLANTING DATE, FERTILIZATION, PROTECTION AND CULTIVAR EFFECT) AND THEIR INTERACTION ON SORGHUM YIELD WITH SPECIAL REFERENCE TO *RABI* SORGHUM.

2.1.1 Effect of Management Factors on Sorghum Yield

The interaction effects of management practices on grain and stover yield in grain sorghum have not been well documented (Rosenthal et al. 1993). It was well known that the interactions of genotypes, planting dates, seeding rates, irrigation schedules and fertility management treatments form the basis towards better management strategies for efficient resource utilization and in the production of the sorghum crop (Krieg and Lascano (1990). This was demonstrated in the study by Rathore (1989) of improved versus traditional cultivation methods for sorghum production under dryland agriculture. This study showed an increase in grain yield of 192% due to hybrid use compared to the control. A grain yield of 5.2 t/ha was achieved with the concomitant use of fertilization (60:30:0), hybrid CSH - 5 and spacing of 45 x 15 cm as against 1.74 t/ha with traditional cultivation (local sorghum, 30 x 15 cm and FYM alone). This increase was 198% with improved practices over traditional practices. A target yield level of 6 t/ha with improved management practices was quantified achievable in *rabi* sorghum by Sonar et al. (1983).

With improved management practices, the grain and fodder yield response of *rabi* sorghum to N application was enhanced (Umrani and Patil 1983). The authors reported an increase in *rabi* sorghum yields by 27% (grain) and 16% (fodder) with traditional management and an increase of 85% (grain) and 43% (fodder) with improved management when 25 kg N/ha was applied. The positive effect of improved management practices in *rabi* sorghum yield and returns were also documented by Chouhan et al. (1994).

2.1.2 Effect of Planting Date on Grain Yield

The grain yield response of *rabi* sorghum to sowing date was in favour of early sowing (15 September to 15 October) rather than late sowing (beyond 1 November),(Chorge and Ramshe 1990). From their study they reported average *rabi* grain yield at 4.6 t/ha (early sowing) as against 3.4 t/ha (late sowing). They related the higher yields to higher N and P uptake. This was also observed by Dahatonde and Moghe (1991) who recorded a grain yield level of 1.22 t/ha (27 Sept. sowing) compared to 0.81 t/ha (27 oct. sowing) with no significant effect of sowing date on fodder yield or test weight.

The delaying of *rabi* sorghum sowing was reported to reduce the yield by 27 - 66% (shallow soil) and by 16 - 35% (medium deep soil) (Umrani et al. 1983b). Patil and Chavan (1989), in *rabi* sorghum, concluded that early sowing (mid Sept.) had significantly greater grain and fodder yields than late sowing (mid Oct.) on shallow (30 cm depth) and medium deep soils (60 cm depth) with genotypes yielding more on medium deep soil. The authors reported a yield decline of 797 to 270 kg/ha on the shallow soil and a decline of 2.36 to 1.53 t/ha on the deeper soil when sowing was delayed.

2.1.2.1 *Effect of planting date on dry matter, yield and radiation interception*

The limitation to grain yield in sorghum hybrids when sowing was delayed was attributed by

Herbert et al. (1986) to a shortened time to anthesis and to reduce tiller number; however Muchow (1986) noticed small effects of sowing date during both the dry and the wet seasons. He attributed the high grain yield in the dry season (double) compared to the wet season to greater radiation interception that was efficiently used in above - ground dry matter production as well as to the proportion of dry matter partioned to the grain. Muchow (1989a) associated the variation in biomass across sowing dates with differences in the amount of radiation intercepted than in the RUE in maize, sorghum, and pearl millet; while Muchow (1989c) related the higher yields from January sowing to increased efficiency of use of intercepted radiation (RUE), and to a longer grain filling period which was unaffected by nitrogen.

2.1.2.2 *Effect of planting date on radiation interception and radiation use efficiency*

Jadhav et al. (1993), on RUE in *rabi* sorghum and different sowing dates, revealed high RUE at 75 DAS on all the sowing dates. They found sowing at 4 October to achieve higher RUE than the other sowing dates (19 September, 19 October). They also showed a higher RUE for the first 45 days after sowing for 19 September sown crop compared to those sown during other dates. This was also true from study by Jayrao et al. (1987). Early sowing of *rabi* sorghum was also reported to increase RUE values (for M35-1 at 75 DAS) compared to late sowing (Jadhav et al. 1993).

2.1.3 Effect of Fertilizer (N and P) and Farm Yard Manure (FYM) on Sorghum Grain Yield)

Sonar et al. (1982), determining soil test crop response correlation studies in *rabi* sorghum, estimated about 2.07 and about 0.78 kg of N and P_2O_5 to be required to produce about 100 kg of sorghum grain and that about 34 and 37% of crop available N and P were contributed from the soil as compared to 44 and 39% N and P contributed through the added fertilizer nutrients. An estimate of sorghum growth yield of 0.73 - 0.74 g biomass per g glucose with adequate N (300 kg N/ha) and of 0.77 - 0.78 g with low N (50 kg N/ha) and a growth respiration consuming 19% of the carbon utilized in the growth process at high N level and about 17% at low N level were estimated by Lafitte and Loomis (1988b). Optimum grain and fodder yields of dryland grain sorghum were reported by Ogunlela (1988) at N rates of 60 - 120 kg N/ha and at P levels of 11 kg P/ha. Sharma (1986), studying rainfed sorghum, recorded the highest grain yield and an uptake of P from an application of 4 t/ha FYM in combination with 22 kg P/ha. He considered this combination as suitable for achieving optimum yields and P recovery from black soils. The recommended N fertilizer dose by Sharma (1990) was 75 - 100 kg N/ha.

In several studies (Muthuvel et al. 1988; Brar et al. 1990) *rabi* sorghum yield increased under increasing N rates (20,30,40 50 kg N/ha). Gaikwad et al. (1993) and Ogunlela (1991) observed significant increases in the grain and the fodder yields of *rabi* sorghum from an application of 25 kg N and higher total monetary returns with fertilization, stressing the importance of N fertilization in *rabi* sorghum. This was also documented in *rabi* sorghum by Shingte and Jadhav (1982) who related the 19% yield advantage to increased N and P uptake when the crop was fertilized (25 kg N/ha). An increasing sorghum yield (4.90 to 6.20 t/ha) with increasing nitrogen levels was also reported by Gorbet and Wright (1986). This was variously related to an increased enzymatic activity and accordingly to higher photosynthetic rate as N content was increased (Ogata et al. 1983); to a predominant influence of N on nutrient uptake (Badanur and Deshpande 1987); to a higher specific leaf nitrogen (amount of leaf N per unit leaf area) at higher nitrogen rates (Muchow 1988a); and to differences in the rates of accumulation and the extent of mobilization of pre - anthesis dry matter and nitrogen (Muchow 1988b).

The effects of increasing nitrogen or FYM levels and their combinations on yield and / or nutrient uptake were related to their effects on yield or yield parameters (Tej Singh et al. 1987; Bhosekar and Raikhelkar 1990; Patil and Zade 1991; Khistaria et al. 1991). Gono (1990), on the effect of N and P on sorghum yield, found that the N application (50 or 100 kg N/ha) significantly increased the grain yield (26 - 99%) as a result of increased grain number per head and / or to an increased grain weight. The interaction effects of applying nitrogen and green manures were shown by Goudreddy et al. (1989) to increase the number and weight of grains per panicle and 1000 grain weight. In their study, the increase in these yield parameters across nitrogen levels (0,60,120 kg N/ha) resulted in progressive yield levels of 4.42, 5.79 and 6.46 t/ha.

2.1.3.1 *Effect of nitrogen on biomass production, radiation interception and radiation use efficiency*

Muchow and Davis (1988) demonstrated that the differences in biomass accumulation due to variable nitrogen supply (0 - 42 g N/m^2) in sorghum and maize grown under irrigation were more associated with differences in radiation interception and with the efficiency the intercepted radiation was used to produce dry matter. In that study, RUE increased at higher rates of applied nitrogen, and declined during grain filling. Muchow and Sinclair (1994) showed an increase in RUE with increasing leaf nitrogen in maize to 1.7 g/Mj at 1.8 g N/m^2 leaf nitrogen and to 1.3 g/Mj at < 1.3 g N/m^2 leaf nitrogen in sorghum. The authors hypothesized that the leaf quantum efficiency per unit of incident radiation depends on leaf nitrogen such that at low leaf nitrogen, the quantum efficiency was decreased and the RUE consequently decreased to lesser than expected levels. Greenwood et al. (1990) found about 32% more dry matter to be produced per unit of intercepted radiation in C_4 than

C_3 crops, although the uptake of nitrogen per unit of intercepted radiation was approximately the same for the two types.

2.1.3.2 *Effect of nitrogen stress and water stress on leaf area and yield*

Seetharama et al. (1982) attributed the reduced leaf area development in post rainy sorghum under Vertisol to a combined effect of nitrogen stress and water stress resulting in lesser radiation interception and accordingly lower crop yields; with nitrogen stress reducing yields more than water stress. This is in agreement with Lafitte and Loomis (1988a), on the effect of limited nitrogen supply on the growth of grain sorghum, who demonstrated that; a low nitrogen supply resulted in leaves with lower N content, lower radiation conversion efficiency and in canopies that were not able to supply N to panicle growth; or to result in reduced leaf number and size with N stress (Verma et al. 1983) and to Cowie and Asher (1986) who attributed the yield reduction in the pre - floral initiation N stress to fewer florets initiated, while florets abortion appeared to be an important source of yield reduction when N stress occured post - initiation, but the grain yield reduction was greater when N stress was imposed pre - initiation. The non beneficial effect of N under water stress and it's helpful effects under mild stress were reported by Chopra and Kumari (1991).

2.1.4 Interaction Effect of Nitrogen and Irrigation

The combined effects of N application and irrigation had a significant and a positive effect on *rabi* and ratoon sorghum productivity (Patel et al. 1990). 150 kg N + 6 irrigations gave the highest yield (4.87 t/ha) compared to 1.78 t/ha with 50 kg N + 3 irrigations. Similar significant nitrogen x irrigation interactions in grain and fodder yields of *rabi* sorghum were observed by Khistaria et al. (1991).

2.1.5 Effect of Genotype

The significant genotype differences, with and without fertilization, and differences among genotypes in general and specific combining ability in *rabi* sorghum had indicated the existence of heterosis among different sorghum lines (Kulkarni and Shinde (1987). The use of improved genotypes increased the grain yield by 29% (Sahib et al. 1989) and by 40% (Rao et al. 1994). The importance of improved variety and crop management factors as tools to obtain higher nitrogen response (11.48 against 5.24 kg grain per kg N applied) has been shown by Daftardar et al. (1982).

2.1.6 Effect of Shoot fly

In *rabi* sorghum, shoot fly infestation levels ranging from 15.2 to 50.5% and higher dead heart levels at low P levels (27.5 kg P_2O_5) in comparison to higher P levels (55 kg P_2O_5/ha) were reported by Narkhede et al. (1982). In sorghum, for each 1% increased dead hearts, there was a reduction of 55.2 and 42.3 kg/ha in grain and fodder yields respectively (Mote 1983a), and about 0.63% yield loss; the infestation levels were at their maximum (up to 75% dead heart) in unprotected plots when the plants were two weeks old (Malee Chawanapong et al. 1988). They obtained a significant negative correlation between the per cent dead hearts and the grain and the fodder yields.

The severe incidence of shoot fly damage during late *rabi* sorghum sowing could be reduced by carbofuran seed treatment (Mote 1983b). In *rabi* sorghum, significantly fewer dead hearts in M35-1 and SPV-86 as compared to CSH-8R and an increase in grain yield up to 22% were obtained using 4% carbofuran treatment (Mote 1986), and the incidence of sorghum shoot fly (*Atherigona soccata Rondani*) was reduced by advancing dates of sowing (Kotikal and Panchbhavi 1991).

2.1.7 Effect of Initial Soil Water and Soil Depth

Lyon et al. (1995), on water - yield relations of several dryland crops, concluded that the soil water at sowing could account for about half of the total variability in grain yield of maize, sorghum and sunflower.

In *rabi* sorghum, there was an yield increase with increased soil depth of 125 and 183% (grain) and of 34 and 190% (fodder) on medium and deep soils respectively (Umrani et al. 1983a). Jadhav et al. (1994) also observed a low grain yield in shallow soil (30 cm depth) compared to deep soil (90 cm depth).

2.2 RADIATION USE, AND CONVERSION EFFICIENCY BY CROP CANOPIES

2.2.1 Radiation Use Efficiency Values in Legumes

In pigeonpea the reported values of RUE at early and late reproductive periods were 1.62 and 1.18 g/Mj (Thirathon et al. 1987); where as in chickpea RUE was 1.4 g/Mj of intercepted PAR (Leach and Beech 1988). This value was similar to that reported by Nanda and Saini (1990). In groundnut RUE was 0.74 g/Mj (Azam - Ali et al. 1989), 2.5 g/Mj in sunflower and 1.0 g/Mj in soybeans (Rinaldi et al. 1991).

2.2.2 Radiation Use and Radiation Use Efficiency Values in Cereals

The existence of considerable variation in radiation transmission coefficient (0.47 - 0.23 g/Mj) and in mean efficiency of energy conversion (1.0 - 2.7 g/Mj) in canopies of pearl millet cultivars was reported by Mohamed et al. (1988). Conversion efficiencies in pearl millet ranging from 1.87 g/Mj to 2.32 g/Mj at spacings ranging from 75.0 x 13.3 cm to 150.0 x 6.6 cm were reported by Jarwal and Singh (1990); where as the range in RUE in different lines of (*Pennisetum purpureum Schumach.*) was from 1.11 - 1.26 g/Mj of total solar radiation (Woodward et al. 1993). Begue et al. (1991) estimated a maximum pearl millet RUE of 2.9 g/Mj under optimum and a minimum of 1.8 g/Mj under drought conditions. Based on total radiation and dry matter accumulation values during crop growth, radiation utilization coefficients at 3.23 g/Mj for sorghum and 2.5 g/Mj for durum wheat were observed by Rinaldi et al. (1991). Rao et al. (1983a), estimated per cent net radiation used by sorghum in the PAR process at 2.6% and an average absorption of the net radiation at 53.13% of that received at the top of the fully developed canopy. In another study, utilization efficiencies of incident short wave radiation in two grain sorghum cultivars during the whole growth period varied from 1.96% - 2.18% and conversion efficiencies of absorbed PAR from 5.61% - 6.07% (Ojima and Invyama 1989). This was in contrast to Myers et al. (1986) who reported no differences between cultivars in their efficiency of conversion of intercepted radiation. Kiniry et al. (1989), in modelling RUE and biomass accumulation prior to grain filling under non - stressed environments, studied the consistency of RUE among and within sunflowers, rice, wheat, sorghum and maize. They reported mean values of above - ground dry biomass produced per unit of PAR at 2.2, 2.2, 2.8, 2.8 and 3.5 g/Mj PAR respectively. The authors concluded that the within - species variability in the values were not due to differences in temperature or incident solar radiation.

An estimate of 4.6% of the visible radiation and 21.4% of the near - infrared radiation incident on the crop canopy was reflected by a fully developed canopy of sorghum during the post - rainy season (Rao et al. 1983b). This was also observed by Shcherbak (1983) who found about 75% of the energy of PAR to be used by sorghum. Rana et al. (1990) concluded that (regardless of the level of agronomic inputs), the conversion of solar radiation into dry matter was greater in sorghum (1.82

kg/m^2) than in sunflowers (1.38 Kg/m^2); the maximum dry matter yield was at 300 Mj/m^2 (sorghum) and at 350 Mj/m^2 (sunflower) of cumulative intercepted net radiation. McGowan et al. (1991) reported a conversion coefficient by sorghum at 1.71 g/Mj.

2.2.3 Some Measures to be Considered while Estimating Radiation Use Efficiency

Marshall et al. (1992), in a greenhouse experiment, observed that the amount of solar radiation intercepted by crop stands increased as temperature was raised from 19 to 31 °C. This was in contrast to Kiniry et al. (1989) who concluded that the within species variability in RUE were not due to differences in temperature or incident solar radiation; but several measurements during the day are needed for reliable estimation of daily PAR for erectophile crops (e.g wheat) but not in planophile (e.g cotton) (Richardson and Wiegand 1989).

2.3 RADIATION INTERCEPTION, RADIATION USE EFFICIENCY, GROWTH, BIOMASS PRODUCTION AND YIELD IN SORGHUM AND OTHER CROPS

2.3.1 Use of Radiation Interception, Radiation Use Efficiency Data to Predict Biomass/Yield

Wanjura and Hatfield (1988) investigated the possibilities of estimating canopy vegetative parameters (plant height, ground cover, leaf area index, foliage density and leaf angle) from reflected radiation. They concluded that the same could be used as a valuable tool for assessing crop stress. The maximum production potential for sorghum, pearl millet, pigeonpea, chickpea and groundnut was reported to be easily estimated based on available radiation at an indicated location (Sinha 1989). This was in agreement to Monteith et al. (1989) who showed the possibility to predict growth and yield of sorghum and pearl millet (based among other factors) on the consistency of dry matter produced per unit of radiation intercepted (radiation use efficiency) during vegetative growth when water was not limiting. In connection with this, Muchow (1989a) investigated the productivity of maize, sorghum, and pearl millet based on the amount of incident radiation intercepted by the crops, its efficiency of use in dry matter production, and the proportion of dry matter partioned to the grain.

Hammer and Vanderlip (1989), on genotype x environment interaction in grain sorghum, suggested that total dry matter produced by a crop can be modelled as the product of intercepted PAR and RUE. They reported RUE values of 4.89 and 3.76 g/Mj for different grain sorghum hybrids at 25 °C. Terry (1990) also observed a direct relationship between dry matter production and the amount of radiation intercepted by the canopy in drought susceptible and drought tolerant sorghum genotypes.

2.3.2 Interrelationship between Radiation Interception, Radiation Use Efficiency and Growth Parameters in Cereals and Legumes

Monteith (1994) concluded that there was a valid relation between crop growth and intercepted radiation since crop growth depends on intercepted solar radiation. Gallagher and Biscoe (1978) on radiation absorption, growth and yield of cereals, stated that dry matter production was proportional to intercepted radiation during the vegetative growth of cereals.

In sorghum, McGowan et al. (1991) found a direct relation between the dry matter accumulation and the amount of radiation intercepted, which was largely independent of spacing between rows. Myers et al. (1986) concluded that, in the growth and development of grain sorghum in tropical and subtropical environments, the growth rate was related to the estimated intercepted radiation. In another study, sorghum crop growth rate was shown to be proportional to intercepted radiation and therefore to an exponential function (expolinear) of leaf area (Goudriaan and Monteith 1990).

A linear relationship between dry weight and intercepted photosynthetic active radiation during vegetative and reproductive phases was also reported in millet, but in groundnut such linearity was observed in the vegetative phase only (Marshall and Willey 1983).

In chickpea, a linear relationship between above - ground dry matter and intercepted radiation up to 119 days after sowing was also observed (Leach and Beech 1988). In another study, it was observed that the amount of energy fixed by chickpea was proportional to the energy intercepted, up to a green leaf area index of 5, and that the PAR absorbed was linearly related to crop growth rate (Nanda and Saini 1990). The authors reported RUE value of 1.45 g/Mj corresponding to a growth efficiency of 2.5% with negligible differences between cultivars.

In pigeonpea, Thirathon et al. (1987) showed that the accumulation of the photosynthetic output of the canopy (POC) from the top of the canopy and downwards was linearly related to PAR intercepted during early and later stages of growth, but the POC efficiency of PAR conversion to decrease with age. From study in pigeonpea and mungbean intercropping, it was concluded that the solar radiation interception was positively correlated with leaf area index (Legha and Dhingru 1991). Sivakumar and Virmani (1984) reported that the interception of photosynthetic photon flux density (PPFD) by canopies of maize, sorghum, pigeonpea and maize/pigeonpea intercrop was closely related to the leaf area index.

Balakrishnan and Natarajaratnan (1987) showed that yield was positively correlated to radiation interception, and radiation interception was negatively correlated to extinction coefficient (K). This was in contrast to Craufurd and Bidinger (1989) who showed strong correlation between grain number and intercepted radiation during floral initiation - flowering, but grain yield was weakly correlated to intercepted radiation.

Muchow (1989c) mentioned that the specific leaf nitrogen content was positively related to the average RUE from emergence - maturity, but not during grain filling. The reason was attributed to transfer to the grain of nitrogen assimilated before anthesis.

2.3.3 Radiation Use Efficiency and Yield

Inthapan and Fukai (1988) related the low grain yield of rice (680) compared to sorghum (1240 g/m^2) and maize (1060 g/m^2) despite the similarities in the harvest indices, to an inefficient conversion of solar radiation to dry matter in rice canopies. This was in agreement to Vanangamudi et al. (1990) who related the higher yields in hybrid grasses to their higher mean solar radiation interception and to their higher conversion efficiencies. Bishnoi (1983) observed a maximum photosynthetic active radiation absorptivity and conversion efficiency in the order of pearl millet > sorghum > maize under all moisture regimes, but both absorption and conversion decreased with increased moisture stress.

Sivakumar and Virmani (1984) observed that the maize/pigeonpea intercrop was most efficient in converting intercepted radiation to dry matter, followed by sole crops of maize, sorghum and pigeonpea.

2.3.4 Radiation Use Efficiency and Growth Stages

Ferraris and Foale (1986), in the comparative growth of sweet and forage sorghum, found similar production and efficiency of PAR use in the high and low tillering lines during pre - anthesis. Rachidi (1990) found no significant differences in the radiation use efficiency between sunflowers and sorghum during vegetative stage, but after flowering, sorghum had higher radiation use efficiency than sunflowers. This was in agreement with Muchow (1986), comparing sorghum hybrids, who found no differences in the amount of radiation intercepted or it's conversion efficiency between emergence and anthesis during wet and dry seasons, but that both interception and conversion were low at anthesis to maturity during the wet season and accordingly resulted in a low dry matter production and low grain yield.

Matthews et al. (1988), working on the physiological basis of yield difference in groundnut, found similar amounts of dry matter per unit of intercepted radiation (RUE) to be produced before pod filling, but that RUE for different groundnut genotypes at pod filling was different.

2.3.5 Radiation Use Efficiency and Water Stress

Muchow (1989b), comparing the productivity of maize, sorghum and pearl millet, found the decrease in biomass in response to water deficit to be more associated to a reduction in RUE than to a reduction in radiation interception. Mc Intyre et al. (1993), on radiation use and growth of pearl millet in a semi arid environment, stated that in irrigated crops, the RUE did not vary significantly (1.7 g/Mj), but was significantly reduced (0.8 g/Mj) in non irrigated crops when temperature was high (33 °C).

2.3.6 Radiation Use Efficiency and CO_2

Clifford et al. (1993), in groundnut, found the elevated CO_2 concentration (700 ppm) to increase RUE through increasing intercepted radiation by 30% (from 1.66 to 2.16 g/Mj) in irrigated, and by 94% (from 0.64 to 1.24 g/Mj) on a drying soil profile (weekly irrigated, no irrigation from 35 days after sowing). The authors concluded that the primary effects of elevated CO_2 on growth and yield of groundnut stands were mediated by an increase in the conversion coefficient for intercepted radiation and by the prolonged maintenance of higher leaf water potentials during increasing drought stress.

2.3.7 Radiation Use Efficiency and Saturation Vapor Pressure Deficit (SVPD)

Stockle and Kiniry (1990) concluded that the effects of SVPD should be considered when RUE is used to estimate biomass accumulation in sorghum and maize.

2.3.8 Radiation Use Efficiency, Site and Season

Muchow and Davis (1988) concluded that RUE may not be stable across environments and may vary with site and season for a given crop (Demetriades - Shah et al. 1992).

2.4 MOISTURE EXTRACTION, EVAPOTRANSPIRATION AND WATER USE EFFICIENCY

Onken et al. (1992) observed that soil fertility levels have smaller effects on crop evapotranspiration (ET), but resulted in proportional changes in evaporation (E) and transpiration (T); with increasing soil fertility levels increasing T and decreasing E. The authors suggested that genotype x nutrient interactions (which affect nutrient uptake and water use) be quantified to develop appropriate agronomic solutions for stability and sustainability of sorghum production in the Sahelian Africa. Rizzo et al. (1990) observed a greater ET with low inputs (489 mm) than with high inputs (352 mm), but WUE values were rather greater at high levels of inputs. This was in contrast to Dhonde et al. (1986) who concluded that WUE of *rabi* sorghum declines with increasing frequency of irrigation.

Khauna - Chopra and Kumari (1995) reported WUE values of 2.5 kg/ha per mm (no irrigation) and 9.7 kg/ha per mm (one irrigation, 40 kg N). Others (Patel et al. 1987; Prasad and Sam 1990; and Osmanzai 1990) observed WUE values for *rabi* sorghum of 11.67, 9.92 and 11.4 kg/ha per mm respectively. In sorghum, grain water use efficiency was reported to range from 1.7 to 22.0 t/ha per m and total water use efficiency from 36.3 to 68.0 t/ha per m (Kanemasu et al. 1984).

The interaction of water use and N levels were investigated by Reddy and Reddy (1988). The authors found slight increase in the consumptive use of water (ET) with increasing N rates (0 - 140 kg N/ha); maximum WUE was obtained at 80 kg N/ha and at irrigation frequency at 20 and 40% available soil moisture depletion (ASMD); beyond these levels, WUE had decreased.

A consumptive water use of 342 mm with irrigation and 291 mm with straw mulch and corresponding WUE values of 10.28 and 10.98 kg/ha per mm in *rabi* sorghum were reported by Ghugare and Khade (1989). A mean dry matter water use efficiency value of 17.5 t/ha per m for C_3 crops (Pino, soybean and sunflower) and 33.3 t/ha per m for C_4 crops (Corn, grain sorghum and pearl millet), with sunflower depleting more water from deeper soil depths (0.99 - 1.60 m) than the remaining five crops was shown by Hattendorf et al. (1988). Ghugare et al. (1982), in *rabi* sorghum, reported a moisture depletion of 197 mm (at 165 kg P2O5) and WUE to increase from 23.6% (no P) to 46.6% with P application. The water requirement of *kharif* and *rabi* sorghum (based on potential evapotranspiration values and climatic data 1946 - 1985) was reported to range from 587 mm (*kharif* sorghum) to 458 mm (*rabi* sorghum) (Ghadekar and Patil 1990).

The water extraction pattern (% of total water extraction by soil depth) of *rabi* crops (wheat, sorghum, safflower, maize and bengal gram) from different soil depths was estimated by Radder et al. (1991) to range from 39.1 - 43.5% (0-15 cm); 27.1 - 28.2% (15-30 cm); 18.0 - 20.5% (30-60 cm); and 11.6 - 13.0% (60-90 cm). As is evident, there was a decrease in %moisture extraction with increasing soil depth in all the crops under that study. The differences in the water extraction of different crops were attributed by Pandey et al. (1987) to differences in their rooting depth and to their ability to extract soil water within the rooting zone.

2.5 NUTRIENT UPTAKE, NITROGEN USE EFFICIENCY AND THEIR INTERACTION

N, P, K and S uptake increased with increased levels of N, sulphur and moisture (Badanur and Deshpande 1987). N use efficiency (kg N per kg grain/ha) was estimated to range from 9.4 to 12.4 when N was applied at a dose of 50 to 150 kg/ha (Thakre et al. 1989). Alagarswamy and Bidinger (1987) studying genotypic variation in biomass production and nitrogen use efficiency of pearl millet, showed that genotypes having similar nitrogen uptake from the soil could differ significantly in their biomass production and accordingly in their nitrogen use efficiency. Godwin et al. (1989), simulating N dynamics in cropping systems of the semi - arid tropics, concluded from their 25 year simulation studies that the availability of soil moisture in the drier environments and N leaching in the wetter areas were the key factors to low N efficiency. Youngquist and Maranville (1988) revealed that nitrogen uptake efficiency contributed more to biomass production while N utilization efficiency was more important for grain production and that the uptake and utilization efficiencies were similar at high and low N soils, though the importance of the utilization efficiency was greater in low N soils.

2.6 YIELD CORRELATION, ITS LIMITATION, STABILITY AND IMPROVEMENT

In a study by Unger (1991) on dryland sorghum, seeds /m^2 and stover weight were considered variables significantly related to grain yield. Cheralu and Rao (1989), on genetic variability and character association for yield and yield components in *rabi* sorghum, observed a high and significant positive correlation between grain yield and ear weight, number of primary and secondary panicle branches and total dry matter. This was also reported by Shahane and Borikar (1982) and by Kulkarni et al. (1983). Jadhav et al. (1994) observed a positive correlation between grain yield and growing degree days measured at panicle emergence, flowering and at physiological maturity. A positive and significant correlation between grain yield and plant N content measured at 50 - 90 DAS (summer crop) and 40 - 80 DAS (*kharif* crop) was observed by Korikanthimath and Palaniappan (1987). Joshi and Jamadagni (1990), on relation of physiological characters to grain yield in *rabi* sorghum, pointed that a high value of photosynthetic structures (LAI and LA duration) during the grain filling stage and a high rate of dry matter accumulation and HI were responsible for high yields in cultivars CSH 8R (690 g/m^2) and SPV 8R (672 g/m^2) compared to M35-1 (396 g/m^2). Higher grain number per panicle, 1000 grain mass, better panicle and grain setting percentages and a high leaf area duration were responsible for highest yield in *rabi* sorghum (Pinjari and Shinde 1995). On different *rabi* sorghum genotypes, many authors (Anonymous 1982; Youngquist et al. 1990) associated high grain yield with high HI (39%) and low yield with low HI (19%). Blum (1988), comparing the productivity and drought resistance of genetically improved and native landrace sorghum, reported a 3 (dryland) to 4 (irrigated) fold range in yield due to 3 to 4 fold range in the HI through breeding. The reduction in yield from irrigated to dryland conditions could not be altered by breeding; but landraces showed a greater variability to drought susceptibility (measured by reduction in yield from irrigated to dryland conditions). Muhammad Rafiq and Muhammad Afzal (1988), on the contribution of some sorghum production factors to yield, concluded that fertilization had the greatest effect on sorghum yield, followed by insecticide, improved cultivars and herbicide; with N fertilizer advancing anthesis, increasing plant height and number of panicles per plant.

It was concluded by Saeed (1992) from 54 grain sorghum genotypes in 48 environments that stability for seed number component is more important than stability for seed weight in contributing to yield stability in genotypes of all maturity groups. Youngquist et al. (1990) also attributed the stability in low rainfall environments to an ability to maintain head number and seed number per head.

Murty (1994) attributed the slow improvement in *rabi* sorghum types (compared to the rainy season types) despite the intensive conventional breeding efforts over the past 25 years, to differences between cultivars in their genotype x environment interactions rather than genetic differences per se. The factors influencing productivity of *rabi* sorghum were investigated by Seetharama (1986) and Seetharama et al. (1990). The former attributed the differences in *rabi* sorghum productivity among cultivars to differences in their harvest index rather than differences in biomass productivity. The latter attributed the low productivity of *rabi* sorghum in India to environmental factors including climatic; edaphic; insect and disease problems and management factors.

2.7 RETURNS FROM SORGHUM IN RELATION TO OTHER CROPS, FACTORS AFFECTING RETURNS

Nikam et al. (1988) concluded that safflower and sorghum had the highest returns under the dryland conditions in the Kandesh region of Maharashtra. The higher net profit in SPV 86 and M35-1 than CSH 8R (though the yield was greater in the latter) was attributed by Lomte et al. (1988) to a better quality and a higher fodder yield in both cultivars. The reported returns from *rabi* sorghum cultivation were in the range of US $ 280/ha (Patel et al. 1987); Rs 1379/ha at the research farm and Rs 781 at the farmers' fields (Rao et al. 1983c).

CHAPTER III

MATERIALS AND METHODS

3.1 EXPERIMENTAL SITE

3.1.1 Location

The experiment was conducted at ICRISAT Asia Center (IAC) (India) during *rabi* season 1995 and 96. The location is situated at an altitude of 545 m above sea level, 18 °N, 78 °E near Patancheru village, state of Andhra Pradesh (ICRISAT, 1985).

3.1.2 Climate

The climate at IAC is a typical semi - arid tropical environment characterized by a short period of rainfall (3 - 4 months) and a prolonged dry period (8 - 9 months). Three distinct seasons characterize this environment:

1) *Kharif* or monsoon season, which usually starts in mid June and extends into early October and during which > 80% of the total rainfall (760 mm) is received. In this season rainfed crops are raised (ICRISAT, 1989).

2) *Rabi* or postrainy season extending from mid October to February. This season is relatively dry, cool and with short days. Cropping is done on stored soil moisture. The experiment under investigation was raised during this season.

3) Summer, the hottest season which starts in March and continues until the rains commence in June. During summer crops are raised under irrigation.

During the conduct of the experiment, ranifall, temperature and solar radiation data were shown in Fig 1 and detailed weather data for the same period and parameters were shown in Appendix 1 and 2.

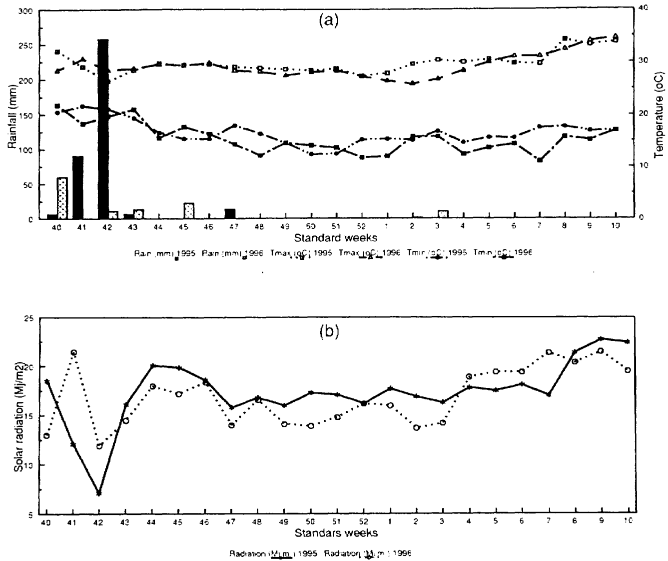


Fig.1. Rainfall (mm), temperature (oC) (a) and solar radiation (Mj/m2) (b) during rabi 1995 and 96 seasons.

3.1.3 Soil

Two sites to represent two contrasting moisture environments were chosen. The first is deep Vertisol (>150 cm soil depth) and the second is shallow Inceptisol (< 50 cm soil depth). The subsoil profile of the vertic Inceptisol site is dominated by calcarious material which is not fully weathered. The soil physical and chemical analysis of both sites at *rabi* 1995 and 1996 were shown in Tables 1 and 2.

3.2 EXPERIMENTAL DETAILS

The experiment in the deep Vertisol site was laid out in a three - level split plot design involving (in order) planting date, fertility, insect protection level and cultivar type (Fig 2). The experiment in the vertic Inceptisol site was a two level split plot design involving sowing dates, fertility and genotypes (Fig 3).

The main effects in both experiments were contrasting levels of management factors known to affect productivity. These were:

(1) early (SD1) and normal (SD2) planting dates (early sowing was carried at 22/9 at the vertic Inceptisol and at 25/9 in the deep Vertisol site during both 1995 and 1996, while the normal planting in the vertic Inceptisol was at 27/10 (during 1995), 17/10 (during 1996) and at 31/10 (during 1995 and 1996) in the deep Vertisol site.

(2) fertilization level. FYM (F1), FYM + 20 kg N + 9 kg P as basal dressing (F2) and FYM + 20 kg N and 9 kg P as basal dressing + 46 kg N as topdressing (F3). There were three levels of fertilities in the deep Vertisol site (F1, F2, F3) and two levels at the vertic Inceptisol site (F1 and F2).

(3) Non (NP) and full protection (PR) against the shoot fly. These treatments were used only in the deep Vertisol site, the vertic Inceptisol site was fully protected.

4) Genotypes. Three genotypes to represent:

a) A traditional *rabi* landrace (M35-1); b an improved *rabi variety* (swathi) and c) *rabi* hybrid (ICSH 94004), it's pedigree is (ICSA 91003 X M35-1-36).

3.2.1 Fertilizer Application

FYM (F1) was manually and evenly broadcasted at a rate of 10 t/ha every alternate year. The first dose was applied on 1994 *rabi* season and the second dose on 1996. The FYM had 0.70% N and 0.26% P (average of four samples). DAP (28:28:0) at the rate of 70 kg/ha was basally applied. Later (25 days after emergence, DAE), urea (46% N) was topdressed at a rate of 46 kg/ha. Nitrogen and phosphorous were applied (basal or topdressing) by animal drawn fertilizer driller.

3.2.2 Planting and Shoot fly control

Sowing of both experiments was carried out by a tractor mounted three row precision planter on flat land at a row spacing of 50 cm. During sowing carbofuran granules 3 G at a rate of 40 kg/ha were applied about 5 cm from the seed row to the fully protected treatments through an insecticide unit attached to the driller. After crop emergence, the fully protected treatments were manually sprayed with cypermethrin (at 0.50 li/ha) using a motorized backpack sprayer when the crop was at 5 DAE at 5 - 7 day intervals and continued upto 25 DAE. Three sprayings were given in *rabi* 1995 and four in 1996 at each site. The plants were thinned to a spacing of 10 - 15 cm apart at 15 DAE. Both sites were periodically weeded (whenever was necessary) during both seasons and kept at optimum level.

Table 1. Physical and chemical properties in the deep Vertisol site (*rabi* 1995 and 1996).

	Deep Vertisol site (*rabi* 1995)								Deep Vertisol site (*rabi* 1996)						
Depth (cm)	Bulk Density (g/cc)	PH	EC (ds/m)	Avail.P (ppm)	NH4N (ppm)	NO3N (ppm)	Total N (ppm)	OC (%)	PH	EC (ds/m)	Avail.P (ppm)	NH4N (ppm)	NO3N (ppm)	Total N (ppm)	OC (%)
0-15	1.56	8.32	0.26	0.49	4	3	356	0.49	8.36	0.17	8.6	8	4.0	611	2.12
15-30	1.54	8.45	0.19	0.41	7	2	420	0.41	8.34	0.17	2.0	6	3.0	419	0.46
30-45	1.53	8.50	0.19	0.36	6	2	327	0.36	8.38	0.16	1.3	5	3.0	353	0.37
45-60	1.49	8.48	0.19	0.35	7	4	341	0.35	8.38	0.21	1.0	4	6.0	358	0.34
60-75	1.46	8.60	0.20	0.33	5	1	309	0.33	8.28	0.23	0.9	5	5.0	327	0.32
75-90	1.44	8.55	0.24	0.33	5	1	298	0.33	8.37	0.22	0.8	5	3.0	297	0.28
90-105	1.39	8.75	0.22	0.37	5	1	270	0.37	8.37	0.25	0.7	4	2.0	299	0.47
105-120	1.48	8.87	0.25	0.29	4	2	258	0.29	8.38	0.26	0.4	5	1.0	277	0.34
120-135	1.45	8.90	0.26	0.20	5	2	237	0.20	8.40	0.27	0.4	4	0.5	242	0.18
135-150	1.54	8.95	0.29	0.13	6	2	210	0.13	8.38	0.30	0.4	4	0.5	238	0.23

Table 2. Physical and chemical properties in the vertic Inceptisol site (*rabi* 1995 and 1996).

	Vertic Inceptisol site (*rabi* 1995)								Vertic Inceptisol site (*Rabi* 1996)						
Depth (cm)	Bulk density (g/cc)	PH	EC (ds/m)	Avail.P (ppm)	NH4N (ppm)	NO3N (ppm)	Total N (ppm)	OC (%)	PH	EC (ds/m)	Avail.P (ppm)	NH4N (ppm)	NO3N (ppm)	Total N (ppm)	OC (%)
0-15	1.55	8.30	0.13	1.0	3.0	4	310	0.46	8.30	0.20	6.4	11	5	753	1.00
15-30	1.56	8.32	0.13	1.0	1.0	4	392	0.46	8.29	0.20	3.4	9	6	706	0.94
30-45	1.66	8.50	0.13	0.8	1.0	4	400	0.37	8.32	0.21	3.0	7	4	440	0.65
45-60	1.70	8.50	0.15	0.8	1.0	4	351	0.34	8.35	0.20	2.2	5	4	350	0.55
60-75	1.60	8.65	0.14	0.7	0.5	4	357	0.34	8.46	0.18	1.3	3	4	311	0.27
75-90	1.64	8.70	0.14	0.6	1.0	3	288	0.25	8.43	0.20	1.3	3	4	247	0.21
90-105	1.60	8.90	0.17	0.7	0.5	3	234	0.34	8.52	0.20	1.3	4	4	217	0.21
105-120	1.64	8.90	0.17	0.9	2.0	3	182	0.43	8.42	0.20	2.0	4	4	214	0.30
120-135	1.59	8.92	0.19	0.7	0.5	3	210	0.33	8.51	0.17	1.5	2	3	139	0.21
135-150	1.58	8.95	0.18	2.4	0.5	2	106	0.48	8.53	0.18	2.2	3	3	98	0.12

3.2.3 Experimental Design and Layout

The treatments were arranged in a split split split in the Vertisol site and split split plot designs in the Inceptisol site, with three replications in each site (Figs 2 and 3). The gross plot size in both sites was 9 m length, six rows width, with a row spacing of 50 cm between rows (27 m^2). Half of the plot area (6 rows x 4.5 m) was used for sampling purposes (sampling plots), while the other half for moisture, radiation and yield data (yield plots).

3.2.4 Summary of Observations and Measurements

The observations collected in the two sites during both seasons were:

1) Crop sampling. Three samples were taken to monitor the changes in total plant dry weights and leaf area. Total dry weight was the sum of dry weights of green leaves, stems during early stages (30 and 50 DAE) and the dry weights of green and dry leaves, stems, and panicles during flowering stage (FL sample). These were also used to calculate the radiation use efficiency at the corresponding sampling intervals.

2) radiation interception. Measured on a weekly basis using Accu PAR Ceptometer (minimum of three observations above and three below) in a designated position in all the plots of the three cultivars.

3) Water use (M35-1 only). Monitored by a neutron probe (one access tube per each M35-1 plot) on a fortnightly interval at 15 cm soil depth intervals upto a depth of 150 cm.

4) Nutrient analysis. Total N and total P uptakes at flowering (FL) and harvest (HAR) time were determined; at FL, the analysis was carried out in the green leaves, stems and in the panicles separately. However; at HAR time, it was carried out in the stover (stems and leaves combined together) and on the grain. Both total N and total P uptakes during either season were estimated from the growth analysis samples at FL and from the HAR sample.

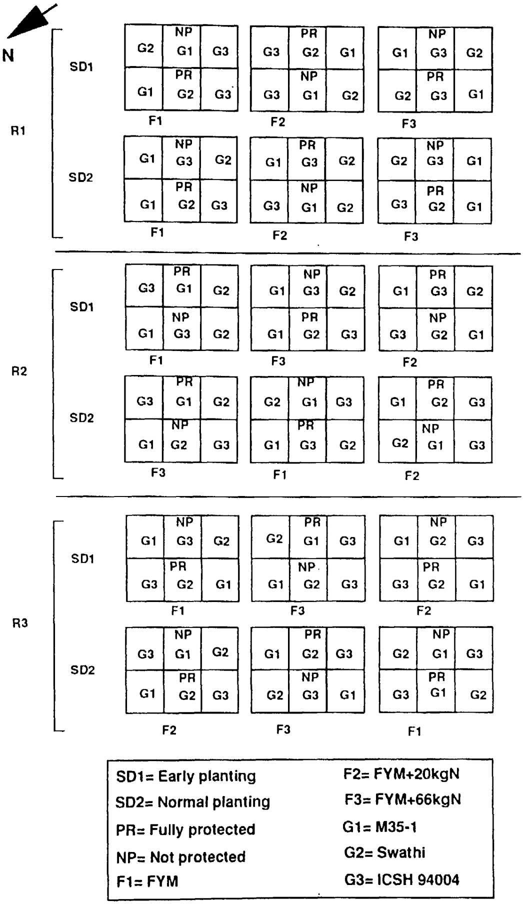


Fig.2. Field layout in the deep Vertisol site (rabi 1995 and 1996).

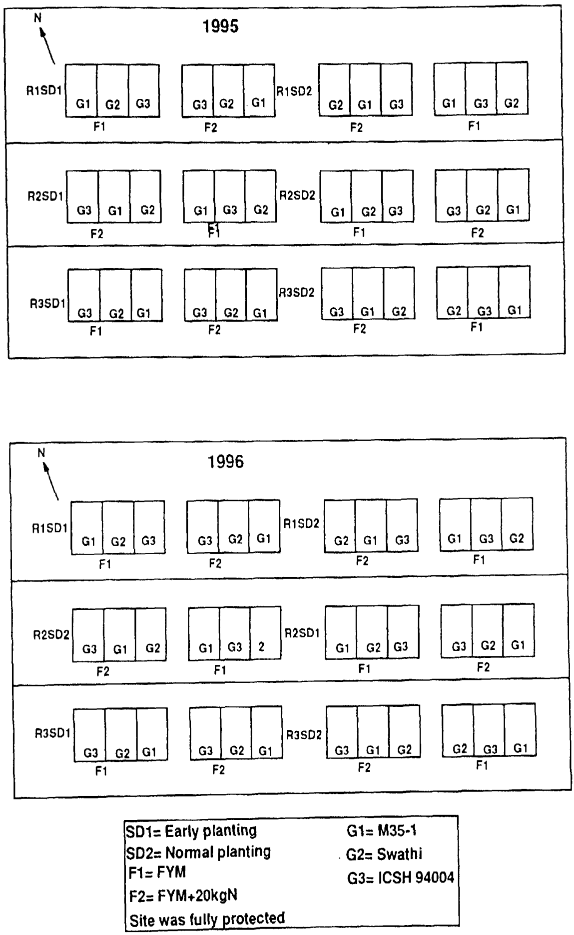


Fig.3. Field layout in the vertic Inceptisol site (rabi 1995 and 1996).

5) Insect damage. Counts were recorded for shoot fly dead heart damage at 21 and 30 DAE. After FL, a second count was taken to determine per cent intact (%IN), per cent insect affected but recovered (%AR) and per cent affected and non recovered (%AN) plants. The IN plants were those which were not affected by the shoot fly. Those which were affected but were able to recover through the production of one or more tillers that bore panicles at HAR time constituted the AR plants. The sum of the IN and AR plants was an estimate to the productive plants. The AN plants were unable to recover from infestation due to repeated shoot fly dead heart damage on the tillers and as a consequence did not bear any panicles.

6) Lodging score. Carried out by eye observation at harvest during both seasons in each site. Scale of 1 to 5 was used; 1 stands for standing crop (zero lodging), 2 for 25%, 3 for 50%, 4 for 75% and 5 for 100% lodging.

7) Flowering dates (FLD). Recorded in the four central rows in the yield plots when 50% of the plants were in the bloom stage.

8) Plant height (cm) and panicle length (cm). Measured before harvest (by scale) in each site during each season.

9) Stover, grain, biomass yields. Carried out in the yield plots in an area of 6 m^2 (4 central rows x 50 cm between rows x 3 m length).

3.3 PLANT GROWTH ANALYSIS

Three destructive samples; at growing point differentiation (about 30 DAE); flag leaf stage (about 50 DAE); FL (about 63 - 70 DAE) were undertaken in both experiments.

3.3.1 Sampling Procedure

In both experiments three destructive samples were taken from a length of 50 cm of four central rows (1 m^2) from the sampling area of the plots. Samples were immediately brought to the laboratory, separated into leaves, stems and/or panicles. Total leaf fresh weight (TLFW) from each plot was recorded. A subsample on fresh weight basis of leaves (SSLFW) of approximately 30% of the TLFW was taken. On this, subsample leaf area (SSLA) and subsample leaf dry weights (SSLFDW) were recorded for all treatments (108 in the deep Vertisol site and 36 in the shallow Inceptisol site). Stem and/or panicle dry weights were measured on the whole sample for each plot. Drying was done on oven with temperature adjusted at 75 °C till constant weight was achieved. The following parameters were recorded for each sample at each site during both seasons.

1) Leaf area (cm^2). Leaf area was measured on the green leaves by a LI - COR LI 300 leaf area meter.

2) Leaf dry weight (g).

3) Stem dry weight (g).

4) Panicle dry weight (g).

5) Total dry weight (g).

The sum of green leaves, stems, and / or panicle dry weight at each sampling time gave the total dry weight of that sample.

3.4 PER CENT RADIATION INTERCEPTION (%LI) AND RADIATION USE EFFICIENCY (RUE)

The radiation interception measurements (recorded at 7 day intervals) started at 16 DAE and continued upto 81 DAE during 1995, and at 18 DAE upto 84 DAE during 96). Photosynthetically active radiation (PAR) is generally considered to be the radiation in the 400 to 700 nanometer waveband. It represents the portion of the spectrum which plants use for photosynthesis. irradiances vary from full sun to almost zero over the space of a few centimeters and reliable measurements of PAR require many samples at many locations under the canopy.

3.4.1 Average and Intercepted PAR

Monteith et al. (1989) observed that the dry matter production of a plant canopy is directly related to the amount of photosynthetically useful radiation intercepted by the canopy. The dry matter production is modelled as the product of three terms:

DM = f x RUE

where DM is the amount of dry matter produced, (f) is the fractional radiation intercepted, and RUE is a conversion efficiency (radiation use efficiency). Conversion efficiency and fractional interception,f, are determined by crop physiological factors and crop management, and the incident solar radiation becomes the only environmental factor affecting the relationship.

If (f) is monitored over the period of crop growth, and DM is measured e.g at FL, RUE can be determined and the results of experimental treatments or the influence of genetics can be interpreted in terms of their effect on RUE and f.

The radiation incident on a canopy can either be absorbed by the canopy, transmitted through the canopy and absorbed or reflected at the soil surface, or reflected by the canopy. In principle, only PAR absorbed by the canopy is useful in producing dry matter. If (t) is the fraction of incident radiation transmitted by the canopy, (r) is the fraction of incident radiation reflected to a sensor above the canopy and r_s is the reflectance of the soil surface, then the absorbed radiation is calculated from:

$f = 1-t-r+tr_s$

The last two terms are often ignored and the fractional interception is approximated by: f = 1-t. Accordingly the biomass produced may be modelled as the product of cumulative radiation intercepted by the crop (Σ I) and RUE. It is an alternative approach to the destructive sampling by measurement of (I) during growth combined with RUE.

DM = Σ I x RUE. This relationship was validated for many crops, including sorghum (Hammer and

Vanderlip 1989) and it has been shown that RUE is a conservative value, radiation interception has been the primary factor limiting to growth.

Fractional radiation interception (f) in this trial was measured by placing PAR Ceptometer above and under the canopy. The radiation intercepted was estimated as the difference between above and below canopy incident radiation value. The radiation interception measurements were made on a weekly basis (between 10 am and 2 pm.) for all the treatments at both sites. Three measurements above and three below (each below canopy measurement was an average of six readings) canopy were taken in each treatment. The average of the three above canopy readings constituted an average to the incoming radiation while the average of the eighteen below canopy readings constituted an average to the below canopy readings. The ratio of below canopy radiation : above canopy radiation is t, accordingly (f) was approximated by 1 - t. When (f) was multiplied by the total solar radiation value (in Mj/m^2) from the meteorological station located near the two sites, an estimate of the cumulative radiation (CUM) intercepted (in Mj/m^2) could be obtained. In this experiment during both seasons actual (f) values were used to calculate the cumulative radiation. The ratio between the measured dry matter (at three sampling periods, 0 - 30, 0 - 50 DAE and 0 - FL; 0 stands for emergence) and the cumulative radiation intercepted was an estimate of the radiation use efficiency (RUE) at each sampling time at each treatment.

Since during the conduct of the experiment three DM samples were taken, the validity and the consistency of RUE could be tested. Likewise, the DM could be estimated from the relation at any time during the growth of the crop.

3.5 WATER USE (WATER EXTRACTION PATTERN) AND WATER USE EFFICIENCY

The evapotranspiration component was calculated from the following equation:

$ET = I + RF \pm CWS - D - R - P.$

where:

ET = evapotranspiration.

I = irrigation.

RF = rainfall.

CWS = change in the water status (could be a positive or a negative value).

D = drainage.

R = runoff.

P = Percolation beyond the rooting zone.

It was assumed that drainage, runoff and percolation to be negligible during the *rabi* season. Also and since the trial was not irrigated, but totally raised on residual soil moisture, the above equation could be rewritten as:

$ET = RF \pm CWS$

The change in the water status (water used) was monitored by neutron probe, the rainfall was measured at ICRISAT weather station (400 m from the experimental sites).

The amount of water used during the season (WU) was approximated as follows:

$W_{ij} = VWC_{ij}/100 \times D.$

Where: W = water in mm, VWC = Volumetric water content (%),

I= layer, j= time of each measurement and D = Depth in mm.

The water used during the season was calculated as the sum of the moisture extraction at each depth from each layer during each measurement throughout the season. Nine moisture observations were taken and used in the calculations for each sowing date at each site.

Water use efficiency was then calculated as follows:

WUE = YLD/ET or Bio/ET.

Where :

WUE = water use efficiency.

YLD = grain yield.

Bio = biomass yield.

3.6 NUTRIENT ANALYSIS

The dry samples from growth analysis and harvest samples (green leaves, stems, panicles, stover and grain) were crushed into fine powder by a laboratory mill and thoroughly mixed. A subsample of 5 g each was taken for N and P analysis. When the %N and the %P was multiplied by the corresponding dry weights (green leaves, stems and panicles at FL), (stover and grain yield dry weights at HAR), an estimate of total N and total P content or uptake could be found. The nitrogen use efficiency (NUE) was calculated during HAR in the grain and biomass yields. It was found as the ratio between the grain and / or biomass yields to the total N uptake.

3.7 INSECT COUNTS

Two counts for the shoot fly dead heart were recorded (21 and 30 DAE) at both sites during both seasons. Another count after flowering was taken to determine the %IN, %AR and %AN as stated earlier. Counts were taken in the six rows for the shoot fly dead heart and in the four central rows of the yield plots for the %IN, %AR and %AN. In the shoot fly counts, the total plant number was recorded and the shoot fly affected plants counted. The average ratio (from the two counts) of the affected to the total plant number was an estimate to the percent shoot fly dead heart. The count after FL was carried to have an insight on the performance of each treatment in it's ability to respond to the shoot fly attack. The total plant number of each four central rows, the IN plants and the AR plants were counted. The AN plants were found by difference from the total plant number (total - IN - AR). The ratio of each (IN, AR, AN) to the total plant number was an estimate to the %IN, %AR and %AN plants.

3.8 PLANT HEIGHT (PLH) AND PANICLE LENGTH (PNLN)

Before HAR and on a randomly five plants, stem height was measured from the ground to the base of the panicle and the PNLN from the base to the tip of the panicle. PLH was the sum of stalk height and PNLN.

3.9 HARVEST DATA: STOVER, BIOMASS AND GRAIN YIELDS

From an area of 6 m^2, plants were cut at the ground level, panicles were separated counted, stover tied into bundles and their fresh weight was measured. Panicles were dried in an oven adjusted to 75 °C for 72 hrs. The fresh weight of the stover was recorded; a subsample on fresh weight basis (approximately 33% of the fresh weight) was mechanically chopped (to facilitate complete drying) and oven dried at 75 °C for 72 hrs. This subsample was retained and used for total N and total P estimation discussed earlier. After drying, panicles were mechanically threshed and the grain yield was recorded. The dried stover subsample was weighed, total stover dry weight was found by calculation. Biomass was the sum of total panicle and total stover dry weights.

The HI was found as the ratio of the biological yield transferrable to economic yield.

The following yield parameters were also calculated:

1) 100 seed mass. 100 grain counts were made on three randomly selected samples. The grain mass was an average of the three samples.

2) grain number per panicle (GRNO/PN). GRNO/PN = (GRWT/PNNO) x (100/GRM) where GRWT

is the grain weight from the harvested area (6 m^2), PNNO, panicle number from 6 m^2, and GRM is 100 grain mass.

3) grain number per unit area (GRNO/m^2). GRNO/m^2 = (GRWT/6) x (100/GRM), 6 is the harvest area.

4) grain weight per panicle (GRWT/PN). GRWT/PN = GRWT/PNNO.

3.10 PATH ANALYSIS

It was carried to determine the direct and the indirect effects of independent factors and their correlations with grain yield (dependent factor).

3.11 COST BENEFIT ANALYSIS

The recent market price for grain and stover was used in the calculation.

3.12 DATA ANALYSIS

The data from each site in each season were analyzed and presented separately for separate seasons. This and the pool analysis from both seasons in each site was carried at IAC through the Vax system using genestat package. Throughout the write up, *, **, *** stands for $P< 0.05$, < 0.01 and < 0.001. A sample of the program used in the analysis and the partioning of the degrees of freedom at the deep Vertisol site were given as Appendix 3 and 4.

CHAPTER IV

RESULTS

4.1 LEAF AREA INDEX (LAI)

4.1.1 Deep Vertisol Site (1995 and 1996)

Early and normal planting of sorghum had no effect on LAI during 1995 and 1996 seasons. LAI of both planting dates at the three sampling periods were statistically the same. (Fig 4). Leaf area indices of sorghum during both dates progressively increased from 30 DAE, reached a maximum at 50 DAE and decreased slightly by FL. The effects of fertility treatments on LAI of sorghum were distinct during both seasons at the three sampling periods. The crop fertilized with F2 and F3 levels was significantly superior than that under F1 treatment at 30, 50 DAE and FL time (Fig 4). Likewise the effect of crop protection against shoot fly on LAI of sorghum was also significant. The crop under NP treatment recorded LAI values of 0.41 and 0.99 (at 30 DAE) and 1.78 and 2.63 (at 50 DAE) in comparison to 0.72 and 1.37 (at 30 DAE) and 2.97 and 3.11 (at 50 DAE) under PR treatment during 1995 and 1996 seasons respectively. The cultivar effect on LAI could be seen from Fig 4. IC 94004 consistently showed significantly greater LAI than Swathi and M35-1 at the three sampling periods during both seasons.

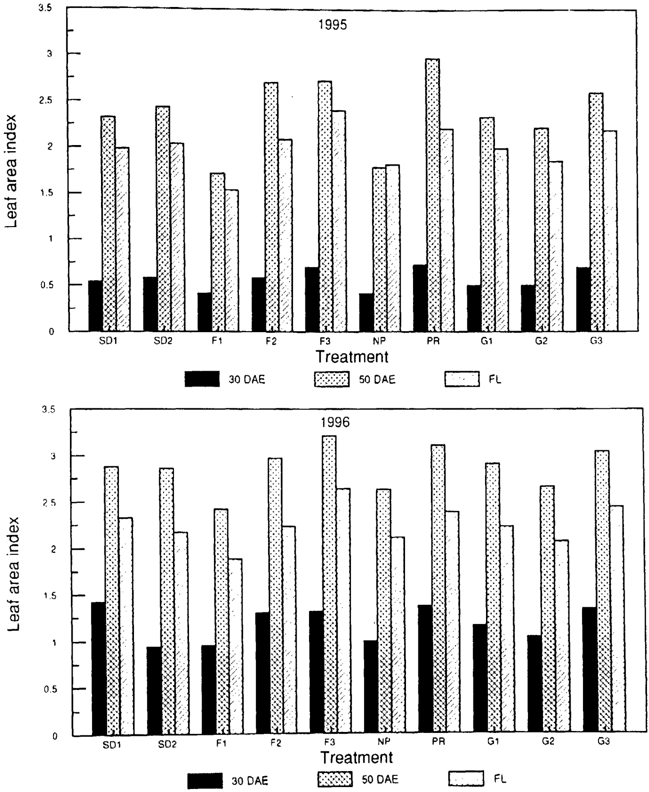


Fig.4. Leaf area index by management treatments and genotypes in sorghum during three sampling periods in the deep Vertisol site (rabi 1995 and 1996).

4.1.2 LAI in the Vertic Inceptisol Site (1995 and 1996)

The picture was different from that described for deep Vertisol site. Early planting of sorghum had statistically greater LAI than normal planting at 30 DAE during 1995 but not so during 1996 season. There were no significant differences on LAI between the two dates at 50 DAE and FL time. Among the fertility levels, the crop fertilized with F2 level had significantly greater LAI than that under F1 at the three sampling periods during both 1995 and 1996 seasons. A maximum LAI of 2.55 and 3.24 at F2 level and of 1.51 and 2.46 at F1 level were observed at 50 DAE during 1995 and 1996 respectively. By FL, LAI of sorghum decreased in both fertility treatments during both seasons. The cultivar effect on LAI differed from that described in the deep Vertisol site. IC 94004 recorded significantly greater LAI than Swathi and M35-1 during 1995 and 1996 at 30 DAE. However, at later sampling periods (50 DAE and FL), there were no significant differences during 1995; but differences between the three genotypes were significant at both 50 DAE and FL during 1996 (Fig 5).

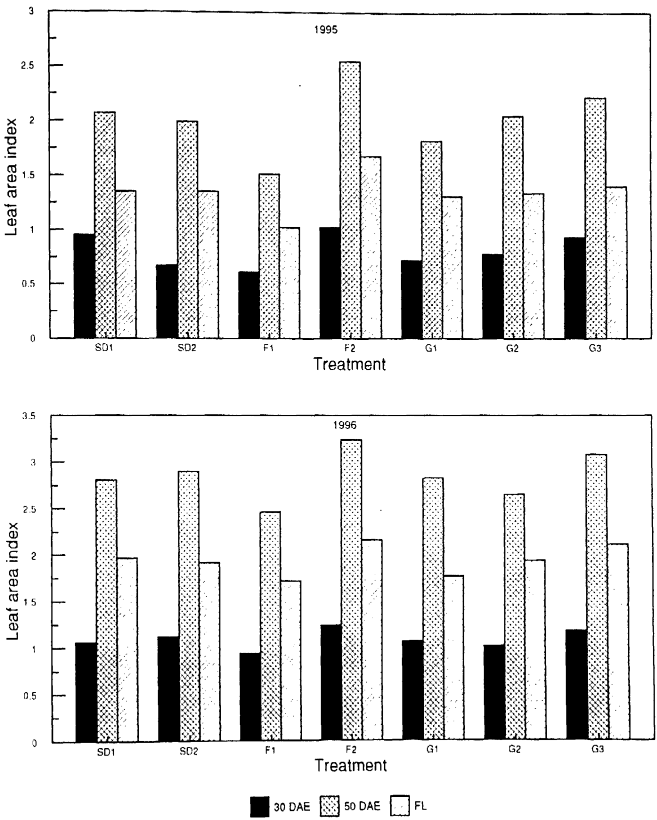


Fig.5. Leaf area index by management and genotype treatments in sorghum during three sampling periods in the vertic Inceptisol site (rabi 1995 and 1996).

4.2 LEAF DRY WEIGHT (LFDW) (g/m^2)

4.2.1 Deep Vertisol Site (1995 and 1996)

Like LAI, and among seasons and sampling periods, there were no significant effects of planting dates of sorghum on LFDW. The effect of fertility treatments on LFDW followed the same pattern as LAI. The crop fertilized with F2 and F3 levels was significantly different in leaf dry weight from that under F1 at the three sampling periods during both 1995 and 1996. The LFDW across fertility levels continued to increase up to FL reaching a maximum of 137.7, 178.9 and 196.2 g/m^2 during 1995 and a maximum of 163.7, 185.9 and 185.9 g/m^2 during 1996 for F1, F2 and F3 fertility levels respectively (Table 3). The PR crop recorded significantly greater LFDW during both seasons at 30, 50 DAE and FL than the crop under NP treatment. There was a reduction in LFDW of NP compared to PR crop of 18 - 41% during 1995 and at 10 - 27% during 1996. Among genotypes, IC 94004 recorded significantly greater LFDW than Swathi or M35-1 at 30 and 50 DAE during 1995. At the same sampling periods during 1996, IC 94004 and M35-1 LFDW was statistically superior than Swathi. By FL time during both seasons, there were no significant differences between the three genotypes (Table 3).

4.2.2 LFDW in the Vertic Inceptisol Site (1995 and 1996)

Irrespective of the season and the sampling period, early and normal planting of sorghum had no effect on LFDW (Table 4). The crop under F2 was statistically different from that under F1 fertility level at 30, 50 DAE and FL during both 1995 and 1996. During 1995 and 1996 at 30 DAE, IC 94004 alone (at 1995) or IC 94004 and M35-1 (at 1996) LFDW was significantly different from M35-1 and Swathi (at 1995) or from Swathi alone (at 1996). No statistical differences were seen during 50 DAE or FL period during both seasons.

Table 3. Management treatments (planting time, fertility and shoot fly control) and cultivar effects on leaf dry weight (g/m²) in sorghum during three sampling periods in the deep Vertisol site (*rabi* 1995 and 1996).

	Rabi 1995			*Rabi* 1996		
TRT	30 DAE	50 DAE	FL	30 DAE	50 DAE	FL
SD1	18.3	115.2	165.2	54.1	141.7	158.1
SD2	19.6	104.4	176.2	35.9	135.2	162.8
SED±	1.09	18.24	17.51	6.20	14.42	14.06
F	NS	NS	NS	NS	NS	NS
F1	13.5	76.4	137.7	35.7	113.5	131.9
F2	20.2	125.0	178.9	49.0	144.6	163.7
F3	23.3	127.9	196.2	50.3	157.7	185.9
SED±	2.24	11.16	16.90	3.32	8.61	7.94
F	**	**	*	**	**	***
NP	14.1	84.0	153.9	37.8	128.9	152.4
PR	23.9	135.5	188.0	52.1	148.3	168.6
SED±	1.24	6.46	5.94	1.93	4.87	3.64
F	***	***	***	***	**	***
M35-1	16.6	106.9	160.9	44.9	139.0	165.3
Swathi	16.7	102.3	174.1	39.6	129.6	155.3
IC 94004	23.7	120.0	177.8	50.4	147.2	160.9
SED±	1.06	5.49	7.45	1.74	4.18	6.48
F	***	**	NS	***	***	NS
CV(%)	7.0	20.4	12.5	16.4	12.8	7.1

Table 4. Management treatments (planting time and fertility) and cultivar effects on leaf dry weight (g/m²) in sorghum during three sampling periods in the vertic Inceptisol site (*rabi* 1995 and 1996).

	Rabi 1995			*Rabi* 1996		
TRT	30 DAE	50 DAE	FL	30 DAE	50 DAE	FL
SD1	29.5	99.3	128.3	43.1	125.3	152.8
SD2	24.0	88.5	114.6	43.8	140.9	167.0
SED±	1.45	9.30	11.69	6.48	8.08	13.02
F	NS	NS	NS	NS	NS	NS
F1	20.4	68.2	92.1	37.2	113.2	141.4
F2	33.1	119.6	150.7	49.6	153.0	178.5
SED±	3.35	6.47	9.01	4.04	9.58	9.72
F	*	**	**	*	*	*
M35-1	23.4	86.7	113.7	42.6	131.3	153.6
Swathi	25.5	95.8	117.5	40.7	127.0	168.3
IC 94004	31.3	99.1	133.2	46.9	141.1	157.9
SED±	1.68	7.57	11.18	2.35	5.91	7.87
F	***	NS	NS	*	NS	NS
CV(%)	6.6	12.1	11.8	13.2	10.9	12.1

4.3 STEM DRY WEIGHT (STDW) (g/m^2)

4.3.1 STDW in the Deep Vertisol Site (1995 and 1996)

The planting date had little effect on STDW of sorghum. At 30 DAE, there were no statistical differences between the two planting dates during 1995; but differences between them were significant during 1996. At 50 DAE and at FL, STDW of sorghum at early or normal planting was statistically at par (Table 5). Across planting dates and seasons, the maximum STDW was at FL. Among fertility levels at 30, 50 DAE and at FL, the crop fertilized with F3 and F2 levels had significantly greater STDW than that fertilized with F1 during both 1995 and 1996 seasons. During 1995, the effect of PR treatment on STDW of sorghum was consistently the same at the three sampling periods and was significantly different from NP treatments. During this season, there was about 27 - 54% reduction in STDW of the crop with NP compared to PR crop. The corresponding reduction in STDW during 1996 was 9 - 31%. In this season, the crop under PR was statistically significant from NP crop in STDW during 30, 50 DAE and FL sampling periods. Among genotypes during both seasons at 30 and 50 DAE, IC 94004 recorded significantly greater STDW than Swathi and M35-1. By FL, there were no differences in STDW among the three genotypes during 1995; but differences in STDW of IC 94004 and M35-1 over Swathi at FL were significant during 1996 (Table 5).

4.3.2 STDW in the Vertic Inceptisol Site (1995 and 1996)

Differences in STDW between early and normal planting were significant at 30 DAE during 1995, and at 50 DAE during 1996. By FL, differences in STDW of the crop between the two dates during either season were not significant. The STDW of sorghum at any sampling time was enhanced by early than normal planting; and at corresponding STDW values (early/normal) across the sampling periods (30, 50 DAE and FL) at (16.3/11.8, 122.4/112.7, 308.0/231.5 during 1995 and at (29.3/25.0, 172.9/198.2, 351.0/328.0) g/m^2 during 1996 (Table 6). Among fertility levels at 30, 50 and FL, the crop fertilized with F2 level was statistically different than that under F1 in STDW (Table 6). Amongst cultivars, IC 94004 recorded significantly higher STDW compared to that of Swathi and M35-1 at 30, 50 DAE and at FL in both years. By FL period there were no significant differences between the cultivars during 1995 and 1996.

Table 5. Management treatments (planting time, fertility and shoot fly control) and cultivar effects on stem dry weight (g /m²) in sorghum during three sampling periods in the deep Vertisol site (*rabi* 1995 and 1996).

	Rabi 1995			*Rabi* 1996		
TRT	30 DAE	50 DAE	FL	30 DAE	50 DAE	FL
SD1	9.8	119.4	359.6	40.0	202.7	401.0
SD2	9.6	116.2	317.6	20.5	200.3	285.4
SED±	0.78	12.02	47.95	4.50	28.89	37.87
F	NS	NS	NS	*	NS	NS
F1	6.8	72.9	259.1	22.3	152.5	284.4
F2	10.1	129.4	367.3	32.6	214.9	361.3
F3	12.2	151.1	389.3	35.8	237.1	384.0
SED±	1.25	17.19	41.32	2.61	17.92	22.15
F	**	**	*	**	**	**
NP	7.4	74.1	285.2	24.7	183.7	327.5
PR	12.1	161.5	391.9	35.8	219.4	359.0
SED±	0.67	10.86	16.46	1.91	10.69	10.62
F	***	***	***	***	**	*
M35-1	7.6	106.1	347.3	28.8	186.9	360.2
Swathi	8.8	107.5	315.0	25.6	169.3	307.1
IC 94004	12.7	139.9	353.4	36.3	248.3	362.5
SED±	0.57	8.67	17.39	1.62	9.50	14.72
F	***	***	NS	***	***	***
CV(%)	9.8	12.5	17.3	4.1	20.0	18.2

Table 6. Management treatments (planting time and fertility) and cultivar effects on stem dry weight (g/m²) in sorghum during three sampling periods in the vertic Inceptisol site (*rabi* 1995 and 96).

	Rabi 1995			*Rabi* 1996		
TRT	30 DAE	50 DAE	FL	30 DAE	50 DAE	FL
SD1	16.3	122.4	308.0	29.3	172.9	351.0
SD2	11.8	112.7	231.5	25.0	198.2	328.0
SED±	0.63	21.45	49.90	4.39	5.35	33.4
F	*	NS	NS	NS	*	NS
F1	9.9	67.4	183.0	22.6	141.2	303.0
F2	18.2	167.7	356.0	31.8	229.9	376.0
SED±	1.98	13.52	16.90	2.79	15.54	18.90
F	*	**	***	*	**	*
M35-1	11.4	95.1	260.0	25.9	177.4	344.0
Swathi	13.0	113.4	244.0	25.5	155.4	332.0
IC 94004	17.8	144.1	305.0	30.1	223.8	342.0
SED±	1.33	13.54	32.60	1.54	12.04	27.2
F	***	**	NS	*	***	NS
CV(%)	5.4	22.3	22.7	13.9	15.9	19.6

4.4 PANICLE DRY WEIGHT (PNDW) (g/m^2)

4.4.1 PNDW in the Deep Vertisol Site (1995 and 1996)

Irrespective of the season, PNDW of sorghum during FL at early or normal planting was statistically at par (Table 7). The pattern of PNDW across fertility treatments during 1995 and 1996 had followed the pattern of shoot dry weight in that F3 and F2 were significantly greater than F1. The PNDW of sorghum (g/m^2) across F1, F2 and F3 levels was 40.8/45.8, 59.9/59.4 and at 63.8/72.4 during 1995/1996 respectively. Spraying against shoot fly had no effect on PNDW of sorghum and as a result the crop under PR and NP treatments behaved similarly during both seasons (Table 7). Within cultivars during both 1995 and 1996 seasons, IC 94004 had the least PNDW (48.3 and 54.7 g/m^2), Swathi the highest (65.3 and 65.0 g/m^2), and M35-1 in between these (50.5 and 57.9 g/m^2). Swathi had significantly greater PNDW than either of the two cultivars tested (Table 7).

4.4.2 PNDW in the Vertic Inceptisol Site (1995 and 1996)

During both 1995 and 1996 seasons, planting date had no effect on PNDW (Table 8). The crop fertilized with F2 level compared to that under F1 had a two fold increase in PNDW during 1995 and 1.4 fold increase during 1996; and the differences between the two levels were significant during both seasons. There were no significant differences in PNDW among cultivars during 1995, but PNDW of Swathi was significantly greater from that of M35-1 and IC 94004 during 1996.

Table 7. **Management treatments (planting time, fertility and shoot fly control) and cultivar effects on panicle dry weight (g/m²) in sorghum at flowering in the deep Vertisol site (*rabi* 1995 and 1996).**

TRT	*Rabi* 1995 FL	*Rabi* 1996 FL
SD1	48.7	67.3
SD2	61.0	51.0
SED±	11.57	12.28
F	NS	NS
F1	40.8	45.8
F2	59.9	59.4
F3	63.8	72.4
SED±	7.91	4.78
F	*	**
NP	53.7	61.0
PR	56.0	57.4
SED±	3.86	2.88
F	NS	NS
M35-1	50.5	57.9
Swathi	65.3	65.0
IC 94004	48.3	54.7
SED±	4.04	3.16
F	***	**
CV(%)	25.8	22.6

Table 8. Management treatments (planting time and fertility) and cultivar effects on panicle dry weight (g/m²) in sorghum at flowering in the vertic Inceptisol site (*rabi* 1995 and 1996).

TRT	*Rabi* 1995 FL	*Rabi* 1996 FL
SD1	41.2	56.1
SD2	36.7	47.7
SED±	6.72	9.42
F	NS	NS
F1	25.9	43.7
F2	52.0	60.1
SED±	3.39	3.50
F	**	*
M35-1	34.9	49.0
Swathi	40.3	59.9
IC 94004	41.7	46.7
SED±	7.73	5.09
F	NS	*
CV(%)	12.8	11.7

4.5 TOTAL DRY WEIGHT (TDW) (g/m^2)

4.5.1 TDW in the Deep Vertisol Site (1995 and 1996)

During both seasons and at the three sampling periods (30, 50 DAE and FL), planting date of sorghum had small effect on TDW (Fig 6). Irrespective of the season and the sampling period, the crop fertilized with F3 (Plates 3 and 4) and F2 treatments recorded statistically greater TDW than that under F1 (plates 1 and 2) (Fig 6). The effect of protection against shoot fly on sorghum TDW was pronounced. Over the three sampling periods, the crop under NP (plates 1 and 3) had about 23 - 40% less TDW than PR crop (Plates 2 and 4) during 1995 and about 9 - 29% less TDW during 1996. The average reduction in TDW over the three sampling periods was 36% during 1995 as a result of 32% reduction in LFDW and a 40% reduction in STDW in the crop under NP treatments. This in comparison to an average reduction of 18% in TDW of the crop during 1996 resulting from 17% reduction in LFDW and a reduction of 19% in STDW. This point emphasizes that sorghum PNDW was not affected by shoot fly damage, and that STDW was more affected than LFDW. No matter at what sampling time, the crop under PR treatment was significantly different in TDW from NP crop during both 1995 and 1996 (Fig 6).

Among the cultivars during 1995 and 1996, TDW of IC 94004 exceeded that of Swathi and M35-1; and the differences between them were significant at 30 and 50 DAE only. At FL, there were no differences between the cultivars during 1995, but the superiority of IC 94004 or M35-1 in TDW over Swathi were real during 1996 (Fig 6).

4.5.2 TDW in the Deep Vertisol Site (Pooled)

4.5.2.1 *Effect of season*

There were marked differences in TDW between 1995 and 1996 seasons at 30 DAE and 50 DAE only.

4.5.2.2 *Effect of planting date*

Although early planting of sorghum generally had a greater TDW at the three sampling periods compared to normal planting; differences were significant at 30 DAE only.

4.5.2.3 *Effect of fertility and protection*

The effects of both fertility and protection levels were consistent at 30, 50 DAE and at FL in that the crop under F2 and F3 fertility levels or PR treatments had statistically greater TDW than under F1 or NP.

4.5.2.4 *Effect of genotype*

Within genotypes, IC 94004 accumulated greater TDW at the three sampling periods than either Swathi or M35-1. The differences between the three genotypes were significant at 30 and 50 DAE only (Fig 6).

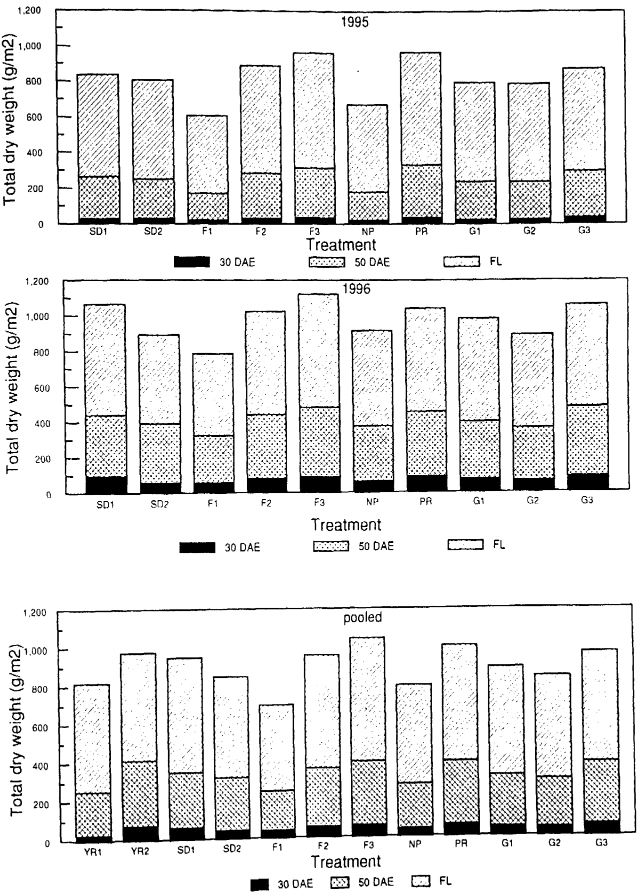


Fig.6. Total dry weight by management treatments and genotypes in sorghum during three sampling periods in the deep Veritisol site (1995, 1996 and pooled).

Plate 1. Rabi Sorghum fertilized by FYM and not protected against shoot fly (Deep Vertisol site)

Plate 2. Rabi Sorghum fertilized by FYM and protected against shoot fly (Deep Vertisol site)

ate 3. Rabi Sorghum fertilized by 'M+66 kgN and not protected against oot fly (Deep Vertisol site)

Plate 4. Rabi Sorghum fertilized by FYM+66 kgN and protected against shoot fly (Deep Vertisol site)

4.5.3 TDW in the Vertic Inceptisol Site (1995 and 1996)

During 1995 and 1996, early planting of sorghum had higher TDW than normal planting at 30 DAE during 1995 season only. Differences on TDW between the two dates were not significant at 50 DAE or FL periods during both 1995 and 1996 seasons . Across sampling periods (30, 50 DAE and FL), the crop fertilized with F2 level (Plate 5) recorded significantly greater TDW than that under F1 (Plate 6) during both 1995 and 1996. At FL, the application of F2 increased sorghum TDW over F1 by 46% during 1995 and by 21% during 1996. During both 1995 and 1996, there were significant differences in TDW between the three sorghum cultivars up to 50 DAE only, cultivar IC 94004 being the highest in TDW.

4.5.4 TDW in the Vertic Inceptisol Site (Pooled)

4.5.4.1 *Effect of season*

During 1996, TDW of sorghum was significantly greater than that of 1995 at 30, 50 DAE and at FL.

4.5.4.2 *Effect of planting date*

There was no significant difference between the two dates of sorghum planting in TDW during the three sampling periods.

4.5.4.3 *Effect of fertility*

Among the fertility levels irrespective of the sampling time, the crop fertilized with F2 level had significantly greater TDW than under F1.

4.5.4.4 *Effect of genotype*

The TDW pattern of the three sorghum genotypes had followed their TDW pattern in the deep Vertisol site. IC 94004 at 30 and at 50 DAE had significantly greater TDW than either Swathi or M35-1. However, there were no differences on TDW between the three genotypes at FL (Fig 7).

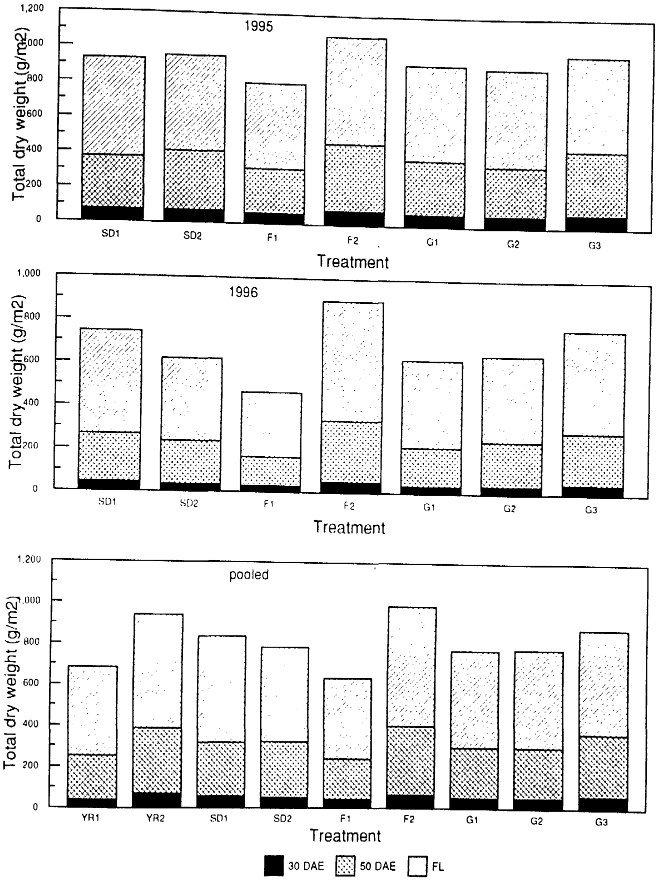


Fig.7. Total dry weight by management and genotype treatments in sorghum during three sampling periods in the vertic Inceptisol site (1995, 1996 and pooled).

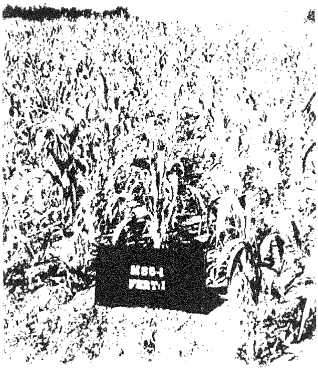


Plate 5. Rabi Sorghum fertilized by FYM (Vertic Inceptisol site) (Site fully protected against shoot fly)

Plate 6. Rabi Sorghum fertilized by FYM+20 kgN (Vertic Inceptisol site) (Site fully protected against shoot fly)

4.6 PER CENT RADIATION INTERCEPTED (%LI)

4.6.1 %LI in the Deep Vertisol Site (1995 and 1996)

During 1995 over the whole light measured period, normal planting intercepted more radiation than early planting. There were no differences between the two dates of sorghum planting during early stages (16 - 24 DAE), but differences between them were significant at 31, 38 and 45 DAE. There were no appreciable differences in radiation interception between planting dates for the rest of the radiation measured period (52 - 81 DAE). During 1996, early sorghum planting intercepted numerically more but not significantly greater amount of radiation than normal planting (Fig 8). Across both dates irrespective of the season, the maximum radiation interception coincided with 60 - 63 DAE, a period just before flowering (Fig 8).

Among the fertility levels, the crop fertilized with F2 and F3 levels was statistically different from that under F1 in %LI during 16 - 60 DAE in 1995 and significantly different during 25 - 77 DAE in 1996 (Fig 8). During both 1995 and 1996 seasons for the whole period, sorghum crop protection significantly enhanced %LI compared to the crop under non protected treatment. In both seasons, for the whole period, IC 94004 intercepted significantly more radiation than either Swathi or M35-1 (Fig 9).

4.6.2 <u>%LI in the Deep Vertisol Site (Pooled)</u>

4.6.2.1 *Effect of planting date*

There was no effect due to planting date of sorghum on %LI at early stages (18 - 32 DAE) or at later stages (54 - 82 DAE). However, the effect of planting date on %LI during 40 and 47 DAE was significant; the crop at normal planting intercepted more radiation than that at early planting.

4.6.2.2 *Effect of fertility and protection*

Across fertility levels during the whole measured period (18 - 82), the %LI in the crop fertilized with F2 and F3 levels was statically greater from that under F1 (Fig 8). Likewise, %LI (during the whole period) was statistically more in sorghum PR than NP treatment (Fig 9).

4.6.2.3 *Effect of genotype*

Among genotypes, IC 94004 intercepted more radiation than either Swathi or M35-1 for the whole measured period; differences between the three genotypes were significant for all measurements (Fig 9).

4.6.2.4 *Effect of season*

The %LI during 1996 at 25, 32, 40, 47 and 54 DAE was statistically greater than the %LI during 1995. There were no statistical differences in %LI between the two seasons at 61, 68, 75 and 82 DAE (Fig 10).

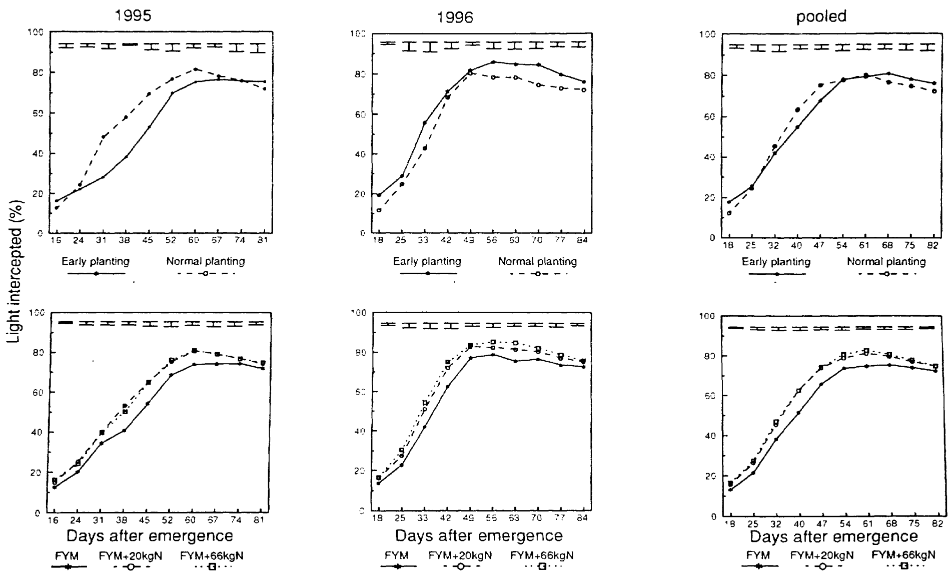


Fig.8. Per cent light interception by planting dates and fertility treatments in sorghum in the deep Vertisol site (rabi 1995, 1996 and pooled).
vertical bars are SED.

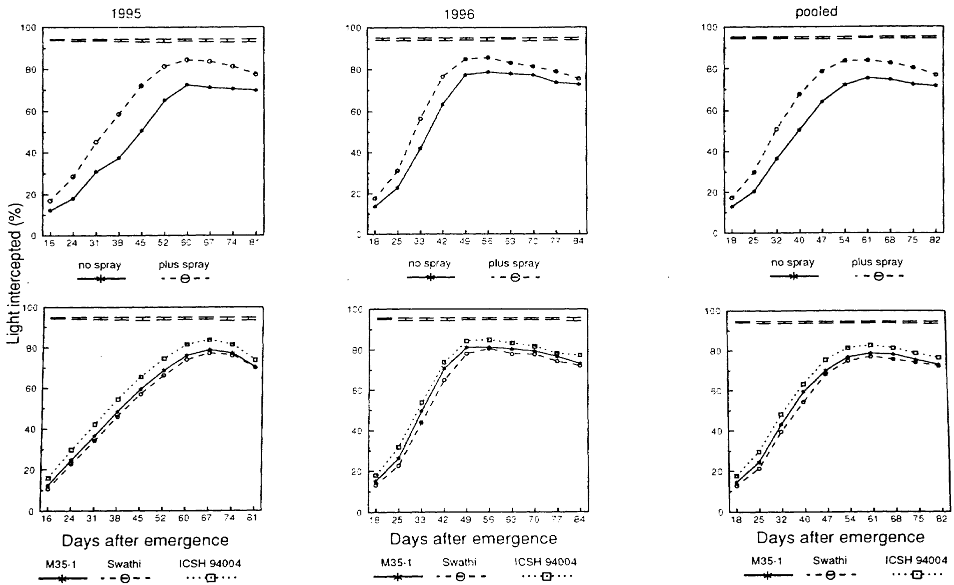


Fig.9. Per cent light interception by spray and genotype treatments in sorghum in the deep Vertisol site (rabi 1995, 1996 and pooled).
vertical bars are SED.

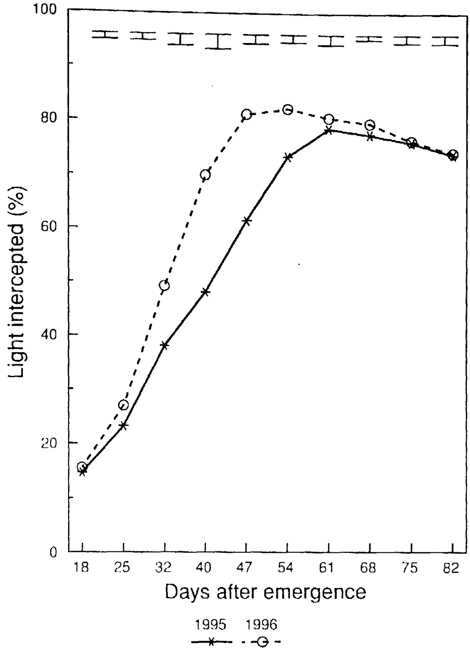


Fig.10. Per cent light interception in sorghum in the deep Vertisol site (1995 and 1996).

vertical bars are SED.

4.6.3 %LI in the Vertic Inceptisol Site (1995 and 1996)

During 1995, planting date of sorghum had no effect on %LI for the whole measured period (16 - 83 DAE). During 1996, early planting intercepted more radiation than normal planting; differences between the two dates were significant at 46 and 77 DAE. Across the levels of fertility during 1995, the crop fertilized with F2 level was statistically different from that under F1 at all dates of measurements. During 1996, there were significant differences between the two levels only at 18, 39, and 46 DAE (Fig 11). IC 94004 (in 1995), or IC 94004 and M35-1 (in 1996) intercepted more radiation than M35-1 and Swathi (in 1995) or more than Swathi alone (in 1996); differences between them were significant. Across 1995 and 1996, the maximum radiation intercepted by the three cultivars was between 60 - 69 DAE coinciding with heading - flowering period depending on the genotype (Fig 12).

4.6.4 %LI in the Vertic Inceptisol Site (Pooled)

4.6.4.1 *Effect of planting date*

Among planting dates, early planting of sorghum intercepted significantly greater amount of radiation at 75 and 82 DAE.

4.6.4.2 *Effect of fertility*

Among fertility levels, the crop fertilized with F2 level intercepted significantly more radiation than that under F1 during the whole period.

4.6.4.3 *Effect of genotype*

Within genotypes during the whole period, IC 94004 intercepted significantly more radiation than either Swathi or M35-1; differences between the three genotypes were significant. The maximum radiation interception across genotypes was attained by 60 DAE, a period just before flowering (Fig 12).

4.6.4.4 *Effect of season*

During the whole light measured period, there was a greater %LI by the crop during 1996 than during 1995 (Fig 13).

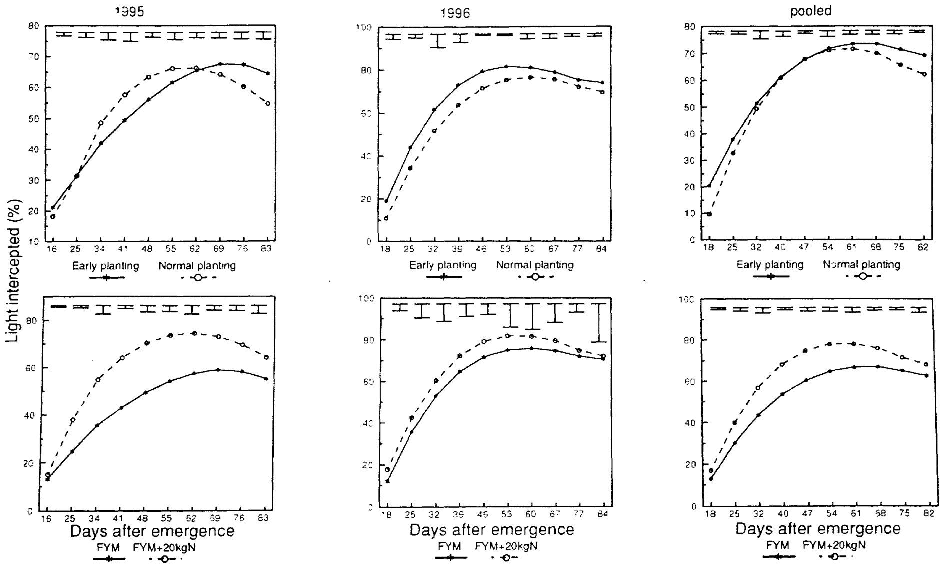


Fig.11. Per cent light interception by planting dates and fertility treatments in sorghum in the vertic Inceptisol site (rabi 1995, 1996 and pooled).
vertical bars are SED.

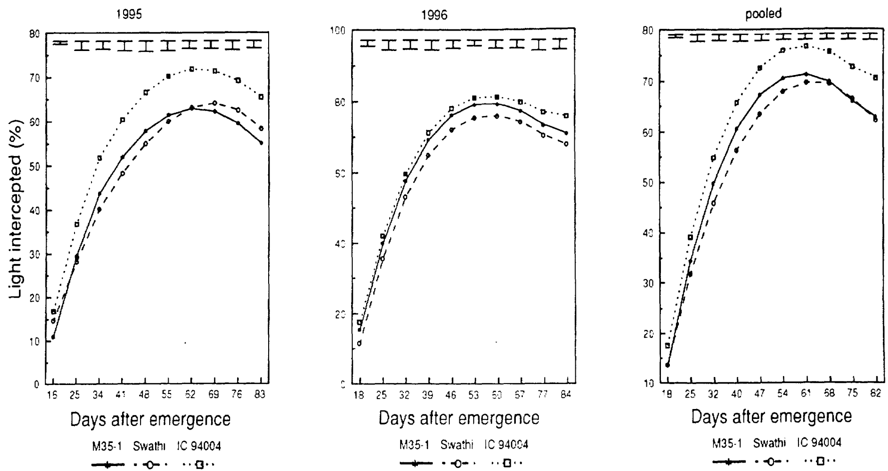


Fig.12. Per cent light interception by three genotypes of sorghum in the vertic Inceptisol site (rabi 1995, 1996 and pooled).

vertical bars are SED.

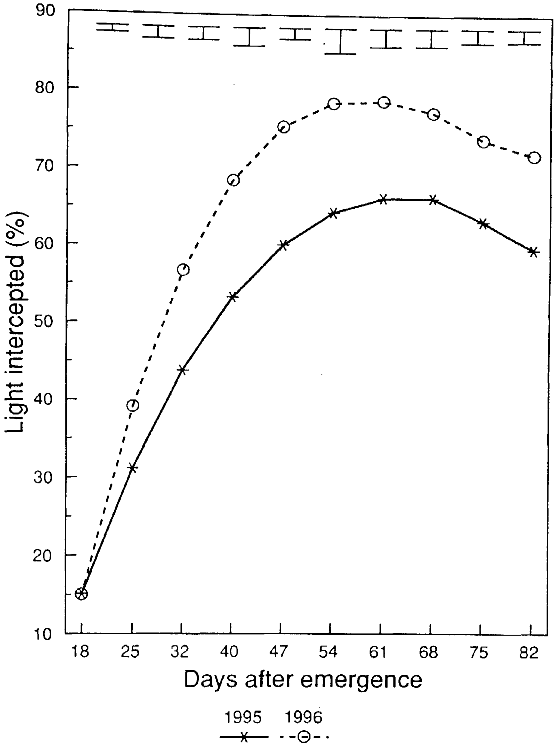


Fig.13. Per cent light intercepted by sorghum in the vertic Inceptisol site (rabi 1995 and 1996).

vertical bars are SED

4.7 CUMULATIVE RADIATION INTERCEPTED (CUM)

4.7.1 CUM in the Deep Vertisol Site (1995 and 1996)

The CUM during 1995 (16 - 81 DAE) and 1996 seasons (18 - 84 DAE) was presented in Fig 14. During 1995, differences between the two dates of sorghum planting were significant between 24 - 60 DAE, normal planting had greater CUM than early planting. There were no differences during the same period (25 - 63 DAE) in 1996 and for the rest of the CUM measured period in 1995 and 1996 seasons. The application of F3 or F2 levels to sorghum resulted in statistically greater CUM compared to F1 at 16, 38, 45, 52, and 60 DAE during 1995 and significantly different CUM at 25, 33, 42, 49, 56, 63 and 70 DAE during 1996. The crop under PR treatment had significantly greater CUM than NP crop for the whole measured period during both 1995 and 1996 seasons. Among cultivars during both seasons, IC 94004 alone or IC 94004 and M35-1 had statistically greater CUM than Swathi and M35-1 or Swathi alone at 16 - 74 DAE during 1995 and for the whole period (18 - 84 DAE) during 1996 (Fig 15).

4.7.2 CUM in the Deep Vertisol Site (Pooled)

4.7.2.1 *Effect of planting date*

During 1995, normal planting of sorghum had a greater CUM than early planting between 25 - 61 DAE, and less CUM between 68 - 82 DAE; differences were significant only during the period 32 - 47 DAE (Fig 14).

4.7.2.2 *Effect of fertility*

Among fertilities, the crop fertilized with F3 or F2 level was statistically greater than that under F1; accumulating about 525 compared to 508 Mj/m² for F1 at 82 DAE. This difference between the three fertility levels as well the differences between 18 - 75 DAE were significant (Fig 14).

4.7.2.3 *Effect of protection*

The CUM during the whole period (18 - 82 DAE) was statistically greater in sorghum PR than NP crop. With protection at 82 DAE, the radiation accumulation was 540 compared to 500 Mj/m² in NP crop. This as well as the CUM between 18 - 75 DAE were significantly more for PR than NP crop (Fig 15).

4.7.2.4 *Effect of genotype*

Within genotypes, IC 94004 had more CUM than either Swathi or M35-1 alone and by 82 DAE, IC 94004 had a maximum accumulation of 540 compared to a maximum of 510 Mj/m² by either Swathi or M35-1 (Fig 15).

4.7.2.5 *Effect of season*

The CUM across 1995 and 1996 had increased from 18 DAE up to 82 DAE (Fig 16). There were significantly greater CUM between 18 - 54 DAE during 1996 than 1995 and significantly greater CUM between 61 - 82 DAE during 1995 than 1996 (Fig 16).

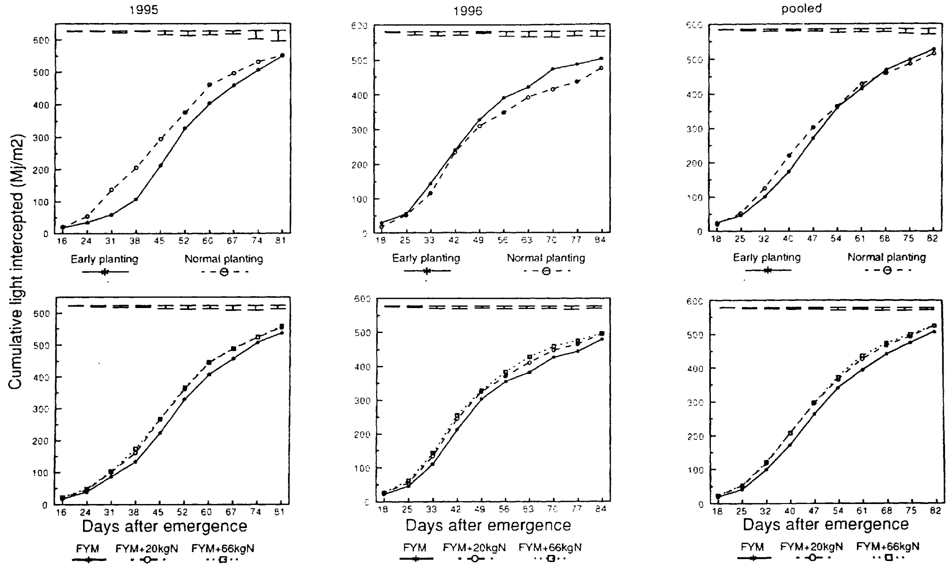


Fig.14. Cumulative light interception by planting dates and fertility treatments in sorghum in the deep Vertisol site (rabi 1995, 1996 and pooled).

vertical bars are SED.

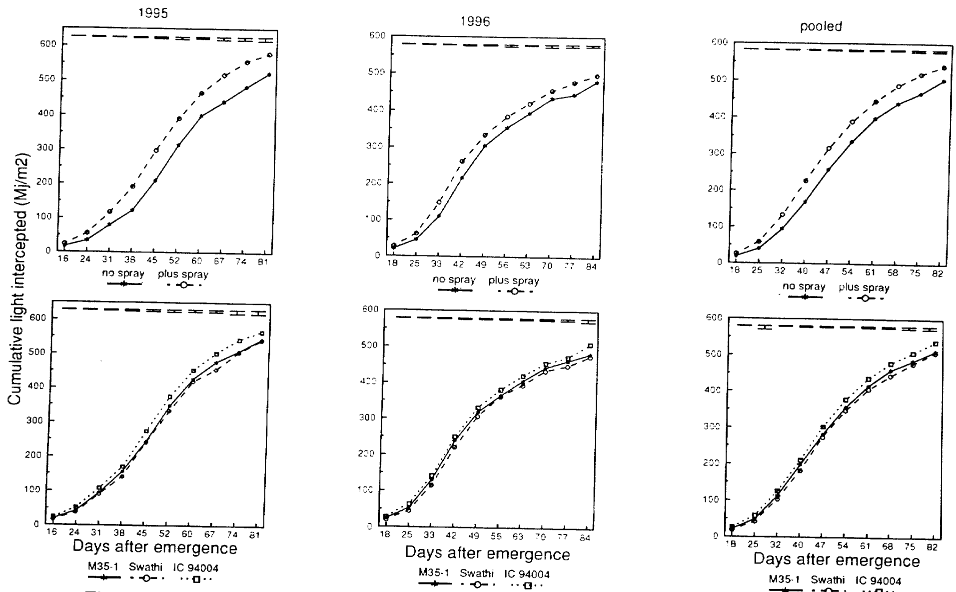


Fig.15. Cumulative light interception by spray and genotype treatments in sorghum in the deep Vertisol site (rabi 1995, 1996 and pooled).
vertical bars are SED

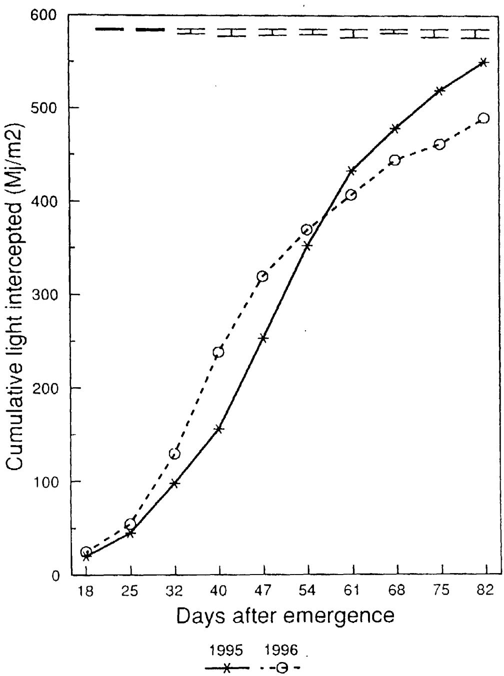


Fig.16. Cumulative light interception in sorghum in the deep Vertisol site (rabi 1995 and 1996).

vertical bars are SED.

4.7.3 CUM in the Vertic Inceptisol Site (1995 and 1996)

During 1995, normal planting of sorghum had significantly greater CUM than early planting during the period 25 - 48 DAE, the two dates were statistically at par for the rest of the period (55 - 83 DAE) (Fig 17). The CUM in the crop fertilized with F2 level was statistically greater than that under F1 between 16 - 83 DAE (Fig 17). Among genotypes, the CUM of IC 94004 was significantly greater than either Swathi or M35-1 and for the whole period (16 - 83 DAE (Fig 18). During 1996, early planting had a higher CUM than normal planting during the whole CUM period; and the differences between them were significant only at 46, 53 and 77 DAE (Fig 17). Across fertility levels, the crop fertilized with F2 level had significantly greater CUM than that under F1 (Fig 17). The CUM of IC 94004 and/or M35-1 was significantly greater than that of Swathi at 18, 25, 32, 53, 60, 67, and 84 DAE (Fig 18).

4.7.4 CUM in the Vertic Vertisol Site (Pooled)

4.7.4.1 *Effect of planting date*

Although normal planting of sorghum at 25 - 61 DAE had slightly greater non significant CUM than early planting, by the end of the season (68 - 82 DAE), early planting had greater CUM than normal planting; and the differences between the two dates were significant between 75 - 82 DAE.

4.7.4.2 *Effect of fertility*

The CUM of the crop fertilized with F2 level as compared to F1 was significantly greater during 18 - 82 DAE (Fig 17).

4.7.4.3 *Effect of genotype*

Among genotypes, IC 94004 accumulated significantly greater CUM than either Swathi or M35-1 during the period 18 - 82 DAE (Fig 18).

4.7.4.4 *Effect of season*

Between seasons, there were statistical differences in the sorghum CUM only at 40 and 47 DAE. There were no differences between the seasons for the rest of the period (18 -32 and 54 - 82 DAE) (Fig 19).

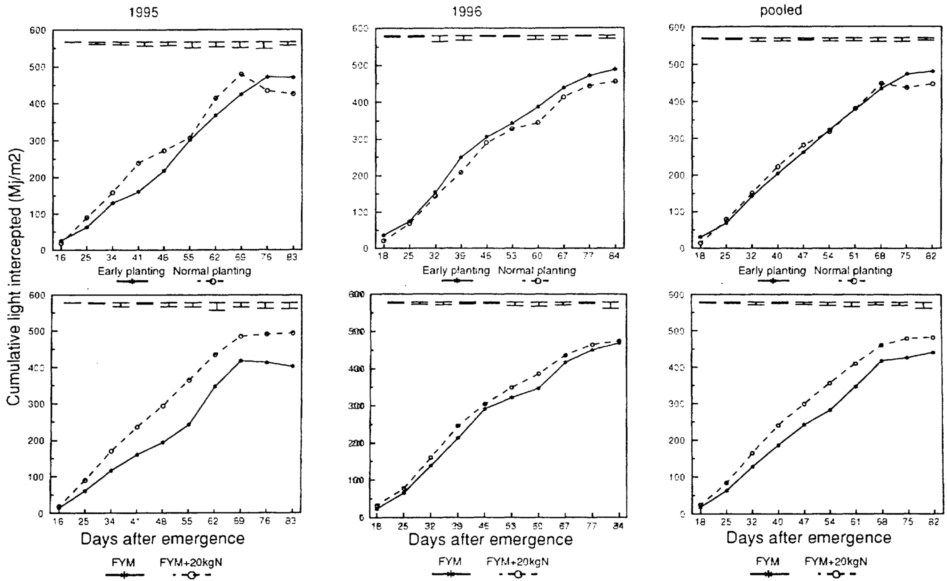


Fig.17. Cumulative light interception by planting date and fertility treatments in sorghum in the vertic Inceptisol site (rabi 1995, 1996 and pooled).
vertical bars are SED

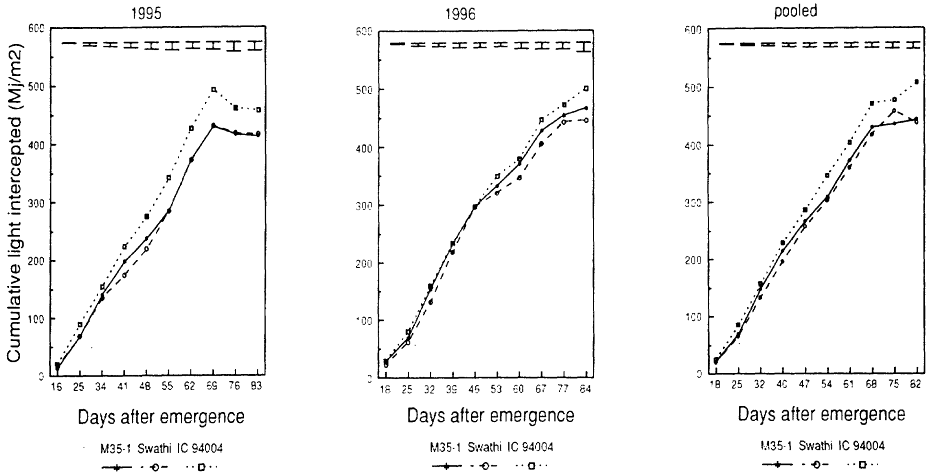


Fig.18. Cumulative light inteception by three genotypes of sorghum in the vertic Inceptisol site (rabi 1995, 1996 and pooled).

vertical bars are SED.

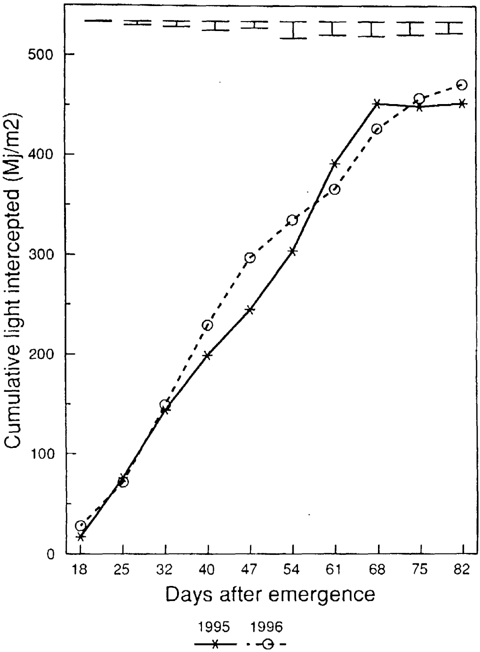


Fig.19. Cumulative light interception by sorghum in the vertic Inceptisol site (rabi 1995 and 1996).

vertical bars are SED

4.8 MOISTURE EXTRACTION PATTERN DURING THE SEASON

4.8.1 Water Used (mm) from 0-150 cm Soil Depth in the Deep Vertisol Site (1995 and 1996)

The total cumulative moisture extraction of sorghum crop during 1995 and 1996 at 18 - 116 days from different soil layers (15 - 150 cm) increased steadily and reached a maximum of 42 mm at 60 DAE (Fig 20). This maximum moisture extraction had coincided with heading time and the period of maximum %LI (Figs 8 and 9). The total seasonal moisture extraction from different soil layers was 212 mm during 1995 and 195 mm during 1996; and the differences in the moisture extracted within the various soil layers were significant. During 1995 and 1996, about 60% of the total water extracted was from 0 - 60 cm soil depth, the remaining balance was from 75 - 150 cm soil depth.

4.8.2 Water Used (mm) by Management Treatments in the Deep Vertisol site (1995 and 1996)

From Table 9, during 1995, there were statistical differences between early and normal planting of sorghum. Normal planting of the crop used more water (230 mm) compared to early planting (194 mm). During 1996, there were no statistical differences between the two dates; early planting used 197 mm and normal planting used 193 mm. There were no effects on crop water used due to fertility or protection during either seasons (Table 9).

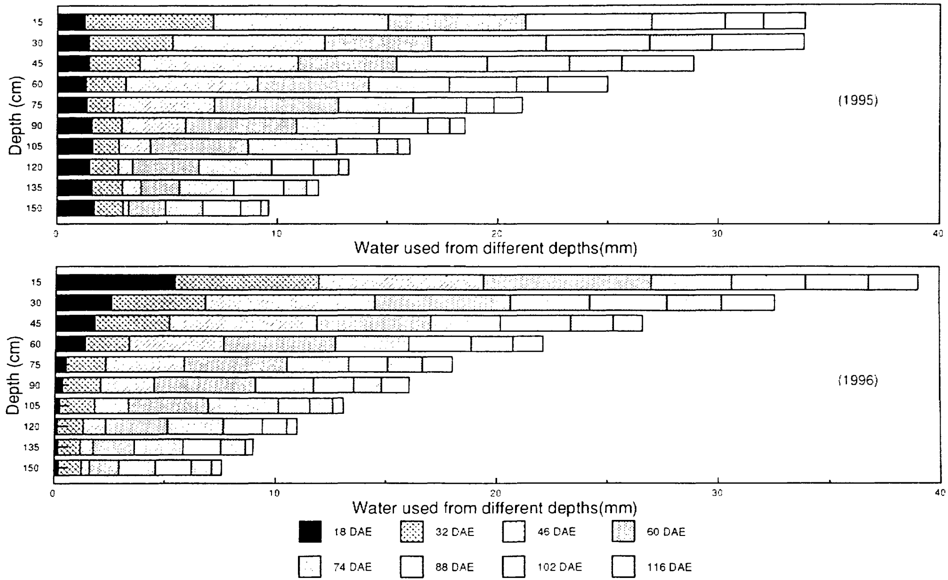


Fig.20. Water used by sorghum from different soil depths at different crop age in the deep Vertisol site (rabi 1995 and 1996).

Table 9. **Management treatments (planting time, fertility and shoot fly control) and cultivar effects on water used (mm) by M35-1 in the deep Vertisol site (*rabi* 1995 and 1996).**

TRT	*Rabi* 1995 Water used (mm)	*Rabi* 1996 Water used (mm)
SD1	193.7	196.8
SD2	230.2	192.9
SED±	4.3	2.8
F	***	NS
F1	196.8	181.3
F2	230.3	206.6
F3	208.7	202.6
SED±	16.3	11.7
F	NS	NS
NP	215.8	191.0
PR	208.0	198.7
SED±	8.5	9.8
F	NS	NS
0-15	33.9	39.0
15-30	33.9	32.6
30-45	28.9	26.6
45-60	25.0	22.1
60-75	21.1	18.0
75-90	18.5	16.0
90-105	16.0	13.1
105-120	13.2	11.0
120-135	11.9	9.0
135-150	9.6	7.6
SED±	0.88	0.97
F	***	***
CV(%)	13.3	12.5

4.8.3 Water Used (mm) from 0-150 cm Soil Depth in the Vertic Inceptisol Site (1995 and 1996)

There was a decreasing trend in moisture extraction within each soil layer throughout 1995 and 1996 seasons. The maximum moisture extracted per measurement period across various soil depths during 1995 and 1996 was reached around 46 DAE coinciding with booting stage of the crop. There were statistical differences among the different soil depths throughout 1995 and 1996 seasons. About 55% (70 mm) during 1995 and 50% (67 mm) during 1996 of the total extracted moisture was from 0 - 60 cm soil depth (Fig 21). The total water extracted was about 60% during 1995 and about 70% during 1996 of that extracted in the deep Vertisol site.

4.8.4 Water Used (mm) by Management Treatments in the Vertic Inceptisol Site (1995 and 1996)

Early planting of sorghum extracted significantly more water (136 mm) than normal planting (118 mm) during 1995. During 1996, though the differences between the two dates of sorghum planting were not significant, early planting extracted more water (151 mm) than normal planting (127 mm) (Table 10). During both seasons, there were no significant differences between fertility treatments, but the crop fertilized with F2 level had used slightly more water than that under F1 (134 and 142 mm) in comparison to (120 and 136 mm). The water used by the crop under F1 and F2 levels of fertilization was about 60% of that used in the deep Vertisol site during 1995 and about 70% during 1996.

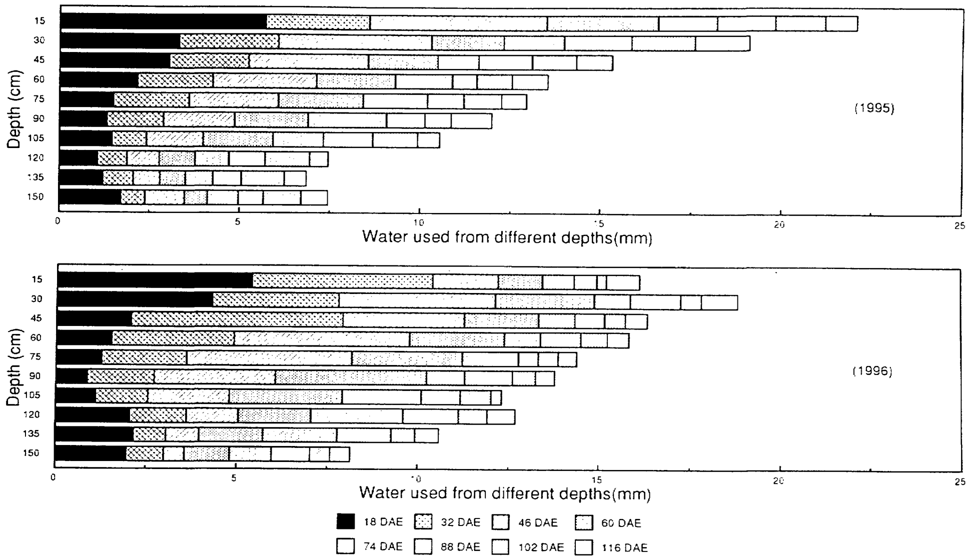


Fig.21. Water used by sorghum from different soil depths at different crop age in the vertic Inceptisol site (rabi 1995 and 1996).

Table 10. **Management treatments (planting time and fertility) effects on water used (mm) by M35-1 in the vertic Inceptisol site (*rabi* 1995 and 1996).**

	Rabi 1995	*Rabi* 1996
TRT	Water used (mm)	Water used (mm)
SD1	135.9	150.6
SD2	118.4	127.4
SED±	4.9	7.0
F	*	NS
F1	120.0	136.3
F2	134.3	141.7
SED±	3.6	11.9
F	NS	NS
0-15	22.1	16.1
15-30	19.1	18.8
30-45	15.3	16.3
45-60	13.5	15.8
60-75	12.9	14.4
75-90	12.0	14.0
90-105	10.5	12.3
105-120	7.4	12.7
120-135	6.8	10.6
135-150	7.4	8.1
SED±	0.95	1.40
F	***	***
CV(%)	12.7	8.8

4.9 TOTAL NITROGEN (TOTAL N) AND TOTAL PHOSPHOROUS (TOTAL P) UPTAKE

4.9.1 Total N and P Uptake in the Deep Vertisol Site (1995)

There were no statistical differences either at FL or at HAR between early or normal planting of sorghum for total nitrogen or total phosphorous uptake (Table 11). F2 and F3 fertility treatments of sorghum at FL and at HAR were significantly greater than F1 for total N and total P. There were 60 - 90% at FL and 30 - 50% at HAR more N uptake in the crop with F2 or F3 level than F1 at these periods. The crop under PR treatments was statistically different for total N at FL and at HAR and also significantly different for total P uptake at FL and at HAR. The three genotypes did not vary for total N or total P during FL or at HAR.

4.9.2 Total N and P Uptake in the Deep Vertisol Site (1996)

There were no differences between early or normal planting of sorghum in total N or total P uptake at FL or at HAR time. During FL or at HAR time, total N uptake by the crop across fertilities was statistically greater in F2 and F3 levels compared to F1. This was also true for the crop total P uptake during FL; but by HAR time, there were no differences in the total P uptake at any fertility level. There was no effect of protection during FL or at HAR between PR and NP crop for total N or total P uptakes. Among genotypes, there were no significant differences between them in total N uptake during FL or at HAR; and no differences for total P uptake during FL. However, there were statistically more total P uptake by M35-1 and IC 94004 than Swathi by HAR time (Table 11).

4.9.3 Total N and P Uptake in the Vertic Inceptisol Site (1995)

There were no differences in total N uptake between early or normal planting of sorghum at FL. At HAR, early planting was significantly different from normal planting for total N uptake. Total P uptake of the crop at the two dates at either FL or HAR was not significant (Table 12).

Total N and total P uptakes during FL and HAR in the crop fertilized with F2 level were statistically greater than under F1. There were no statistical differences between the three genotypes for total N or total P at either FL or HAR.

4.9.4 Total N and P Uptake in the Vertic Inceptisol Site (1996)

There was no effect of planting date of sorghum on total N uptake at either FL or HAR, and no effect to planting date on total P uptake at FL. By HAR, total P uptake of the crop was significantly more in early than in normal planting. Within fertility levels, the crop fertilized with F2 level had statistically greater N uptake at FL and HAR and significantly greater total P uptake at FL. By HAR, there were no differences in total P uptake of the crop at either fertility level. Among genotypes, there were no differences between them for total N or total P uptake during either FL or HAR (Table 12).

Table 11. Management treatments (planting time, fertility and shoot fly control) and cultivar effects on total nitrogen and total phosphorous uptake in sorghum at flowering and harvest time in the deep Vertisol site (*rabi* 1995 and 1996).

	Rabi 1995				*Rabi* 1996			
	Total N (kg/ha)		Total P (kg/ha)		Total N (kg/ha)		Total P (kg/ha)	
TRT	FL	HAR	FL	HAR	FL	HAR	FL	HAR
SD1	49.8	27.9	4.2	4.2	59.8	32.1	8.2	4.6
SD2	50.0	29.9	4.0	5.2	53.6	34.9	5.6	4.2
SED±	9.17	0.84	1.03	0.83	6.93	1.71	1.40	0.44
F	NS	NS	NS	NS	NS	NS	NS	NS
F1	33.3	22.7	3.1	4.2	39.8	27.7	5.5	3.9
F2	54.0	30.1	4.4	4.8	53.7	30.8	6.9	4.4
F3	62.4	33.8	4.7	5.2	76.5	42.0	8.4	5.0
SED±	5.85	1.95	0.44	0.36	4.73	2.27	0.53	0.38
F	**	**	*	*	***	***	**	NS
NP	46.6	26.3	3.2	4.3	56.7	33.7	7.0	4.4
PR	53.2	31.5	4.3	5.1	56.6	33.3	6.8	4.4
SED±	2.43	1.54	0.30	0.31	3.92	1.94	0.25	0.22
F	*	**	*	*	NS	NS	NS	NS
M35-1	49.5	30.3	4.0	4.9	58.8	34.8	7.1	4.7
Swathi	51.1	27.6	4.1	4.4	56.5	31.8	6.6	4.0
IC 94004	49.0	28.7	4.1	4.9	54.8	33.9	7.1	4.5
SED±	2.75	1.26	0.27	0.24	2.30	1.40	0.26	0.20
F	NS	NS	NS	NS	NS	NS	NS	***
CV%	7.5	4.6	11.4	14.7	9.9	17.7	16.1	19.8

Table 12. Management treatments (planting time and fertility) and cultivar effects on total nitrogen and total phosphorous uptake in sorghum at flowering and harvest time in the vertic Inceptisol site (*rabi* 1995 and 1996).

	Rabi 1995				*Rabi* 1996			
TRT	Total N (kg/ha)		Total P (kg/ha)		Total N (kg/ha)		Total P (kg/ha)	
	FL	HAR	FL	HAR	FL	HAR	FL	HAR
SD1	37.5	23.3	2.8	3.6	38.5	34.1	5.4	5.1
SD2	22.6	18.7	2.1	3.0	37.7	30.9	4.0	3.1
SED±	5.87	0.91	0.34	0.23	6.10	5.40	0.54	0.48
F	NS	*	NS	NS	NS	NS	NS	*
F1	20.2	15.9	1.7	2.8	30.0	29.2	3.8	3.8
F2	39.9	26.2	3.3	3.8	46.2	35.7	5.6	4.4
SED±	2.42	1.42	0.15	0.20	3.17	2.29	0.36	0.38
F	**	**	**	**	**	*	**	NS
M35-1	30.7	23.1	2.6	3.4	36.1	34.1	4.4	4.3
Swathi	26.7	20.5	2.2	3.2	41.0	31.1	4.8	3.8
IC 94004	32.7	19.5	2.6	3.2	37.2	32.4	4.8	4.2
SED±	3.55	2.52	0.29	0.30	3.25	2.31	0.39	0.32
F	NS	NS	NS	NS	NS	NS	NS	NS
CV%	19.5	5.3	4.7	8.5	14.4	17.4	13.2	19.2

4.10 PER CENT SHOOT FLY DEAD HEART (%SFDH) (21 DAE), PER CENT INTACT (%IN), PER CENT AFFECTED AND RECOVERED (%AR) AND PER CENT AFFECTED AND NOT RECOVERED (%AN) PLANTS

4.10.1 %SFDH (21 DAE), %IN, %AR AND %AN in the Deep Vertisol Site (1995 and 1996)

The %SFDH across management treatments was less during 1996 compared to 1995. During 1995, early planting of sorghum had significantly less %SFDH when compared to normal planting. However, during 1996, there were no statistical differences between the two sorghum planting dates in %SFDH (Fig 22). The crop fertilized with F1, F2 and F3 fertility levels recorded similar %SFDH during 1995 and 1996. The sorghum under NP had 50% SFDH compared to 24% for PR crop during 1995, and 14% (without protection) and only 1% (with protection) during 1996. These differences in the %SFDH of sorghum between NP and PR crop over both seasons were significant. Cultivar IC 94004 was more susceptible than either Swathi or M35-1; and the differences between them during either season were significant (Fig 22).

Significantly higher %IN plants were observed in early than normal planting of sorghum during 1995 and 1996. It was interesting to note that the affected plants from normal planting of sorghum during both seasons were able to recover significantly more than those from early planting. The %AN plants were more in normal planting of the crop during 1995 (28%) than in 1996 (8%). However, the differences in %AN between early and normal planting of sorghum were not significant during 1995 and were statistically different during 1996. There was no effect of fertilization on %IN, %AR and %AN plants. During 1995, PR sorghum had significantly higher %IN plants and significantly lesser %AN plants when compared to NP crop. Nevertheless, there was no variation between PR and NP sorghum crop in %IN, %AR or %AN plants during 1996. Irrespective of the season, IC 94004 had less %IN and more %AR plants than either Swathi or M35-1 (Fig 23).

Accordingly IC 94004 productive (%IN + %AR) and %AN plants were not significantly different from either Swathi or M35-1 during 1995. During 1996, there were significant differences between the three genotypes for productive plants.

4.10.2 %SFDH (21 DAE), %IN, %AR AND %AN in the Deep Vertisol Site (Pooled)

4.10.2.1 *Effect of season*

There were more %SFDH and more %AN plants of sorghum during 1995 compared to 1996 season (Figs 22 and 23). At the same time, there was significantly higher %IN and %AR plants during 1996 than 1995. This means that there were more productive plants during 1996 (about 95%) compared to 1995 (about 75%).

4.10.2.2 *Effect of planting date*

Between planting dates of sorghum, there was significantly less %SFDH infestation (12 and 33%), and significantly more %IN plants (68 and 25%) in early than in normal planting respectively. At the same time, there were significantly more plants that were able to recover from normal than from early planting of sorghum (58 and 19%) and as such, the two dates had finally the same productive plants and accordingly they did not vary in the %AN plants (Fig 23).

4.10.2.3 *Effect of fertility and protection*

There were no differences in %SFDH, %IN, %AR or %AN plants among fertility levels of sorghum. On the otherhand, in the sorghum crop with protection, the %SFDH was reduced to about 12% compared to 32% in the non protected crop; the %IN was comparatively higher (53% compared to 40% in NP) and the %AN was reduced to 12% compared to 18% with NP (Fig 23).

4.10.2.4 *Effect of genotype*

Within genotypes IC 94004 had significantly greater %SFDH and lesser %IN, but also had significantly more %AR plants than either Swathi or M35-1 and as such the three genotypes had the same percentage of productive plants (about 85% for each).

4.10.3 %SFDH (21 DAE), %IN, %AR AND %AN By Management Treatment And Genotypes in the Vertic Inceptisol Site (1995 and 1996)

There was less %SFDH infection during 1996 as compared to 1995. Early planting of sorghum had significantly less %SFDH than normal planting during 1995 only. During 1995 and 1996, there were no statistical differences between the fertility levels in %SFDH. The genotypes differed significantly during 1995; IC 94004 also being the most susceptible to shoot fly and recorded greater %SFDH than either M35-1 or Swathi. During 1996, there were no significant differences in %SFDH between the three genotypes (Fig 24).

There were significant differences in %IN, % AR and %AN plants between early and normal planting of sorghum during 1995, but no such differences for the aforesaid attributes were observed during 1996. During 1995, the %IN of sorghum differed significantly with fertilization between F2 and F1 but no such differences were observed between them in %AR or %AN during either 1995 or 1996. As fertility level increased to F2, %IN plants in sorghum increased from 34% to 45% during 1995 and from 40 to 54% during 1996. During both seasons, there was an increase in %IN plants and a decrease in %AN plants of sorghum as fertility level of the crop increased from F1 to F2. During 1995 among the cultivars, IC 94004 had significantly lower %IN, but also had greater %AR plants than either Swathi or M35-1, so that finally the productive plants of the three genotypes were similar.

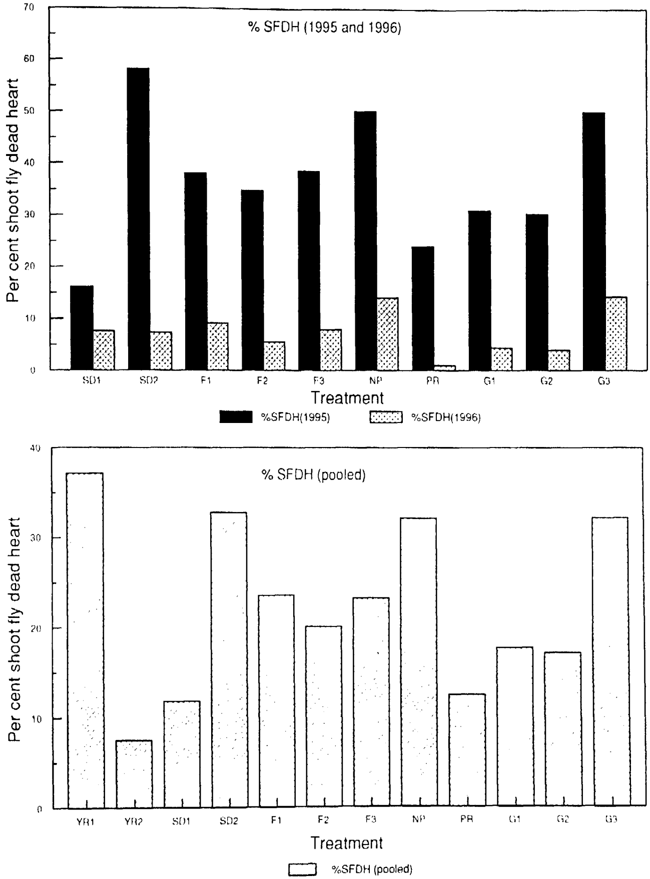


Fig.22. Per cent shoot fly dead heart at 21 DAE by management and genotype treatments in sorghum in the deep Vertisol site (rabi 1995, 1996 and pooled).

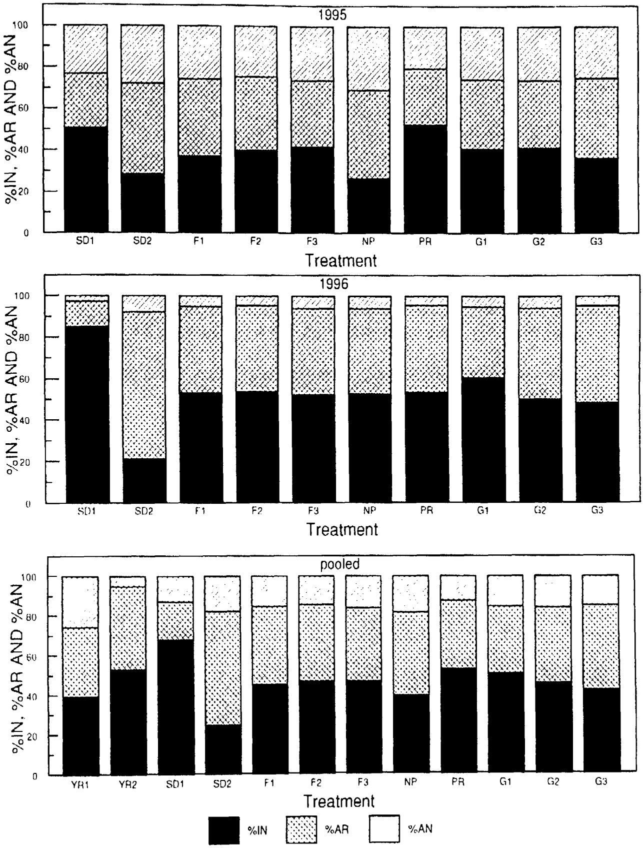


Fig.23. Per cent intact, affected and recovered and affected and non recovered plants due to shoot fly by management and genotype treatments in the deep Vertisol site (rabi 1995, 1996 and pooled).

During 1996, IC 94004 had followed the same trend as that of 1995 (in %productive plants), but without real differences between it and the other two genotypes in either %productive or %AN plants (Fig 25).

4.10.4 <u>%SFDH (21 DAE), %IN, %AR and %AN in the Vertic Inceptisol Site (Pooled)</u>

4.10.4.1 *Effect of season*

Across seasons and as in the deep Vertisol site, there were significantly lesser %SFDH infestation (Fig 24) and significantly more %IN and %AR sorghum plants during 1996 than 1995 (Fig 25). Accordingly, there were about 95% productive plants during 1996 compared to 75% productive plants in 1995.

4.10.4.2 *Effect of planting date*

Among dates, early planting of sorghum had significantly less %SFDH and significantly greater %IN, but it had also significantly less % AR than normal planting of sorghum and as such had the same productive plants as compared to normal planting (85 and 80%).

4.10.4.3 *Effect of fertility*

Among fertility levels, the crop fertilized with F2 and F1 levels had similar %SFDH and %productive plants.

4.10.4.4 *Effect of genotype*

Within genotypes, IC 94004 had significantly more %SFDH; less %IN plants, but more %AR plants than either Swathi or M35-1. Finally, the three genotypes had the same productive plants (81 - 83%).

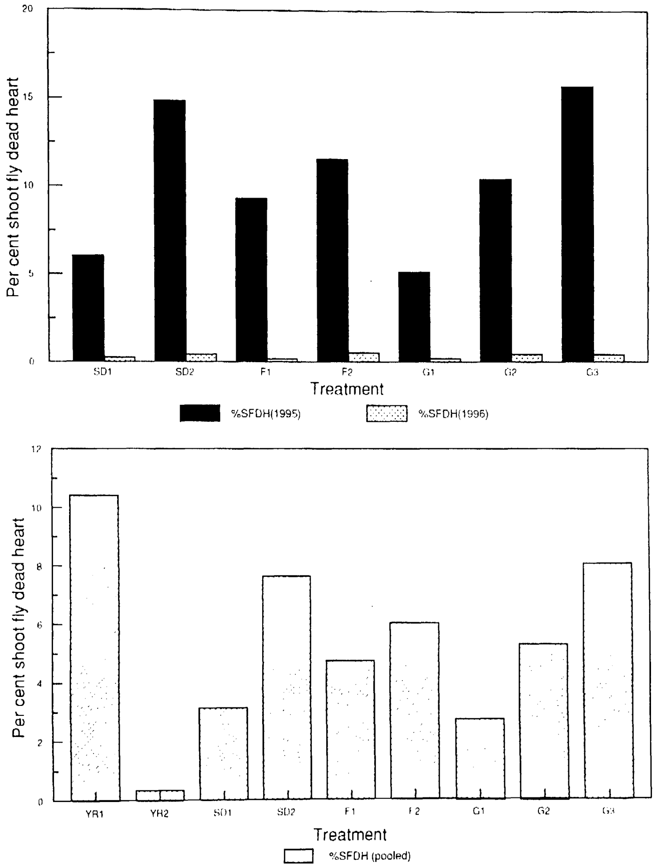


Fig.24. Per cent shoot fly dead heart at 21 DAE by management and genotype treatments in sorghum in the vertic Inceptisol site (rabi 1995, 1996 and pooled).

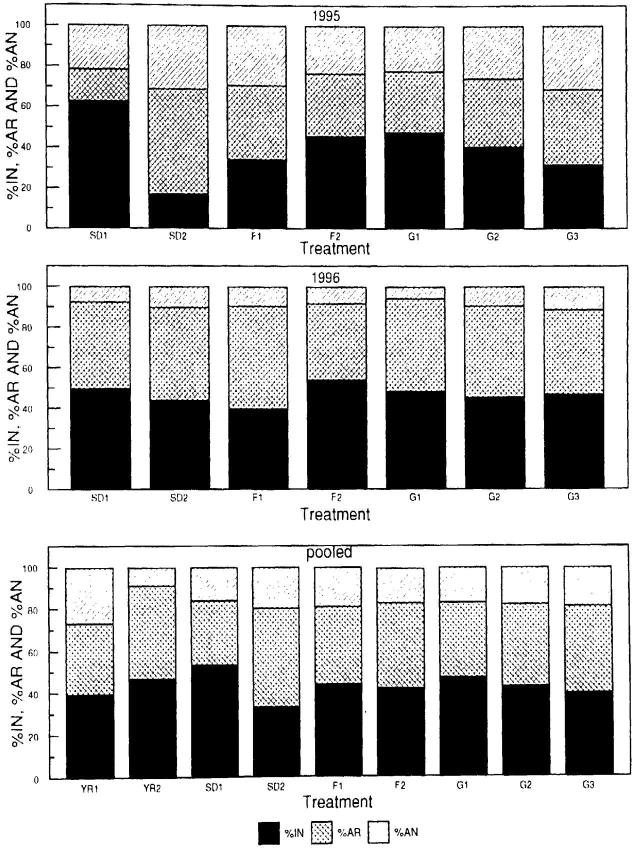


Fig.25. Per cent intact, affected and recovered and affected and non recovered plants due to shoot fly by management and genotype treatments in the vertic Inceptisol site (rabi 1995, 1996 and pooled).

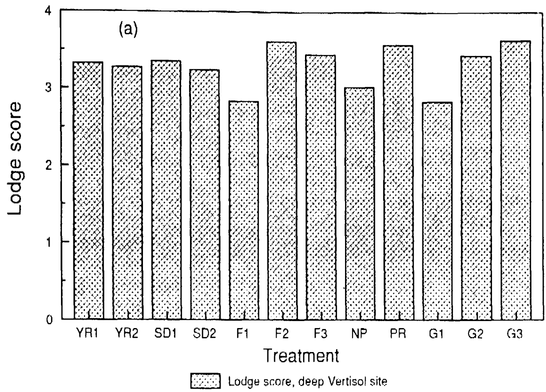
4.11 LODGING SCORE (LS)

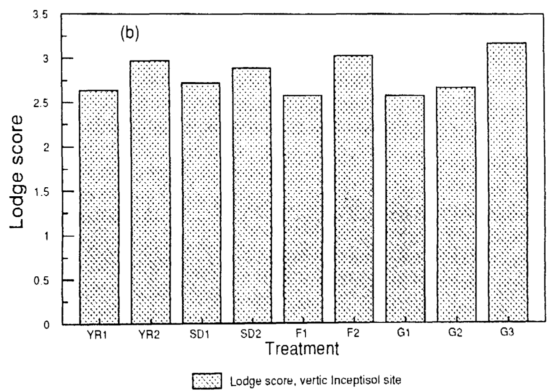
4.11.1 LS in the Deep Vertisol Site (Pooled)

There were no differences in lodging score between the two seasons, between the planting dates or between the three fertilities. There were significantly more lodged plants in sorghum with PR than with NP treatment. Among genotypes, IC 94004 had significantly more lodged plants than either Swathi or M35-1 (Fig 26a).

4.11.2 LS in the Vertic Inceptisol Site (Pooled)

There were no significant differences in lodging score between seasons, planting dates, fertility levels and genotypes of sorghum, but there were slightly more lodged plants during 1996 than 1995, more lodged plants at normal than early planting, at F2 than F1 and with IC 94004 than either Swathi or M35-1 (Fig 26b).





1= no lodging, 2= 25% lodging, 3= 50% lodging,
4= 75% lodging and 5= 100% lodging

Fig.26. Lodge score in sorghum by management and genotype treatments in sorghum in the deep vertisol (a), vertic Inceptisol (b) sites (pooled).

4.12 PLANT HEIGHT (PLH) (cm)

4.12.1 PLH in the Deep Vertisol Site (1995 and 1996)

During 1995 and 1996, early planting of sorghum had significantly taller plants (208 and 218 cm) than normal planting (184 and 194 cm) (Table 13). During both seasons, the crop fertilized with F1 level had significantly shorter plants than the crop at either F2 or F3. Likewise, PR crop plants of sorghum were significantly taller than NP crop plants during both seasons. There were cultivar differences, IC 94004 and M35-1 being the tallest; and the differences between them and Swathi were significant during 1995 and 1996 (Table 13).

4.12.2 PLH in the Vertic Inceptisol Site (1995 and 1996)

Across management treatments and seasons, sorghum plants were shorter in the vertic Inceptisol in comparison to those in the deep Vertisol site. During 1995, early planting of sorghum significantly favoured PLH (189 vs 149 cm). This was also true during 1996 (200 vs 156 cm), differences between the two dates were significant. During 1995 and 1996, PLH increased as fertility level to sorghum increased from F1 to F2. The PLH of the three sorghum cultivars varied significantly during 1995 and 1996; IC 94004 being the tallest than either Swathi or M35-1 (Table 14).

4.13 PANICLE LENGTH (PNLN) (cm)

4.13.1 PNLN in the Deep Vertisol Site (1995 and 1996)

The planting date of sorghum had no significant effect on PNLN during either 1995 or 1996. There was slight increase in plant PNLN with increased fertility level to sorghum from F1 to F2 during 1995, and from F1 to F3 during 1996. The differences in PNLN between the crop fertilized with F2 or F3 levels compared to that under F1 were significant during 1996. PR crop tend to have slightly less PNLN than NP crop, presumably to more plant competition with PR than NP treatment. The differences in PNLN were not significant during 1995, but were statistically different during 1996. During 1995 and 1996, IC 94004 had significantly greater PNLN than either Swathi or M35-1 (Table 13).

4.13.2 PNLN in the Vertic Inceptisol Site (1995 and 1996)

Across management treatments and seasons, PNLN in the vertic Inceptisol was less than in the deep Vertisol site. During 1995 and 1996, and as in the deep Vertisol site, early planting of sorghum with high fertility had slightly greater PNLN (but without significant differences). Also, IC 94004 during 1995 and 1996 had significantly more PNLN than either M35-1 or Swathi (Table 14).

4.14 DAYS TO FLOWERING (DFL)

4.14.1 DFL in the Deep Vertisol Site (1995 and 1996)

Days to FL did not vary significantly in either early or normal planting of sorghum, but during both seasons, the early sown crop plants flowered slightly late (69 vs 64 DAE). Across fertility treatments, there was significant decrease during 1995 and 1996 in sorghum days to FL with increasing fertility levels from F1 to F2 or from F1 to F3. This was also true with protected treatments. PR crop plants needed about 66 DAE to flower in comparison to 67 - 68 DAE in NP crop plants, differences between PR and NP crop were significant during 1995 and 1996. Across seasons among the three cultivars, IC 94004 required about 63 - 65 DAE to flower. This value was significantly different from that of Swathi or M35-1 which had flowered at 67 - 68 DAE during both seasons (Table 13).

4.14.2 DFL in the Vertic Inceptisol Site (1995 and 1996)

Across management treatments, sorghum plants required fewer days to flower during 1996 than 1995 and more days to flower when compared to the deep Vertisol site. During 1995 and 1996, early planting took more days to flower than normal planting, differences between the two dates of sorghum planting were significant during 1995 only. Across both seasons and with increased fertility level to F2, there was significant decrease in the number of days to FL during 1995 and 1996. IC 94004 flowered in statistically less days than either Swathi or M35-1 during 1995 and 1996 (Table 14).

Table 13. Management treatments (planting time, fertility and shoot fly control) and cultivar effects on plant height (cm), panicle length (cm) and days to flowering in sorghum in the deep Vertisol site (*rabi* 1995 and 1996).

	Rabi 1995)			*Rabi* 1996		
TRT	PLH (cm)	PNLN (cm)	FL (days)	PLH (cm)	PNLN (cm)	FL (days)
SD1	207.7	16.7	68.9	217.8	19.4	68.5
SD2	183.7	14.6	64.7	193.8	17.3	64.1
SED±	3.78	0.65	1.14	3.63	0.74	1.58
F	*	NS	NS	*	NS	NS
F1	186.3	14.6	68.8	199.0	18.1	68.3
F2	200.7	16.3	66.1	206.3	18.3	65.5
F3	200.1	16.0	65.5	212.0	18.9	65.0
SED±	3.66	0.74	0.67	4.31	0.21	0.57
F	**	NS	**	*	*	***
NP	183.8	15.6	67.9	195.5	18.8	66.7
PR	207.6	15.7	65.7	216.1	18.0	65.9
SED±	2.45	0.49	0.32	2.12	0.30	0.23
F	***	NS	***	***	*	**
M35-1	192.0	15.1	67.7	197.1	16.8	67.3
Swathi	182.3	15.2	68.1	188.4	17.6	68.2
IC 94004	212.9	16.7	64.6	231.9	20.7	63.4
SED±	2.57	0.51	0.34	2.24	0.22	0.26
F	***	**	***	***	***	***
CV(%)	5.6	5.1	2.1	4.6	5.2	1.7

Table 14. Management treatments (planting time and fertility) and cultivar effects on plant height (cm), panicle length (cm) and days to flowering in sorghum in the vertic Inceptisol site (*rabi* 1995 and 1996).

	Rabi 1995			*Rabi* 1996		
TRT	PLH (cm)	PNLN (cm)	FL (days)	PLH (cm)	PNLN (cm)	FL (days)
SD1	188.9	15.3	70.8	199.7	17.3	68.0
SD2	149.4	13.0	67.7	156.3	14.5	64.5
SED±	6.43	0.59	0.73	0.99	0.80	1.33
F	*	NS	*	***	NS	NS
F1	160.1	13.4	71.9	174.2	15.7	67.5
F2	178.2	14.9	66.7	181.8	16.1	64.9
SED±	7.60	0.68	1.13	2.82	0.36	0.35
F	NS	NS	*	NS	NS	**
M35-1	171.1	12.8	69.9	170.9	14.4	66.4
Swathi	157.4	13.5	71.5	168.1	15.6	68.9
IC 94004	179.0	16.3	66.4	195.0	17.8	63.4
SED±	4.71	0.77	0.89	3.91	0.22	0.57
F	**	***	***	***	***	***
CV(%)	6.8	5.1	1.3	5.4	3.4	2.1

4.15 GRAIN, STOVER, BIOMASS YIELDS AND HARVEST INDEX

4.15.1 In the Deep Vertisol Site (1995)

Early and normal sorghum planting dates in 1995 had similar grain, stover and biomass yields and %HI (Table 15). Grain, fodder and biomass yields in the crop fertilized with F2 and F3 levels were at par, but these treatments were significantly greater than at F1 for the same yield attributes. The %HI remained insensitive with changes in fertility levels and decreased at low fertility level (23.8 %) and increased at high levels (26.6 %). Grain, fodder, and biomass yields significantly responded to spraying against shoot fly, the response was greater for fodder and biomass yields and narrower for grain yield resulting in significantly lower %HI in the crop with spray treatments (Table 15). Among genotypes, M35-1 and IC 94004 significantly out-yielded Swathi in grain, fodder and biomass yields. The %HI of the three cultivars were similar.

4.15.2 Deep Vertisol Site (1996)

Early planting of sorghum produced significantly more grain, fodder and biomass yields and significantly more %HI than normal planting (Table 15). Among fertility levels, the crop fertilized with F2 and F3 levels was significantly different from that under F1 in grain, stover and biomass yields. There were no significant differences between the levels of fertilization in %HI, but similar trend as in 1995 for %HI to increase as fertility level increased from F1 to F3. Unlike sorghum grain yield, which was not affected by spraying, sorghum stover and biomass yields were statistically enhanced by spraying. The %HI pattern of the crop during 1996 was similar to that during 1995 in that it decreased slightly with spraying but non significantly different in 1996. Among the three genotypes, IC 94004 and M35-1 had significantly more grain, stover and biomass yields than Swathi. The three genotypes did not differ in their %HI (Table 15).

Table 15. **Management treatments (planting time, fertility and shoot fly control) and cultivar effects on stover, grain, biomass yields (t/ha) and per cent harvest index (%HI) of sorghum in the deep Vertisol site (*rabi* 1995 and 1996).**

	Rabi 1995 (t/ha)				*Rabi* 1996 (t/ha)			
TRT	stover	grain	biomass	%HI	stover	grain	biomass	%HI
SD1	3.38	1.14	4.79	23.8	4.14	1.91	6.67	28.5
SD2	3.24	1.36	5.22	26.1	3.20	1.10	4.73	22.6
SED±	0.10	0.10	0.18	1.22	0.08	0.14	0.12	2.46
F	NS	NS	NS	NS	**	*	**	NS
F1	2.98	1.06	4.45	23.8	3.39	1.32	5.15	24.8
F2	3.59	1.29	5.30	24.3	3.62	1.49	5.60	25.2
F3	3.36	1.40	5.27	26.6	4.01	1.71	6.36	26.7
SED±	0.18	0.11	0.26	2.08	0.22	0.12	0.28	1.39
F	*	*	*	NS	*	*	**	NS
NP	2.51	1.14	4.08	27.9	3.39	1.51	5.43	26.9
PR	4.11	1.36	5.94	22.9	3.96	1.50	5.98	24.3
SED±	0.16	0.08	0.21	1.68	0.13	0.09	0.19	1.43
F	***	*	***	*	***	NS	*	NS
M35-1	3.29	1.35	5.13	26.3	3.78	1.59	5.91	26.0
Swathi	2.98	1.14	4.59	24.8	3.38	1.39	5.31	25.8
IC 94004	3.66	1.26	5.31	23.7	3.85	1.53	5.89	24.9
SED±	0.13	0.07	0.17	1.23	0.12	0.06	0.16	0.78
F	***	*	***	NS	***	**	***	NS
CV(%)	3.9	9.9	4.4	5.9	2.6	11.5	2.6	11.8

4.15.3 Deep Vertisol Site (Pooled)

4.15.3.1 *Effect of season*

There were no differences between 1995 and 1996 in the crop grain and biomass yields and %HI. The two seasons were significantly different for stover yield (Table 16).

4.15.3.2 *Effect of planting date*

Across both years, early planting of sorghum had significantly greater stover, grain and biomass yields than normal planting. There were no differences in %HI between early or normal planting (Table 16).

4.15.3.3 *Effect of fertility*

The crop fertilized with F3 or F2 level had statistically more stover, grain and biomass yields than that under F1. There were no differences between the fertility levels in the crop %HI.

4.15.3.4 *Effect of protection*

The crop under PR had significantly greater stover and biomass yields but significantly lower %HI than the crop under NP treatment. There was no significant difference in sorghum grain yield between PR and NP crop (Table 16).

4.15.3.5 *Effect of genotype*

IC 94004 and/or M35-1 had significantly greater stover, grain and biomass yields than Swathi. The three genotypes did not differ in their %HI (Table 16).

Table 16. Management treatments (planting time, fertility and shoot fly control) and cultivar effects on stover, grain, biomass yields (t/ha) and per cent harvest index (%HI) of sorghum in the deep Vertisol site (pooled).

	Deep Vertisol site (Pooled)			
TRT	stover (t/ha)	grain (t/ha)	biomass (t/ha)	%HI
YR1	3.31	1.25	5.01	25.3
YR2	3.67	1.51	5.70	25.6
SED±	0.12	0.17	0.27	1.95
F	*	NS	NS	NS
SD1	3.76	1.50	5.73	25.8
SD2	3.22	1.26	4.98	25.1
SED±	0.06	0.08	0.11	1.37
F	**	*	**	NS
F1	3.18	1.19	4.80	24.7
F2	3.60	1.39	5.45	24.9
F3	3.68	1.56	5.81	26.7
SED±	0.14	0.08	0.19	1.25
F	**	**	***	NS
NP	2.95	1.32	4.75	27.3
PR	4.03	1.43	5.96	23.6
SED±	0.10	0.06	0.14	1.10
F	***	NS	***	**
M35-1	3.54	1.47	5.52	26.3
Swathi	3.18	1.27	4.95	25.5
IC 94004	3.76	1.40	5.60	24.6
SED±	0.09	0.05	0.12	0.72
F	***	***	***	NS
CV(%)	4.3	11.0	6.3	9.4

4.16 INTERACTION AMONG TREATMENTS FOR STOVER, GRAIN, BIOMASS YIELDS AND PER CENT HARVEST INDEX IN THE DEEP VERTISOL SITE (POOLED DATA)

4.16.1 Stover Yield

The interaction effect of protection x genotype was significant. The stover yield in IC 94004 responded more to shoot fly protection than in each of the other two cultivars (Fig 27).

4.16.2 Grain Yield

There were significant interactions of sowing date x genotype and of fertility x genotype as shown in Figs 28a and 28b. In the sowing date x genotype interaction, the grain yield of IC 94004 (unlike that of M35-1 and Swathi) significantly decreased when planting date was shifted from early to normal. The grain yield of M35-1 or Swathi at normal planting was almost the same as that at early planting. The interaction of fertility x genotype for grain yield was due to progressive grain yield response across fertility levels with M35-1 and IC 94004 which was statistically different from the grain yield response of Swathi across the same levels. In Swathi, grain yield remained the same between F2 and F3 levels (Fig 28b).

4.16.3 Biomass Yield

The interaction of sowing date x fertility, of fertility x genotype and of sowing date x fertility x genotype were all significant. In the sowing date x fertility interaction, the biomass responded more to increased fertility in the early than in the normal planting of sorghum (Fig 29a). In the fertility x genotype interaction, there was a positive biomass response to increasing fertility level to F3 in M35-1 and IC 94004, which was significantly different from the biomass response of Swathi (only to F2)

(Fig 29b). In the sowing date x fertility x genotype interaction of sorghum, in the early planting, there was a biomass increase in Swathi even at higher fertility levels (F3). This biomass increment at early planting with fertility increments to F3 was relatively more in M35-1 and IC 94004 than Swathi. At normal planting, the biomass response at F3 level was positive in M35-1 and IC 94004 and negative in Swathi (Fig 29c).

4.16.4 Per cent Harvest Index (%HI)

The sowing date x genotype and the sowing date x fertility x genotype interactions were significant for %HI. In the first interaction and as sorghum planting was advanced to early date, there was a positive %HI response in IC 94004 but a negative %HI response in M35-1 (Fig 30a). In the sowing date x fertility x genotype interaction of sorghum, the %HI of IC 94004 at early planting had increased with fertility increase up to F3 and in the normal planting in M35-1 only (Fig 30b).

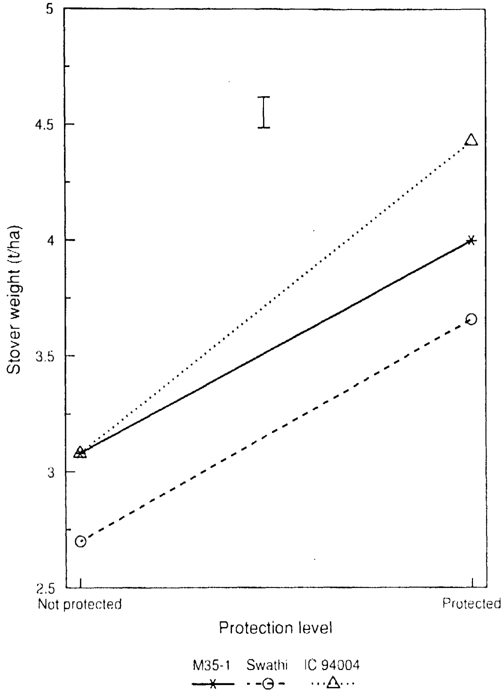


Fig.27. Protection x genotype interaction for stover weight of sorghum in the deep Vertisol site (pooled data).

vertical bar is SED.

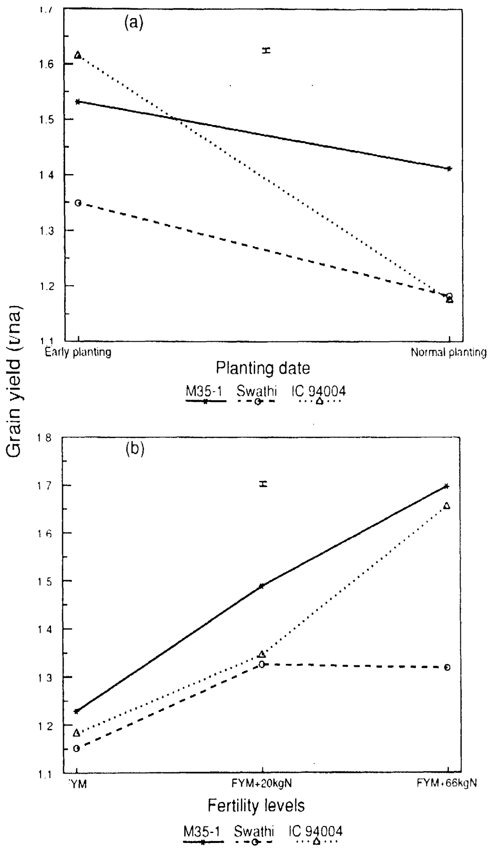


Fig.28. Planting date x genotype (a) and fertility x Genotype (b) interactions for grain yield of sorghum in the deep Vertisol Site (pooled data).

vertical bars are SED.

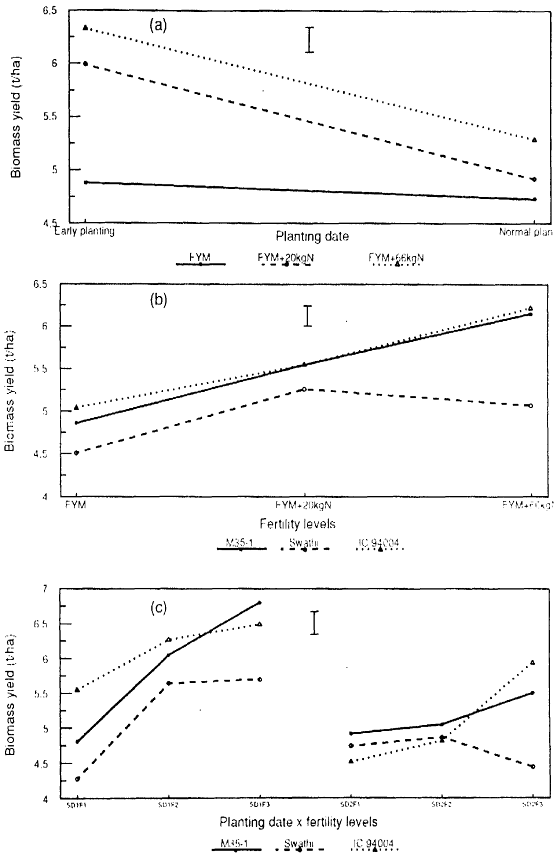


Fig.29. Planting date x fertility (a), fertility x genotype (b) and planting date x fertility x genotype (c) interactions for biomass yield of sorghum in the deep vertisol site (pooled data).

vertical bars are SED.

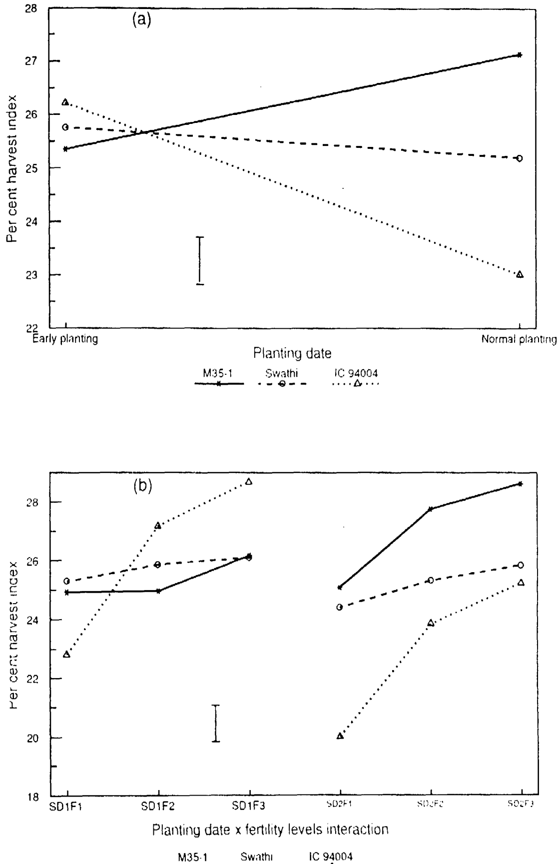


Fig.30. Planting date x genotype (a) and planting date x fertility x genotype (b) interactions for harvest index (%) of sorghum in the deep Vertisol site (pooled data).

vertical bars are SED.

4.17 GRAIN, STOVER, BIOMASS YIELDS AND HARVEST INDEX

4.17.1 Vertic Inceptisol Site (1995)

Planting date of sorghum had no effect on fodder, grain and biomass yields and no effect on %HI (Table 17). Sorghum crop fertilized with F1 level out - yielded that under F2 in fodder and biomass yields, and differences were significant only for grain yield. There were no statistical differences between the crop fertilized with F1 and F2 levels in their %HI. Across cultivars, fodder and biomass yield pattern followed the same pattern as that in the deep Vertisol site in that M35-1 and IC 94004 generally out-yielded Swathi for the aforesaid yield attributes, but differences between the three cultivars in these attributes were not significant (Table 17).

4.17.2 Vertic Inceptisol Site (1996)

The stover and biomass yields in the early planting were significantly greater than in the normal planting. Although there were no statistical differences between early and normal planting of sorghum in grain yield or %HI, these followed the same pattern of stover and biomass yields (Table 17). The application of F2 significantly enhanced the biomass yield of sorghum and resulted in small non significant increase in both grain and stover yields. The %HI was at par over the two fertility levels. Among genotypes, IC 94004 and M35-1 were significantly different from Swathi in grain yield, all the three genotypes were statistically the same in their stover and biomass yields (Table 17). M35-1 had significantly lower %HI than either Swathi or IC 94004.

4.17.3 Vertic Inceptisol Site (Pooled)

4.17.3.1 *Effect of season*

There were significantly greater stover, grain and biomass yields of sorghum and accordingly more %HI during 1996 than 1995.

4.17.3.2 *Effect of planting date*

Early planting of sorghum had significantly greater stover, grain and biomass yields than normal planting. There were no differences in %HI between early or normal planting (Table 18).

4.17.3.3 *Effect of fertility*

Sorghum crop fertilized with F2 level had statistically more stover, grain and biomass yields than that under F1. There were no differences between the levels of fertility in %HI.

4.17.3.4 *Effect of genotype*

IC 94004 and/or M35-1 had greater stover, grain and biomass yields than Swathi, but differences between the three genotypes were significant for stover yield only. The three genotypes had the same %HI.

Table 17. **Management treatments (planting time and fertility) and cultivar effects on stover, grain, biomass yields (t/ha) and per cent harvest index (%HI) of sorghum in the vertic Inceptisol site (*rabi* 1995 and 1996).**

	Rabi 1995 (t/ha)				*Rabi* 1996 (t/ha)			
TRT	stover	grain	biomass	%HI	stover	grain	biomass	%HI
SD1	2.65	0.90	3.84	23.5	3.73	1.71	6.03	28.3
SD2	2.51	0.84	3.67	22.9	2.87	1.15	4.41	26.1
SED±	0.12	0.02	0.16	1.51	0.15	0.24	0.33	3.25
F	NS	NS	NS	NS	*	NS	*	NS
F1	2.14	0.71	3.07	23.0	3.13	1.38	4.95	27.6
F2	3.02	1.04	4.44	23.3	3.47	1.48	5.49	26.7
SED±	0.47	0.12	0.58	2.87	0.13	0.09	0.12	1.30
F	NS	*	NS	NS	NS	NS	**	NS
M35-1	2.57	0.93	3.79	24.5	3.50	1.40	5.37	25.7
Swathi	2.37	0.83	3.50	24.8	3.01	1.31	4.84	27.1
IC 94004	2.80	0.85	3.97	21.4	3.38	1.58	5.45	28.7
SED±	0.26	0.10	0.34	2.00	0.21	0.10	0.33	0.94
F	NS	NS	NS	NS	NS	*	NS	**
CV(%)	5.8	2.3	5.1	7.9	5.5	6.5	7.8	8.5

Table 18. Management treatments (planting time and fertility) and cultivar effects on stover, grain, biomass yields (t/ha) and per cent harvest index (%HI) of sorghum in the vertic Inceptisol site (pooled).

Vertic Inceptisol site (pooled)				
TRT	stover (t/ha)	grain (t/ha)	biomass (t/ha)	%HI
YR1	2.58	0.87	3.75	23.5
YR2	3.30	1.43	5.22	27.2
SED±	0.07	0.09	0.20	0.92
F	***	**	**	*
SD1	3.19	1.31	4.94	26.1
SD2	2.69	0.99	4.04	24.6
SED±	0.09	0.10	0.18	1.79
F	**	*	**	NS
F1	2.63	1.04	4.01	25.3
F2	3.25	1.26	4.97	25.3
SED±	0.24	0.07	0.29	1.58
F	*	*	*	NS
M35-1	3.04	1.16	4.58	25.1
Swathi	2.69	1.07	4.17	25.8
IC 94004	3.09	1.22	4.71	25.2
SED±	0.16	0.07	0.24	1.11
F	*	NS	NS	NS
CV(%)	3.0	9.7	7.1	4.5

4.18 INTERACTION AMONG TREATMENTS FOR STOVER, GRAIN, BIOMASS YIELDS AND PER CENT HARVEST INDEX IN THE VERTIC INCEPTISOL SITE (POOLED DATA)

There were no interactions among treatments in stover, grain, or biomass yields or in %HI in the vertic Inceptisol site.

4.19 GRAIN MASS, GRAIN NUMBER PER UNIT AREA AND GRAIN NUMBER AND WEIGHT PER PANICLE

4.19.1 Deep Vertisol Site (1995)

There were no significant differences in grain mass, grain number per unit area and grain number and weight per panicle between planting dates of sorghum (Table 19). Grain mass was insensitive to changing levels of fertility. The remaining yield components (grain number per unit area and grain number and weight per panicle) had a positive response to increasing fertility levels, the crop fertilized with F3 and F2 levels being significantly greater for these yield components than that under F1 (Table 19). The only yield component that was significantly enhanced by crop protection was grain number per unit area (Table 19). M35-1 and IC 94004 had statistically larger grain mass over Swathi. This was the main reason for the greater grain yield in M35-1 and IC 94004 over Swathi (Table 19). Swathi had slightly greater grain number per panicle, but this was not significant to offset it's smaller seed size.

4.19.2 Deep Vertisol Site (1996)

Grain mass was again unaffected by changes in dates from early to normal planting of sorghum. The remaining yield components (grain number per unit area, grain number and weight per panicle) were significantly increased by early planting. There was significant inverse relation between grain mass with increasing levels of fertility from F1 to F3. The rest of the yield components statistically increased across the levels of fertilities (Table 19). Spraying had no effect on grain mass, grain number per unit area or per panicle, but it had significant effect on the crop grain weight per panicle. Among genotypes, IC 94004 and M35-1 had significantly greater grain mass and grain weight per panicle than Swathi (Table 19).

4.19.3 Deep Vertisol Site (Pooled)

4.19.3.1 *Effect of season*

There were no significant differences between the two seasons in terms of grain mass, grain number per unit area and per panicle or in their grain weight per panicle, although grain number per unit area and per panicle as well as grain weight per panicle during 1996 exceeded that in 1995 by 15 - 25% (Table 20).

4.19.3.2 *Effect of planting date*

The grain number per unit area and per panicle were significantly greater in early than normal planting of sorghum; however, there were no statistical differences between the dates in grain mass or panicle weight.

4.19.3.3 *Effect of fertility*

There was an inverse significant relation between the levels of fertility and grain mass; the crop fertilized with F1 level had a greater mass than that under F2 or F3. The grain number per unit area and per panicle as well as grain weight per panicle were statistically greater in the crop with F2 and F3 levels than with F1.

4.19.3.4 *Effect of protection*

Crop protection against shoot fly had no effect on grain mass and grain number per panicle, but it had significant effect on sorghum grain number per unit area. Grain weight per panicle was significantly less in protected crop (Table 20).

4.19.3.5 *Effect of genotype*

M35-1 and/or IC 94004 had significantly more grain mass than Swathi. There were no differences between the three genotypes in their grain number per unit area or their grain weight per panicle. Unlike IC 94004 and M35-1, Swathi had significantly greater grain number per panicle (Table 20).

Table 19. Management treatments (planting time, fertility and shoot fly control) and cultivar effects on grain mass (g/100), grain number per square meter and grain number and weight per panicle in sorghum in the deep Vertisol site (*rabi* 1995 and 1996).

	Rabi 1995				*Rabi* 1996			
TRT	GRM (g/100)	GRNO (m^2)	GRNO (PN)	GRWT (g/PN)	GRM (g/100)	GRNO (m^2)	GRNO (PN)	GRWT (g/PN)
SD1	2.57	4332	457	11.37	2.35	8297	744	17.15
SD2	2.59	5573	505	12.84	2.49	4429	444	10.96
SED±	0.03	354.6	65.4	1.55	0.26	655.4	60.7	1.18
F	NS	NS	NS	NS	NS	*	*	*
F1	2.62	4106	357	9.11	2.58	5212	490	12.35
F2	2.59	5080	497	12.56	2.38	6334	582	13.67
F3	2.53	5673	589	14.63	2.30	7542	711	16.15
SED±	0.09	510.9	34.8	0.77	0.08	550.3	45.1	0.95
F	NS	*	***	**	*	**	**	*
NP	2.60	4412	491	12.66	2.48	6147	619	15.10
PR	2.55	5494	471	11.55	2.36	6579	570	13.02
SED±	0.07	408.3	33.0	0.71	0.07	426.1	34.9	0.70
F	NS	*	NS	NS	NS	NS	NS	*
M35-1	2.70	5059	468	12.68	2.56	6257	577	14.68
Swathi	2.40	4927	522	12.03	2.19	6571	627	13.36
IC 94004	2.64	4872	453	11.6	2.52	6262	579	14.12
SED±	0.06	322.2	31.4	0.70	0.04	283.9	24.6	0.51
F	***	NS	NS	NS	**	NS	NS	*
CV(%)	1.6	8.5	16.7	15.6	6.9	12.6	12.5	10.3

Table 20. Management treatments (planting time, fertility and shoot fly control) and cultivar effects on grain mass (g/100), grain number per square meter and grain number and weight per panicle in sorghum in the deep Vertisol site (pooled).

Deep Vertisol site (Pooled)				
TRT	GRM (g/100)	GRNO (m^2)	GRNO (PN)	GRWT (g/PN)
YR1	2.58	4953	481	12.11
YR2	2.42	6363	594	14.06
SED±	0.10	609.0	49.0	1.25
F	NS	NS	NS	NS
SD1	2.46	6314	601	14.26
SD2	2.54	5001	475	11.91
SED±	0.13	370.4	44.6	0.98
F	NS	*	*	NS
F1	2.60	4659	423	10.74
F2	2.49	5707	539	13.12
F3	2.42	6608	650	15.39
SED±	0.06	375.4	28.5	0.68
F	*	***	***	***
NP	2.54	5279	555	13.88
PR	2.46	6037	520	12.29
SED±	0.05	295.0	24.0	0.49
F	NS	*	NS	**
M35-1	2.63	5658	523	13.68
Swathi	2.29	5749	574	12.70
IC 94004	2.58	5567	516	12.87
SED±	0.04	218.5	19.9	0.44
F	***	NS	**	NS
CV(%)	9.0	11.3	11.2	11.7

4.20 INTERACTION AMONG TREATMENTS FOR GRAIN MASS, GRAIN NUMBER PER UNIT AREA AND GRAIN NUMBER AND WEIGHT PER PANICLE IN THE DEEP VERTISOL SITE (POOLED DATA)

4.20.1 Grain Mass

The fertility x protection interaction of sorghum for grain mass was significant. There was a negative relation between grain mass and fertility when the crop was protected and when the fertility was increased to F3 (Fig 31a).

The fertility x genotype interaction was significant. The grain mass of Swathi and IC 94004 (unlike that of M35-1 which remained fairly stable) decreased when the fertility level of the crop had increased to F3 (Fig 31b).

4.20.2 Grain Number Per Unit Area

The sowing date x genotype interaction of sorghum was significant. Across planting dates irrespective of genotypes, there was more grain number per unit area from early than from normal planting. In the normal planting across genotypes, the decrease in grain number per unit area was relatively higher in Swathi and IC 94004 than M35-1. There was about an only 8% decrease in M35-1 but about 20% and 33% decrease in grain number per unit area in Swathi and IC 94004 when their planting was delayed to normal (Fig 32a).

4.20.3 Grain Number Per Panicle (GRNO/PN)

There was a significant interaction of sowing date x genotype. The decrease in GRNO/PN in normal planting as compared to early planting of sorghum was significantly greater in IC 94004 (33%) than Swathi (13%) or M35-1 (16%) (Fig 32b).

4.20.4 Grain Weight Per Panicle (GRWT/PN)

The sowing date x genotype interaction was significant. M35-1 and Swathi were not affected by early planting. In IC 94004, the increase in GRWT/PN when was sown early was more than 25% which was significantly greater than the increase in GRWT/PN in M35-1 (3%) and Swathi (5%) when were sown early (Fig 32c).

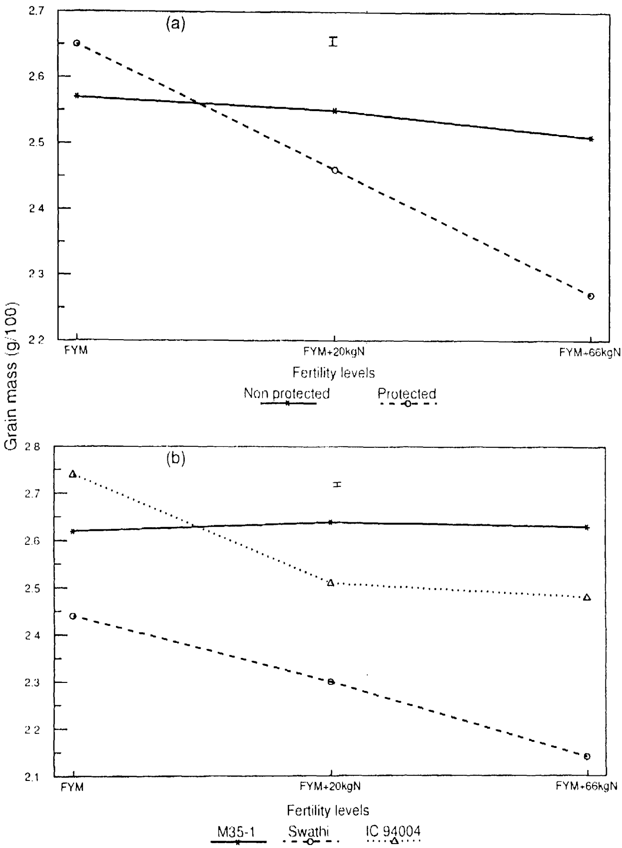


Fig.31. Fertility x protection (a) and fertility x genotype (b) interactions for grain mass in sorghum in the deep Vertisol site (ppoled data).

vertical bars are SED

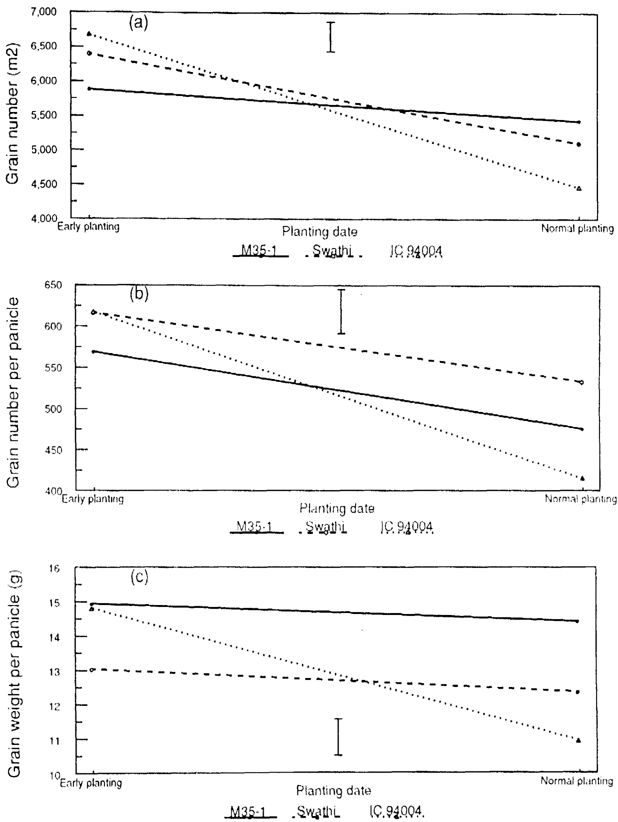


Fig.32. Planting date x genotype interactions for grain number per unit area (a), grain number per panicle (b) and grain weight per panicle (c) of sorghum in the deep Vertisol site (pooled data).

vertical bars are SED

4.21 GRAIN MASS, GRAIN NUMBER PER UNIT AREA AND GRAIN NUMBER AND WEIGHT PER PANICLE

4.21.1 Vertic Inceptisol Site (1995)

Although the planting date of sorghum had no significant effect on all the yield components, early planting consistently enhanced the grain mass, the grain number and the grain weight per panicle as compared to normal planting. There were significant differences in grain mass and significant increase in grain number per unit area, grain number and weight per panicle with increased crop fertility levels (Table 21). The grain mass, the grain number per unit area and the grain number and weight per panicle of the three cultivars were statistically similar, although again Swathi had numerically lower grain mass than M35-1 and IC 94004 (Table 21).

4.21.2 Vertic Inceptisol Site (1996)

As in 1995, though there were no statistical differences in the grain mass, the grain number per unit area or the grain number and weight per panicle between early and normally sown sorghum; early planting favoured all the aforesaid yield attributes (Table 21). The fertility treatments of the crop had no significant effect on the grain number per unit area or the grain number and weight per panicle, but those attributes had increased as the fertility level increased from F1 to F2. On the other hand, grain mass was significantly reduced as fertility was increased to F2. The grain mass of IC 94004 and M35-1 was significantly more than that of Swathi and the grain number and weight per panicle of IC 94004 or Swathi were statistically greater than that of M35-1. There were no differences between the three genotypes in their grain number per unit area (Table 21).

4.21.3 Vertic Inceptisol Site (Pooled)

4.21.3.1 *Effect of season*

There were no differences in grain mass and grain number per panicle between 1995 and 1996. The crop in the two seasons was significantly different for grain number per unit area and grain weight per panicle.

4.21.3.2 *Effect of planting date*

Early planting had significantly greater grain mass than normal planting; the remaining yield components (grain number per unit area and per panicle as well as grain weight per panicle) were statistically the same, but grain number and weight were numerically higher in early than normal planting of sorghum.

4.21.3.3 *Effect of fertility*

The crop fertilized with F1 level had a greater grain mass than that under F2, the remaining yield components were statistically greater in F2 than F1 fertility level (Table 22).

4.21.3.4 *Effect of genotype*

Among the genotypes IC 94004 and M35-1 had a greater grain mass than Swathi. Swathi on the otherhand had significantly greater grain number per panicle than M35-1 and/or IC 94004. There were no differences between the three genotypes in grain number per unit area or grain weight per panicle (Table 22).

Table 21. Management treatments (planting time and fertility) and genotype effects on grain mass (g/100), grain number per square meter, and grain number and weight per panicle in sorghum in the vertic Inceptisol site (*rabi* 1995 and 1996).

	Rabi 1995				*Rabi* 1996			
TRT	GRM (g/100)	GRNO (m²)	GRNO (PN)	GRWT (g/PN)	GRM (g/100)	GRNO (m²)	GRNO (PN)	GRWT (g/PN)
SD1	2.51	3336	412	9.56	2.41	7181	611	14.48
SD2	2.28	3871	291	6.12	2.31	5011	471	10.75
SED±	0.08	505.0	99.7	2.26	0.05	1186.7	124.8	2.44
F	NS	NS	NS	NS	NS	NS	NS	NS
F1	2.57	2866	254	6.30	2.44	5641	504	12.24
F2	2.22	4341	448	9.39	2.28	6551	579	12.99
SED±	0.06	343.9	62.3	1.11	0.05	449.1	43.1	0.82
F	**	*	*	*	*	NS	NS	NS
M35-1	2.52	3550	377	9.36	2.40	5832	475	11.39
Swathi	2.15	3436	370	7.96	2.21	5945	599	13.08
IC 94004	2.52	3324	255	6.21	2.46	6512	550	13.38
SED±	0.17	434.0	74.6	1.27	0.07	489.1	34.1	0.66
F	NS	NS	NS	NS	**	NS	**	*
CV(%)	4.2	17.2	14.8	15.4	7.5	19.7	15.4	12.8

Table 22. Management treatments (planting time and fertility) and genotype effects on grain mass (g/100), grain number per square meter and grain number and weight per panicle in sorghum in the vertic Inceptisol site (pooled).

	Vertic Inceptisol site (pooled)			
TRT	GRM (g/100)	GRNO (m²)	GRNO (PN)	GRWT (g/PN)
YR1	2.39	3603	351	7.84
YR2	2.36	6096	541	12.62
SED±	0.16	771.5	97.8	1.62
F	NS	*	NS	*
SD1	2.46	5258	511	12.02
SD2	2.29	4441	381	8.44
SED±	0.04	644.8	79.9	1.66
F	*	NS	NS	NS
F1	2.51	4254	379	9.26
F2	2.25	5446	514	11.19
SED±	0.04	282.8	37.9	0.69
F	***	**	**	*
M35-1	2.46	4691	426	10.37
Swathi	2.18	4940	510	10.52
IC 94004	2.49	4918	402	9.80
SED±	0.09	326.9	41.0	0.71
F	**	NS	*	NS
CV(%)	4.5	14.3	3.8	16.6

4.22 INTERACTION AMONG TREATMENTS FOR GRAIN MASS, GRAIN NUMBER PER UNIT AREA AND GRAIN NUMBER AND WEIGHT PER PANICLE IN THE VERTIC INCEPTISOL SITE

4.22.1 Grain Mass

There was a significant sowing date x fertility interaction. Grain mass of sorghum remained constant between planting dates in F1, but was significantly greater in the early planting in F2 (Fig 33). There were no other interactions in the remaining grain yield components.

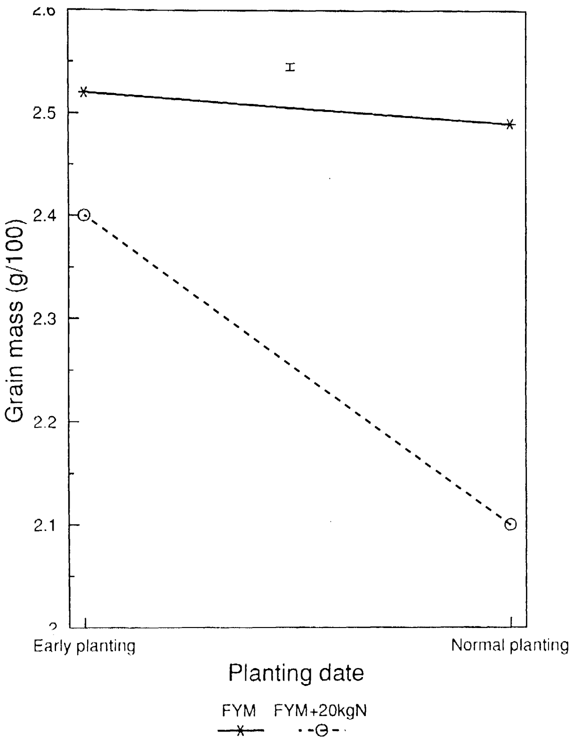


Fig.33. Planting date x fertility interaction for grain mass of sorghum in the vertic Inceptisol site (pooled data).

vertical bar is SED

4.23 RADIATION USE EFFICIENCY (RUE)

4.23.1 RUE in the Deep Vertisol Site (1995 and 1996)

During 1995 and 1996 at the three sampling periods (30, 50 DAE and FL), RUE was consistently higher in early than normal planting of sorghum in both seasons, but differences were significant only at 30 DAE during 1995. During both 1995 and 1996, with increased level of fertility, there was increased RUE. At 30 DAE, RUE in the crop fertilized with F3 level was significantly greater than that under F2 or F1 during 1995, but not during 1996. At 50 DAE and FL time, RUE of the crop in F3 and F2 were statistically higher from F1 in both years (Table 23). Protection of sorghum against insects had no significant effect on RUE during both seasons over non - protected crop, and the only significant effect was observed at 50 DAE during 1995. During both 1995 and 1996, cultivar IC 94004 recorded higher RUE early in the season (30 and 50 DAE), but differences were not always significant. There were no differences in RUE between the three genotypes at any other sampling period during either season (Table 23).

4.24 NITROGEN USE EFFICIENCY (NUE) AT HARVEST

4.24.1 Deep Vertisol Site (1995 and 1996)

During 1995, there were no significant differences in the grain or total NUE between early and normal planting of sorghum, though normal planting had accumulated greater grain NUE (47.5 vs 39.2) and lower total NUE (157.6 vs 164.1) than early planting. During 1996, early planting had significantly greater grain and total NUE than normal planting. During both seasons, grain and total NUE of the fertility treatments of the crop were in reverse order of treatments; the crop fertilized with F1 level having higher grain and total NUE than that under F2 or F3. During 1995, there were no significant differences between crop fertilities in grain NUE, differences were significant during 1996. Total NUE during both seasons was significantly greater in the crop fertilized with F1 than either with

F2 or F3 levels (Table 23) During both seasons, there were no differences in grain NUE between PR and NP sorghum crop, but total NUE of PR was statistically greater than NP crop. Similarly, during both seasons, there were no statistical differences in grain NUE among genotypes, but IC 94004 was significantly higher in total NUE compared to either genotype (Table 23).

4.25 WATER USE EFFICIENCY (WUE)

4.25.1 Deep Vertisol Site (1995 and 1996)

Normal planting of sorghum had significantly greater grain WUE than early planting during 1995, but significantly lower grain WUE during 1996. During both seasons, early planting had more total WUE than normal planting, differences were significant only during 1996 (Table 23). The grain and total WUE in both seasons was numerically greater with increased crop fertility, differences were significant for grain WUE during 1996 (Table 23) However, the effect of protection on grain and total WUE of sorghum was significant during 1995, but there were no differences during 1996 (Table 23).

4.26 RUE, NUE and WUE in the Deep Vertisol Site (Pooled)

4.26.1 *Effect of season*

There were no differences between 1995 and 1996 seasons in the crop RUE at 30 or at 50 DAE, but RUE of sorghum at FL was significantly greater during 1996 than 1995.

The grain and total NUE for the two years were the same. The grain and total WUE of sorghum were significantly greater during 1996 than 1995 (Table 24).

4.26.2 *Effect of planting date*

Early planting of sorghum had greater RUE than normal planting at 30, 50 DAE and at FL periods, and the differences between the two dates were significant only at 30 DAE.

Early planting had significantly enhanced grain and total NUE compared to those in the normal planting of sorghum.

In terms of WUE, early planting had statistically greater grain and total WUE than normal planting.

4.26.3 *Effect of fertility*

The crop fertilized with F2 and F3 levels had higher RUE at 30 DAE, 50 DAE and at FL than that under F1.

In contrast, grain and total NUE of sorghum were significantly greater in F1 than in F2 and F3 levels.

There were no differences between the crop levels of fertility in total WUE, but F3 had significantly greater grain WUE.

4.26.4 *Effect of protection*

PR as compared to NP crop had significantly greater RUE at 50 DAE. There were no differences between PR and NP crop at 30 DAE or at FL.

Protection had no effect on grain NUE, but had significant effect on total NUE. Likewise grain WUE did not differ, but total WUE was significantly greater in PR than NP crop.

4.26.5 *Effect of genotype*

IC 94004 alone had significantly greater RUE at 30 and 50 DAE than Swathi or M35-1. By FL time, the three genotypes had the same RUE (Table 24). The three genotypes behaved the same in terms of their grain NUE, but were significantly different for total NUE: IC 94004 had significantly higher total NUE than either of the two genotypes.

Table 23. Management treatments (planting time, fertility and shoot fly control) and cultivar effects on radiation, nutrient and water use efficiencies in sorghum in the deep Vertisol site (*rabi* 1995 and 1996).

	Rabi 1995							*Rabi* 1996						
	RUE (gDM/Mj)			NUE (kg/kgN/ha)		WUE (kg/ha/mm)		RUE (gDM/Mj)			NUE (kg/kgN/ha)		WUE (kg/ha/mm)	
TRT	0-30 DAE	0-50 DAE	0-FL	grain	toatl	grain	total	0-30 DAE	0-50 DAE	0-FL	grain	total	grain	total
SD1	0.80	1.08	1.24	39.2	164.1	5.4	25.2	0.64	1.07	1.48	61.7	198.3	10.5	36.5
SD2	0.56	0.72	1.11	47.5	157.6	7.5	24.7	0.50	1.04	1.20	31.3	127.3	6.0	25.4
SED±	0.05	0.14	0.14	3.39	5.84	0.43	1.36	0.05	0.11	0.12	1.69	10.25	0.66	0.72
F	*	NS	NS	NS	NS	*	NS	NS	NS	NS	**	*	*	**
F1	0.54	0.68	0.95	46.2	176.6	5.6	22.4	0.53	0.87	1.16	50.2	180.5	7.3	30.1
F2	0.68	0.99	1.24	42.6	164.6	6.2	24.2	0.60	1.10	1.38	48.0	168.6	8.0	29.4
F3	0.83	1.04	1.33	41.4	141.3	7.5	28.2	0.58	1.19	1.48	41.4	139.3	9.4	33.3
SED±	0.06	0.10	0.13	2.90	7.42	0.85	2.78	0.05	0.07	0.08	1.76	6.66	0.59	2.61
F	**	*	*	NS	**	NS	NS	NS	**	*	**	***	*	NS
NP	0.66	0.80	1.12	43.6	143.6	5.7	20.3	0.56	1.02	1.33	46.1	154.6	8.1	30.5
PR	0.70	1.00	1.23	43.1	178.1	7.2	29.5	0.58	1.09	1.35	47.0	171.0	8.3	31.4
SED±	0.05	0.06	0.05	2.67	5.69	0.66	2.44	0.02	0.04	0.04	3.28	6.01	0.90	2.23
F	NS	**	NS	NS	***	*	**	NS	NS	NS	NS	*	NS	NS
M35-1	0.58	0.89	1.16	44.4	1.55	-	-	0.55	1.02	1.38	46.3	160.3	-	-
Swathi	0.72	0.87	1.22	42.1	152.1	-	-	0.55	0.96	1.31	46.1	159.4	-	-
IC 94004	0.74	0.94	1.15	43.6	175.4	-	-	0.61	1.18	1.33	47.2	168.6	-	-
SED±	0.05	0.06	0.06	1.82	4.23	-	-	0.03	0.04	0.06	1.54	3.64	-	-
F	**	NS	NS	NS	***	-	-	NS	***	NS	NS	*	-	-
CV(%)	10.0	7.1	2.8	9.6	4.4	8.3	6.7	11.6	11.8	11.4	14.0	9.5	9.9	4.0

Table 24. Management treatments (planting time, fertility and shoot fly control) and cultivar effects on radiation, nutrient and water use efficiencies in sorghum in the deep Vertisol site (pooled).

Deep Vertisol site (pooled)							
	RUE (gDM/MJ)			NUE (kg/kgN/ha)		WUE (kg/ha/mm)	
TRT	0-30 DAE	0-50 DAE	0-FL	grain	total	grain	total
YR1	0.68	0.90	1.18	43.4	160.8	6.4	24.9
YR2	0.57	1.05	1.34	46.5	162.8	8.2	30.9
SED±	0.05	0.08	0.02	3.40	9.20	0.65	0.82
F	NS	NS	**	NS	NS	*	**
SD1	0.72	1.06	1.36	50.5	181.2	7.9	30.9
SD2	0.53	0.90	1.16	39.4	142.4	6.7	25.0
SED±	0.04	0.09	0.09	1.89	5.90	0.39	0.77
F	**	NS	NS	**	**	*	**
F1	0.54	0.77	1.06	48.2	178.6	6.5	26.2
F2	0.64	1.05	1.31	45.3	166.6	7.1	26.8
F3	0.70	1.11	1.41	41.4	140.3	8.4	30.8
SED±	0.04	0.06	0.08	1.69	4.99	0.52	1.91
F	**	***	**	**	***	**	NS
NP	0.61	0.91	1.23	44.9	149.1	7.0	25.4
PR	0.64	1.05	1.29	45.1	174.5	7.7	30.5
SED±	0.03	0.03	0.03	2.12	4.14	0.56	1.65
F	NS	***	NS	NS	***	NS	**
M35-1	0.57	0.95	1.27	45.3	157.7	-	-
Swathi	0.64	0.92	1.26	44.1	155.8	-	-
IC 94004	0.68	1.06	1.24	45.4	172.0	-	-
SED±	0.03	0.04	0.04	1.20	2.72	-	-
F	**	***	NS	NS	***	-	-
CV(%)	10.2	10.1	11.0	16.1	10.1	11.0	4.8

4.27 RUE, NUE AND WUE: INTERACTION AMONG TREATMENTS AND GENOTYPES

4.27.1 <u>Deep Vertisol Site</u>

There were significant sowing date x fertility and sowing date x protection interactions in RUE of sorghum at 30 DAE. The RUE in early planting was greater than in normal planting at higher levels of fertility and when the crop was protected. In normal planting, there was no difference in RUE even at higher levels of fertility or when the crop was protected (Fig 34a and 34b).

There was a significant sowing date x genotype interaction for grain NUE and a significant protection x genotype interaction for total NUE. In the sowing date x genotype interaction in grain NUE, early planting of sorghum had more grain NUE than normal planting, but differences were stronger in IC 94004. Early planting increased grain NUE by 13% in M35-1, 20% in Swathi and 32% in IC 94004. This might indicate the greater responsiveness to early date of planting in IC 94004 (Fig 35a).

In the protection x genotype interaction for total NUE, the three sorghum genotypes had almost the same total NUE in NP crop. Total NUE of IC 94004 significantly increased by protection than total NUE of the other genotypes (Fig 35b).

There were no interactions in WUE.

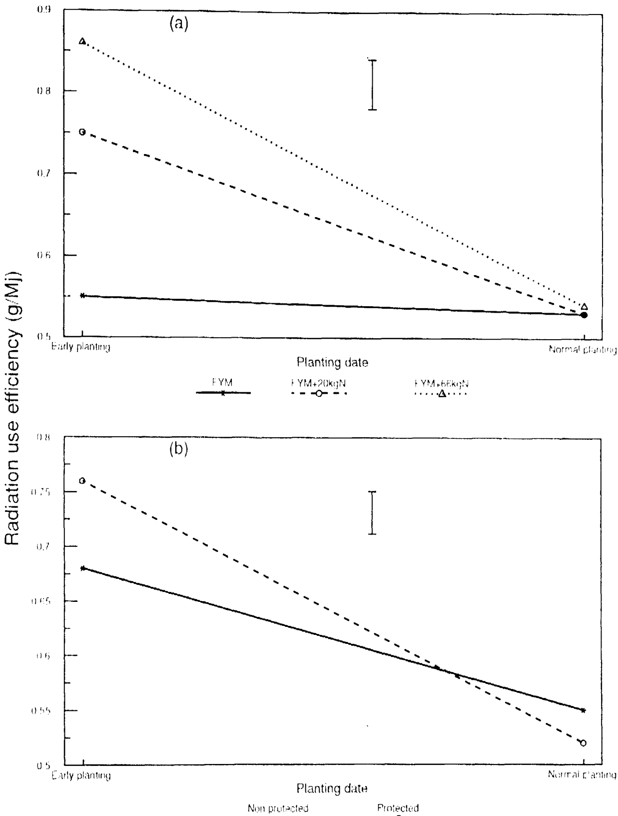


Fig.34. Planting date x fertility (a) and planting date x protection (b) interactions for radiation use efficiency (30 DAE) of sorghum in the deep Vertisol site (pooled data).

vertical bars are SED.

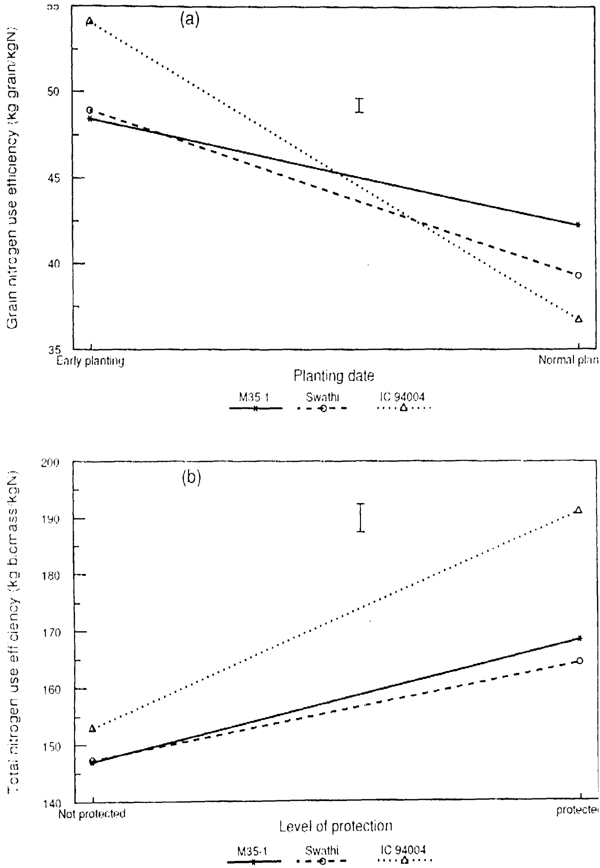


Fig.35. Planting date x genotype (a) and protection x genotype (b) interactions for nitrogen use efficiency of sorghum in the deep Vertisol site (pooled data).

vertical bars are SED

4.28 RUE

4.28.1 Vertic Inceptisol Site (1995 and 1996)

Irrespective of management treatment and season, RUE increased from 30 DAE through 50 DAE and reached a maximum by FL. During 1995, early planting had accumulated greater RUE than normal planting of sorghum, but differences were significant only at 30 DAE (Table 25). During 1996, normal planting had greater RUE than early planting but the significant differences between the two dates were only at 50 DAE. During both seasons, RUE increased consistently as fertility level increased from F1 to F2. The crop under F2 fertility level was statistically different at 50 DAE and FL time during both 1995 and 1996 than that under F1 (Table 25). There were no differences between the three genotypes in 1995, where as during 1996, IC 94004 differed significantly from M35-1 or Swathi only at 50 DAE.

4.29 NUE

4.29.1 Vertic Inceptisol Site (1995)

There were no significant differences in grain NUE between early or normal planting, between fertility levels or among the three genotypes (Table 25).

Normal planting of sorghum had significantly higher total NUE than early planting. There were no differences between crop fertility levels in total NUE. Among genotypes, total NUE of IC 94004 was significantly higher than either Swathi or M35-1.

4.29.2 Vertic Inceptisol Site (1996)

Early planting had statistically higher grain NUE than normal planting, the two dates however did not vary for total NUE. On the otherhand, increased fertility had no effect on grain NUE, but the crop under F1 had significantly greater total NUE compared to that under F2. Within genotypes, IC 94004 had statistically more grain NUE than either Swathi or M35-1, however, the three genotypes did not differ for total NUE (Table 25).

4.30 WUE

4.30.1 Vertic Inceptisol Site (1995 and 1996)

There were no significant differences between early and normal planting, or between the two fertility levels in grain or total WUE during 1995 and 1996. However, grain and total WUE of sorghum were consistently improved by fertilization (Table 25).

4.31 RUE, NUE AND WUE: Vertic Inceptisol Site (Pooled)

4.31.1 *Effect of season*

There were significant differences between 1995 and 1996 seasons in RUE at 30, 50 DAE and FL time, and significant differences in grain and total WUE.

There were no differences between the two seasons in grain or total NUE (Table 26).

4.31.2 *Effect of planting date*

Early planting had numerically greater RUE than normal planting, but differences were not significant at either 30, 50 DAE or FL time.

The grain NUE of early planted sorghum was statistically greater than normal planting; the two dates did not vary in total NUE.

There were no differences in WUE between early and normal planting.

4.31.3 *Effect of fertility*

The crop under F2 had significantly greater RUE than that under F1 at 50 DAE and FL time. Although grain and total NUE of sorghum were higher in F1 than F2, differences were significant only for total NUE.

There were differences between the crop fertility levels in total and grain WUE, but differences were significant only for grain WUE.

4.31.4 *Effect of genotype*

IC 94004 alone had significantly greater RUE at 50 DAE than Swathi or M35-1. At 30 DAE and FL time, the three genotypes had the same RUE (Table 26).

Both grain and total NUE of IC 94004 were statistically greater than grain or total NUE of either Swathi or M35-1 (Table 26).

4.32 RUE, NUE AND WUE: INTERACTION AMONG TREATMENTS AND GENOTYPES

4.32.1 Vertic Inceptisol Site

There was a significant fertility x genotype interaction in RUE at 50 DAE. IC 94004 responded more strongly to increased fertility than M35-1 or Swathi (Fig 36).

There were no interactions in NUE or WUE.

Table 25. **Management treatments (planting time and fertility) and cultivar effects on radiation, nutrient and water use efficiencies in sorghum in the vertic Inceptisol site (*rabi* 1995 and 1996).**

	Rabi 1995							*Rabi* 1996						
	RUE (gDM/Mj)			NUE(kg/kgN/ha)		WUE(kg/ha/mm)		RUE (gDM/Mj)			NUE(kg/kgN/ha)		WUE (kg/ha/mm)	
TRT	0-30 DAE	0-50 DAE	0-FL	grain	total	grain	total	0-30 DAE	0-50 DAE	0-FL	grain	total	grain	total
SD1	0.74	1.01	1.10	40.1	160.4	7.4	29.1	0.96	0.97	1.28	51.1	165.0	11.1	41.1
SD2	0.42	0.71	0.79	46.2	186.9	7.2	30.2	1.07	1.17	1.33	37.3	131.1	9.4	37.6
SED±	0.05	0.13	0.15	2.56	5.06	1.36	3.57	0.17	0.03	0.15	0.21	20.12	2.05	3.09
F	*	NS	NS	NS	*	NS	NS	NS	*	NS	***	NS	NS	NS
F1	0.52	0.75	0.73	45.6	186.5	6.2	26.7	0.96	0.88	1.19	46.8	155.5	9.1	36.5
F2	0.64	0.98	1.16	40.8	160.1	8.4	32.5	1.07	1.27	1.41	41.6	140.6	11.4	42.2
SED±	0.08	0.05	0.08	4.41	12.10	1.44	2.66	0.07	0.07	0.07	2.10	4.54	1.06	4.65
F	NS	**	**	NS	NS	NS	NS	NS	**	*	NS	*	NS	NS
M35-1	0.57	0.78	0.95	42.1	164.5	-	-	1.00	1.04	1.29	41.1	146.3	-	-
Swathi	0.61	0.96	0.92	42.3	162.4	-	-	1.10	0.95	1.41	42.5	142.0	-	-
IC 94004	0.57	0.86	0.97	45.2	194.0	-	-	0.95	1.22	1.22	49.0	155.9	-	-
SED±	0.07	0.07	0.09	3.27	9.05	-	-	0.11	0.06	0.10	2.00	5.83	-	-
F	NS	NS	NS	NS	**	-	-	NS	**	NS	**	NS	-	-
CV(%)	12.1	9.5	3.0	7.2	3.6	9.1	8.3	7.2	4.2	7.1	11.1	9.6	16.7	9.6

Table 26. Effects of management treatments and cultivars on radiation, nutrient and water use efficiencies in sorghum in the vertic Inceptisol site (pooled).

	Vertic Inceptisol site (pooled)						
	RUE (gDM/MJ)			NUE (kg/kgN/ha)		WUE (kg/ha/mm)	
	0-30 DAE	0-50 DAE	0-FL	grain	total	grain	total
YR1	0.58	0.86	0.94	43.2	173.6	7.3	29.6
YR2	1.01	1.07	1.30	44.2	148.1	10.2	39.4
SED±	0.05	0.06	0.05	1.43	13.97	1.05	3.05
F	**	*	**	NS	NS	*	*
SD1	0.85	0.99	1.19	45.6	162.7	9.2	35.1
SD2	0.75	0.94	1.06	41.8	159.0	8.3	33.9
SED±	0.09	0.07	0.11	1.28	10.37	1.23	2.36
F	NS	NS	NS	*	NS	NS	NS
F1	0.74	0.81	0.97	46.2	171.0	7.6	31.6
F2	0.86	1.12	1.28	41.2	150.7	9.9	37.4
SED±	0.05	0.04	0.05	2.44	6.46	0.89	2.68
F	NS	***	***	NS	*	*	NS
M35-1	0.78	0.91	1.12	41.6	155.4	-	-
Swathi	0.85	0.95	1.17	42.4	152.2	-	-
IC 94004	0.76	1.04	1.09	47.1	175.0	-	-
SED±	0.06	0.04	0.07	1.92	5.38	-	-
F	NS	*	NS	*	***	-	-
CV(%)	8.1	8.4	6.1	15.2	11.6	14.8	10.8

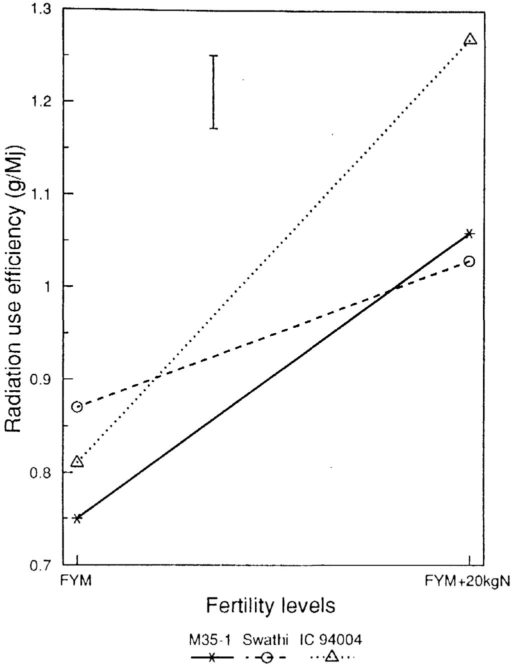


Fig.36. Fertility x genotype interaction by sorghum for radiation use efficiency (50 DAE) in the vertic Inceptisol site (pooled data).

vertical bar is SED

4.33 PATH ANALYSIS (POOLED DATA)

From Table 27, in both deep and shallow soils, *rabi* sorghum grain yield was mostly correlated to the direct effects of total nitrogen uptake (0.58 and 0.82), the HI (0.71 0.61), total WUE (0.51 and 0.79) and to the direct effect of grain number per panicle (0.74 vs 0.60). Even the indirect effect of total nitrogen uptake on *rabi* sorghum yield was positive as total nitrogen uptake increased with biomass increase when the crop was fertilized. The indirect effect of NUE on *rabi* sorghum yield was negative as NUE tend to decrease with high fertility (F2 and F3) and to increase with lower levels (F1) (Table 27). It was apparent that combining both greater GRNO/PN and panicle number per unit area was a rewarding approach in increasing *rabi* sorghum yield. The HI and grain number per panicle have similar correlations with *rabi* sorghum grain yield at both shallow and deep soils, though the HI yield correlation was stronger in deep rather than shallow soils (0.74 vs 0.60). On the otherhand, total nitrogen uptake and WUE (total) were more tightly correlated to yield in shallow rather than deep soils (0.82 and 0.79 vs 0.58 and 0.51).

4.34 COST - BENEFIT RELATIONSHIPS (POOLED DATA)

4.34.1 Deep Vertisol Site

The cost - benefit relationships were shown in Table 28. The gross and net benefit from early planting of sorghum were statistically greater than those from normal planting. There were 47% and 72% greater net benefit from early planting in the deep Vertisol and the vertic Inceptisol sites as compared to normal planting. The gross benefit, the gross cost and the net benefit of the crop fertility levels were significantly different. The net benefit from the crop fertilized with F2 and F3 fertility levels were statistically the same, but either had significantly higher net benefit than that under F1. There was 27 - 46% greater net benefit through the application of either F2 or F3 over F1. Although there were statistical differences in the gross benefit and in the gross cost between NP and PR crop treatments, their net benefits were the same (Table 28). Among genotypes, the net benefit from M35-1 and IC 94004 were statistically greater than that from Swathi.

4.34.2 Vertic Inceptisol Site

The cost - benefit relationships were shown in Table 29. The gross and net benefits from early planting of sorghum were statistically greater than those from normal planting. There were a 72% higher net benefit from early planting as compared to normal planting. The gross benefit and the gross cost of sorghum under the two fertility levels were significantly different, but the net benefits were statistically the same. Among genotypes, the net benefit from M35-1 and IC 94004 were statistically greater than that from Swathi. The cultivation of either M35-1 or IC 94004 generated about 10 times extra net benefit than the cultivation of Swathi (Table 29).

Table 27. Path coefficient analysis for grain yield in three sorghum genotypes over management treatments over both seasons in the deep Vertisol and vertic Inceptisol sites.

Pathway	Vertisol site	Inceptisol site
Total N content vs grain yield		
Direct effect	0.68	0.97
Indirect effect via		
NUE (total)	-0.23	-0.34
HI	0.13	0.19
Correlation	0.58	0.82
HI vs grain yield		
Direct effect	0.64	0.52
Indirect effect via		
Total N content	0.14	0.35
NUE (total)	-0.07	-0.26
Correlation	0.71	0.61
Cumulative light accumulation vs grain yield		
direct effect	0.30	0.40
Indirect effect via		
RUE	0.05	-0.04
HI	-0.02	-0.14
Correlation	0.33	0.22
Evapotranspiration vs grain yield		
Direct effect	0.51	0.48
Indirect effect via		
WUE (total)	-0.36	-0.02
HI	0.18	-0.02
Correlation	0.33	0.44
WUE (total) vs grain yield		
Direct effect	0.76	0.63
Indirect effect via		
ET	-0.24	-0.02
HI	-0.01	0.18
Correlation	0.51	0.79
Panicle number/m^2 vs grain yield		
Direct effect	0.52	0.62
Indirect effect via		
GRNO/PN	-0.14	-0.44
GRWT/100	0.02	0.03
Correlation	0.40	0.21
GRNO/PN vs grain yield		
Direct effect	0.96	1.01
Indirect effect via		
Panicle number/m^2	-0.08	-0.27
GRWT/100	-0.14	-0.14
Correlation	0.74	0.60

Table 28. Cost - benefit relationships of management treatments in sorghum in the deep Vertisol site (*rabi* 1995 and 1996).

TRT	Gross benefits (Rs)	Gross cost (Rs)	Net benefits (Rs)
SD1	9160	6245	2915
SD2	7777	6245	1532
SED±	416.6	5.7	851.9
F	*	NS	*
F1	7366	5786	1580
F2	8546	6367	2178
F3	9494	6567	2927
SED±	418.5	7.0	416.2
F	***	***	*
NP	7952	5894	2058
PR	8986	6586	2400
SED±	322.9	5.7	418.8
F	**	***	NS
M35-1	9771	6233	3538
Swathi	6908	6223	685
IC 94004	8726	6228	2498
SED±	236.8	7.0	325.2
F	***	NS	***
CV(%)	16.8	0.7	6.6

Table 29. Cost - benefit relationships of management treatments in sorghum in the vertic Inceptisol site (*rabi* 1995 and 1996).

TRT	Gross benefits (Rs)	Gross cost (Rs)	Net benefits (Rs)
SD1	7383	5244	2139
SD2	5848	5244	604
SED±	493.2	16.7	493.8
F	*	NS	*
F1	5926	4936	990
F2	7304	5535	1769
SED±	435.6	16.7	436.2
F	*	***	NS
M35-1	7403	5249	2145
Swathi	5436	5239	197
IC 94004	7007	5244	1736
SED±	385.8	20.4	392.0
F	***	NS	***
CV(%)	8.7	1.4	8.4

CHAPTER V

DISCUSSION

Response of *Rabi* Genotypes to Management Treatments

The interaction effects of management practices on grain and stover yields in grain sorghum has not been well documented (Rosenthal et al. 1993). The interactions of genotypes, planting dates and fertility management treatments are vital considerations towards better management strategies for efficient resource utilization (Krieg and Lascano 1990), for increased grain yield (Rathore 1989) and for greater grain and return yields in a *rabi* sorghum environment (Chouhan et al. 1994).

In the study, the response of the main growth and development parameters (LAI and TDW) of the three genotypes across management treatments was different. Differences in LAI or TDW between early and normal planting were small in M35-1 or Swathi, but there was a significantly positive response to early planting in IC 94004. These consistent repetitive patterns in the three genotypes were seen in their resource use (radiation, water and nutrients), their use efficiency (RUE, WUE, NUE) and their grain yield components. This resulted in fairly stable stover, grain and biomass yields and HI in M35-1 and Swathi in both early and normal planting, but significantly greater yields in early than in normal planting in IC 94004. The grain yields (t/ha) (early and normal plantings) were 1.53, 1.41 (M35-1), 1.35, 1.18 (Swathi) and 1.62, 1.18 (IC 94004). The %HI were 25.4, 27.1 (M35-1), 25.8, 25.2 (Swathi) and 26.2, 23.0 (IC 94004) (Figs 28a and 30a).

There were greater responses in yield and yield components at increased fertility levels in IC 94004 and M35-1 compared to Swathi. There was a 28% (grain yield) and 19 to 21% (biomass yield) increase in IC 94004 and M35-1 compared to 12% (grain yield) and 11% (biomass yield) increase in Swathi, as fertility increased from F1 to F3 (Figs 28b and 29b).

The crop response to protection against insects was greater in IC 94004 than in either M35-1 or Swathi with early planting only. When the genotypes were sown at normal times, IC 94004 had a significantly greater shoot fly damage compared to the other genotypes (Fig 22). This means that IC 94004's greater response to inputs (fertilization and insect protection) was only observed when it was sown early, but not necessarily so in M35-1 and Swathi. The strong response of improved cultivars to improved management practices was reported by Umrani and Patil (1983) and by Chouhan et al. (1994).

Response of Growth Parameters, Resource Use and it's Use Efficiency and *Rabi* Sorghum Yield to Planting Date

The grain yield response of *rabi* sorghum to early sowing (15 September to 15 October) is related to higher N and P uptake in the early rather than in the normal planting (beyond 1 November) (Chorge and Ramshe 1990). When sowing is delayed, the limitation to reduced sorghum yield was attributed to a shortened time to anthesis and reduced tiller number (Herbert et al. 1986) and to lower RUE (Jadhav et al. 1993).

In the study, high LAI and high TDW were associated relatively more with early than normal planting in the deep and shallow Vertisol sites (Figs 6 and 7). During early planting, the temperatures were warmer, the soil top profile layer was still wet which facilitated fertilizer dissolution and absorption. These almost certainly allowed for more vigorous seedlings to be established in the early than in the normal planting.

In deep soils, sowing immediately after the cessation of the monsoon rains may bring an unaccounted risk through incidental and exceptionally heavy rains that completely saturate the heavy soils. The situation becomes more grave especially if the land was left fallow and kept weed free from the previous season as is the recommended practice for *rabi* sorghum. Under these circumstances, temperature and solar radiation may also be low; the vigorous seedling vigour during early planting may not occur and the advantage of early planting may not be seen or may be reversed. This happened during *rabi* 1995 when exceptionally heavy rainfall (> 250 mm) and low temperatures (Tmax > 25 °C and Tmin < 15 °C) coincided at seedling stage of the early sown crop (Fig 1a). As was evident from LAI and TDW values obtained during that season, the advantage of early planting during it (*rabi* 95) was small or sometimes reversed (Fig 5). As such, sowing according to weather forecast plays a significant role to reduce this risk.

In the study at exceptionally heavy post - monsoon rains during the first season, early planting increased LAI by 5% and TDW by 10% than normal planting. Greater LAI and TDW resulted in a crop relatively more able to utilize available resources (radiation, moisture and nutrients). From the study, there were about 10% greater radiation interception and about 5% nutrients harnessed by early than by normal planting. Bearing this in mind and as was reported by many authors (Mote 1983a, Malee Chawanapong et al. 1988), early planting in the study had less shoot fly dead heart infestations (12 vs 33%), greater intact plants (68 vs 25%) and less affected and non - recovered plants (13 vs 18%) (Fig 23). The greater the percentage of intact plants, the greater the chance for increased grain yield.

The resource use efficiency (RUE, NUE and WUE) in the early sown crop was greater than the resource use efficiency in the normally sown crop. Early planting, had about 9 and 12% greater RUE, 8 and 22% grain NUE and about 10 and 15% grain WUE than normal planting in the vertic Inceptisol and deep Vertisol sites respectively (Tables 24 and 26). The greater RUE in early planting was observed by Jadhav et al. 1993 and by Muchow 1989c.

In the study, biomass, HI, grain number per unit area, and grain number and weight per panicle were all greater in early rather than normal planting. In vertic Inceptisol and deep Vertisol sites, this had resulted in about 15 and 16% greater stover and about 15 and 24% grain yield of *rabi* sorghum in early planting compared to normal planting. Umrani et al. 1983b reported grain yield increase of 16 - 66% and Chorge and Ramshe 1990 an increase of 27% in the early planting compared to the normal planting.

The yield advantage could be related to a greater ability of early planted sorghum to make use of warmer temperatures during October for faster and rapid growth and development, to efficiently tap environmental resources and with an effective use efficiency and to less shoot fly dead heart infestations as compared to normal planting. This was also observed by Dahatonde and Moghe 1991.

It was not only the direct effect of early planting on crop growth factors, but equally it's interaction effect with management factors that had also a bearing on *rabi* sorghum yield. Biomass yield of *rabi* sorghum responded progressively and statistically different to increased fertility levels only in early planting. In normal planting such progressive responsiveness of the crop was small or not seen at all (Fig 29c). This point suggests that early planting of sorghum provides an opportunity for an economic use of chemical fertilizers that does not appear to exist in normal planting. Umrani and Patil (1989) and Kale (1989) demonstrated that early planting without adequate fertility had no significant effect on yield.

Response of Growth Parameters, Resource Use and it's Use Efficiency and *Rabi* Sorghum Yield to Chemical Fertilization

The response of sorghum growth factors (LAI, TDW) to fertilization has been well documented. The increasing rates of added nitrogen have a predominant influence on nutrient uptake (Badanur and Deshpande 1987), enzymatic activity and accordingly on higher photosynthetic rates (Ogata et al. 1983) and on rates of accumulation and mobilization of pre - anthesis dry matter and nitrogen (Muchow 1988b). N stress and/ or limited N supply reduces leaf area development and grain yield (Seetharama et al. 1990), leaf number and size (Verma et al. 1983), and results in leaves with lower N content, lower radiation conversion efficiency, and canopies that were not able to supply N to panicle growth (Lafitte and Loomis 1988a).

In the study, there was 25 - 30% greater LAI and 27 - 35% TDW in the crop fertilized with F2 and/or F3 than in the crop under F1. The radiation interception and accumulation were enhanced by 9 - 16% (interception) and by 7 - 15% (accumulation) in the crop under F2 and/or F3 than F1. The RUE at FL in the crop fertilized with F2 and/or F3 was 24% greater than that under F1. The increase in RUE at increased fertilization levels could be to an increased photosynthetic area per unit ground area (LAI) and N uptake. Nitrogen uptakes were greater in the crop fertilized with F2 and/or F3 than that under F1. At HAR, there was an increasing total crop N uptake with increasing N level (23 - 34 kgN/ha in the deep Vertisol and 16 - 26 kgN/ha in the Vertic Inceptisol). The increasing N uptakes at increasing N levels were also observed by Badanur and Deshpande (1987). On the other hand, increasing fertility levels had small effects on ET. Similar smaller effects on ET to increasing fertility levels were reported by Onken et al. (1992). The grain NUE ranged from 40 - 48 kg/kgN at decreasing fertility levels and grain WUE from 6 - 10 kg/mm at increasing levels (Tables 23 and 25).

The enhancement in growth parameters, resource use and utilization efficiency in the crop were in most cases not significantly different between F2 and F3 levels, but either of them was statistically different from F1. As a result, stover and grain yield of *rabi* sorghum in the study followed the same pattern in that the crop fertilized with F2 and F3 did not vary significantly for these attributes, but it was significantly different from the crop under F1. The crop fertilized with F2 and/or F3 recorded greater stover yield of 12 - 15% and grain yield of 14 - 23% compared to that under F1. This increase was mainly associated with (apart from greater LAI and resource use and use efficiency throughout the season) significantly greater biomass, HI, grain number per unit area and significantly greater grain number and weight per panicle in the crop fertilized with F2 and/or F3 than the F1 crop. The application of 25 kg N to *rabi* sorghum was reported by Gaikwad et al. (1993) to result in an optimum grain, fodder and monetary returns. Sonar et al. (1982) estimated about 2.07 kgN were required to produce 100 kg of *rabi* sorghum. By comparison, the F2 treatment in the study produced about 144 kg grain (deep Vertisol) and 130 kg grain (vertic Inceptisol) for the same dose (2.07 kgN). It appeared that F2 in this study was an optimum dose for *rabi* sorghum and there was no point to fertilize beyond it (FYM+20kgN+9kgP).

It was not only the direct effect of the F2 level on crop growth factors, but equally true it's interaction with management factors that also explained the repetitive behaviour of F2 when compared to F3. This could be observed from the significant strong interaction effect at increased fertility levels from F1 to F2 and the mild non significant interaction effect between F2 and F3 for biomass yield (Fig 29a). This means that, in *rabi* sorghum environment irrespective of the soil type, there was no necessity for nitrogen dose beyond F2 when FYM is used at the rates in the study. The consistency of the F2 effects could also be seen from the net benefit data (Tables 28 and 29).

Response of Growth Parameters, Resource Use and it's Use Efficiency and *Rabi* Sorghum Yield to Protection against the shoot fly

Protection against shoot fly had a clear effect on growth and development parameters (LAI and TDW), on crop resource use and it's use efficiency and ultimately on *rabi* sorghum stover yield compared to unprotected crop. There was about 24% greater LAI of sorghum in the protected than in the unprotected crop. TDW was greater by 21%, as a result of 20% increase in green leaf dry weight and 22% increase in stem dry weight (Tables 6 and 7). There was no effect of protection on sorghum panicle dry weight (Table 13), however the data indicate that shoot fly effect was more severe on stem (Table 11) rather than green leaves (Table 9) suggesting that the average dead heart infestations in green leaves and stems is an average to the dead heart infestations on the whole plant.

The increase in LAI and TDW in the crop under protection increased radiation use by 16% and the use efficiency by 8%. Nitrogen uptake at HAR was 7% higher in the protected crop. On the otherhand, protection had smaller effect on sorghum grain NUE, but relatively larger effect on total NUE (15% extra). Similarly, crop protection did not affect grain WUE, but total WUE increased by 17%with protection. Thus protection had a greater effect on *rabi* sorghum stover yield than on *rabi* sorghum grain yield. By comparison, fertilization across the same management treatments had a greater effect on *rabi* sorghum grain yield than on *rabi* sorghum biomass yield (Tables 24 and 26).

Among the yield components, grain number per unit area was the single parameter that positively responded to protection. The grain mass, the grain weight and number per panicle were all greater in the unprotected compared to the protected crop as a result of more plant competition in the protected crop. This was expected since with protection the number of productive plants per unit area was also greater as compared to unprotected crop. This sequence of events resulted in a *rabi* crop having a significantly greater biomass (20% greater), and stover (27% greater) yields in the protected crop, but did not differ in grain yield from unprotected crop and accordingly their HI were significantly dissimilar. Mote (1986) obtained 22% grain yield increase with protection compared to 8% in this study. The significantly greater biomass rather than grain yield with crop protection might suggest the use of *rabi* genotypes having greater partioning of assimilates to the grain with protection in a *rabi* sorghum environment. It also might necessitated that if the objective was greater biomass (fodder) rather than grain yield, then protection against shoot fly could be economically sound. This was also clear from the net benefit data (Tables 28 and 29) and from the interaction effect of protection on *rabi* sorghum stover yield (Fig 27).

Yield Correlations (from Path)

From the study conducted at IAC, *rabi* sorghum grain yield had direct and high correlations with total nitrogen uptake and WUE in both the deep and shallow Vertisol sites (r^2 0.58 and 0.82 for total N uptake and r^2 of 0.51 and 0.79 for WUE (Table 27). The direct correlations between both accumulated radiation and total evapotranspiration and *rabi* sorghum grain yield were not strong (r^2 0.33 and 0.33 for deep Vertisol and 0.22 and 0.44 for Vertic Inceptisol).

Among yield components, panicle number per unit area (PNNO/M2), grain number per panicle (GRNO/PN) and HI had a high direct correlation with *rabi* sorghum grain yield (Table 27).

The indirect effects of NUE, WUE, ET, PNNO/M2, GRNO/PN, GRM (100) on *rabi* sorghum grain yield were small. Total NUE is the ratio of biomass to total nitrogen uptake and usually tends to increase relatively greater by fertility than the relative increase in biomass yield. The result was low NUE at higher fertilizer doses and high NUE at lower fertilizer levels. The behaviour of NUE at increasing fertility was opposite to grain yield behaviour at increasing fertility levels, the result is a negative correlation between NUE and grain yield of *rabi* sorghum.

The effects of added inputs (fertilizer, protection) were small on ET, but relatively larger on grain yield. The small indirect effect of ET on grain yield with increasing fertility level was observed by Onken et al. (1992).

As PNNO/M2 increased, GRNO/PN decreased and grain mass also decreased, but to a lesser magnitude. In the study, the grain number and grain weight per panicle increased with increasing fertility and decreased with shoot fly protection. The decrease in sorghum panicle grain weight with protection was probably due to a greater percentage of productive plants and therefore more competition resulting in smaller panicles having fewer seed number and lesser weight than in unprotected crop. The grain mass decreased with increasing fertility levels and with crop protection as fertility increased both grain number and weight per panicle. This compensatory mechanism between yield components as PNNO/M2 increased was also observed by Garcia del Moral et al. (1991). This explains the smaller indirect effect of yield components (PNNO/M2, GRNO/PN, GRWT/PN and GRM) on grain yield. The combination of optimum PNNO/M2 and greater GRNO/PN through agronomical management was surely a rewarding approach in increasing *rabi* sorghum grain yield.

CHAPTER VI

SUMMARY AND CONCLUSIONS

There is an ample information on the effects of individual management practices on the *rabi* sorghum productivity studied separately; however information on the interactions and the impact of three or more practices studied together is lacking. Accordingly an experiment was conducted at ICRISAT Asia Center during *rabi* 1995 and 1996 seasons at two contrasting moisture environments (deep Vertisol and vertic Inceptisol) with an aim to measure the magnitude of the effects of individual management variables (planting date, fertilization, shoot fly management and cultivar) and to identify the important interactions among them for increased grain and fodder yields under *rabi* conditions. The experiment in the deep Vertisol was a four level, while that in the vertic Inceptisol site was a three level split plot design, as the factors of chemical protection were considered more relevant to the deeper soil environment.

The results indicated that early planting of sorghum had relatively smaller effects on growth and development parameters (leaf area index (LAI) and total dry weight (TDW) and resource use (radiation, water, nitrogen), but significantly larger effects on crop use efficiency (radiation use efficiency (RUE), water use efficiency (WUE), nitrogen use efficiency (NUE), per cent intact (%IN) and per cent affected and not recovered (%AN) plants as compared to normal planting. The two dates had the same number of productive plants, but the plants which were affected by the shoot fly and recovered in the early planting were lesser in number than those affected and recovered in the normal planting, and as such, early planting of sorghum had more IN plants with larger panicles and greater grain numbers per unit area and per panicle which resulted in statistically greater stover, grain and biomass yields in early than normal planting.

There were small differences between the crop fertilized with the F2 (FYM+20kgN+9kgP) and/or F3 (FYM+66kgN+9kgP) treatments in growth and development parameters, resource use and use efficiency, in yield and yield components and in net benefits. However, the crop fertilized with either of these treatments had statistically greater values for the aforesaid parameters compared to those of the F1 treatment (FYM at 10 t every alternate year). The application of F2 and/or F3 levels to the crop increased *rabi* sorghum stover yield by 12 - 15%, grain yield by 14 - 23% and the net benefits by 27- 46% compared to the crop in F1. Fertilization had greater effects on *rabi* sorghum grain NUE and grain WUE than on total NUE or total WUE.

LAI and TDW were 24% and 22% greater with protected (PR) than nonprotected (NP) crop. The radiation and nitrogen use were 16% and 7% higher with PR than NP crop. The study showed smaller effects of protection on grain NUE and grain WUE and larger effects on total NUE and total WUE of *rabi* sorghum. Among the yield components, grain number per unit area was the single yield attribute that positively responded to protection as a result of more intact plants per unit area with PR compared to NP treatments. By HAR, stover and biomass yields of *rabi* sorghum were 27% and 20% greater with PR than NP treatments, but their grain yield were similar, and accordingly NP sorghum had a greater %HI than PR crop.

The study showed that the interactions of sowing date x genotype, fertility x genotype and protection x genotype were important considerations for increased *rabi* sorghum productivity. This was because the three genotypes had different responses to management treatments. In M35-1 and Swathi, LAI, TDW, resource use and use efficiency as well as yield and yield components showed smaller response to early planting, but these parameters were greatly enhanced in IC 94004 when it was sown early. The yield and yield components of IC 94004 and M35-1 showed greater response across fertility levels (up to F3) than the yield and yield components of Swathi (up to F2). The response to protection was greater in IC 94004 than of the either genotypes. When normally sown, IC 94004 was much more susceptible to shoot fly than were either M35-1 or Swathi.

The path coefficient analysis indicated that *rabi* sorghum yield was highly correlated to the direct effects of total N uptake, total WUE, PNNO/M2 (panicle number per unit area), GRNO/PN (grain number per panicle) and HI. In the study, total NUE, total WUE, PNNO/M2, GRNO/PN and grain mass had a negligible indirect effect on *rabi* sorghum yield. The direct effects of both cumulative light accumulation and evapotranspiration on grain yield were not strong.

From the study it can be concluded

1) Time of planting per se of *rabi* sorghum had smaller effects on growth and development parameters and resource use, but significantly larger effects on crop use efficiency, %IN and %AN plants.

2) In early planting, there were more %IN plants and plants with larger panicles having greater number of grains per unit area and per panicle resulting in statistically greater stover, grain and biomass yields than normal planting.

3) However, early *rabi* sorghum planting provided a better opportunity for chemical fertilizer use that did not appear to exist with normal planting (support interaction of planting date and fertilization).

4) There were no statistical differences in growth and development parameters, resource use and crop use efficiency as well as in yield and yield components between the crop fertilized with F2 and F3 levels. Accordingly, there was no point to fertilize the *rabi* sorghum at doses beyond F2 level.

5) Protection against shoot fly had greater effects on total NUE, total WUE, stover and biomass yields rather than grain NUE, grain WUE or grain yield.

6) Protection is a costly treatment (as clear from the net benefit data), and could be resorted to if the objective was greater stover rather than greater grain yields.

7) IC 94004 was more responsive to inputs (early planting, fertilization, protection against shoot fly) than either M35-1 or Swathi.

8) Sowing date x genotype, fertility x genotype and protection x genotype interactions are important considerations for increased *rabi* sorghum productivity.

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Appendix 1. Climatological observations at IAC meteorological station during rabi 1995/1996. (week nos 40 to 52, rabi 1995 and 1 to 10 rabi 1996).

STD WEEK	RAIN mm	EVAP mm	TMAX C	TMIN C	RH07 %	RH14 %	WIND kphr	SUNSHINE hr	SOLRAD $(MJ/m^2/D)$
40	6.5	33.9	32.1	20.5	94.1	56.0	4.0	7.9	18.5
41	90.6	31.1	29.1	21.7	95.7	65.6	4.9	1.6	12.1
42	257.6	20.9	26.4	21.1	97.6	93.6	8.8	1.0	7.1
43	6.3	23.7	28.5	19.4	94.4	68.9	4.8	6.8	16.1
44	0.0	32.6	29.8	16.6	95.0	47.6	4.9	10.1	20.1
45	0.0	32.2	29.4	15.4	91.9	44.6	5.4	10.3	19.9
46	0.0	34.6	29.6	15.4	90.1	37.4	5.4	9.7	18.6
47	13.0	29.3	29.1	18.0	93.6	54.7	6.3	8.5	15.8
48	0.0	31.6	28.9	16.4	92.0	42.3	6.9	8.6	16.8
49	0.0	29.6	28.7	14.6	92.6	42.1	4.7	9.1	16.0
50	0.0	29.1	28.4	12.4	94.7	32.1	4.9	10.1	17.3
51	0.0	29.6	28.8	12.5	97.0	37.0	5.6	10.0	17.1
52	0.0	33.3	27.4	15.2	93.5	43.1	8.7	9.6	16.2
1	0.0	35.2	27.9	15.3	89.0	36.1	10.9	10.3	17.7
2	0.0	34.0	29.6	15.1	91.0	32.9	8.5	9.4	16.9
3	0.0	32.3	30.4	16.8	94.6	36.4	6.9	9.3	16.3
4	0.0	39.2	30.0	14.6	87.3	33.9	6.2	10.1	17.8
5	0.0	42.0	30.5	15.6	89.4	34.7	7.6	9.8	17.5
6	0.0	45.6	29.8	15.5	88.6	30.9	9.5	9.8	18.1
7	0.0	38.1	29.7	17.5	90.9	44.0	8.4	8.5	17.0
8	0.0	49.3	34.2	17.7	86.4	25.0	6.8	10.1	21.4
9	0.0	71.5	33.3	16.9	75.1	27.1	10.3	10.6	22.7
10	0.0	53.6	33.8	17.0	73.4	26.7	6.4	10.2	22.4

Appendix 2. Climatological observations at IAC meteorological station during rabi 1996/1997. (week nos. 40 To 52 rabi 1996, and 1 to 10 rabi 1997).

STD WEEK	RAIN mm	EVAP mm	TMAX C	TMIN C	RH07 %	RH14 %	WIND kphr	SUNSHINE hr	SOLRAD $(MJ/m^2/D)$
40	59.6	29.5	28.4	21.8	91.9	73.6	11.2	3.1	13.0
41	0.0	42.8	30.6	18.3	87.4	41.0	3.4	8.8	21.5
42	11.0	32.3	28.5	19.7	85.0	63.4	4.9	5.4	11.9
43	13.0	22.5	28.8	21.0	92.7	65.7	6.5	5.8	14.5
44	0.0	32.9	29.6	15.6	88.3	40.7	4.2	9.3	18.0
45	22.4	33.1	29.4	17.7	84.9	47.7	6.7	8.8	17.2
46	0.0	35.6	29.8	16.3	86.1	41.9	3.3	10.0	18.4
47	0.0	27.8	28.4	14.3	86.3	47.1	3.8	7.4	14.0
48	0.0	30.7	28.2	12.2	91.0	38.4	3.7	10.1	16.6
49	0.0	27.2	27.5	14.6	88.7	42.6	3.7	6.1	14.1
50	0.0	28.6	28.1	14.1	81.4	39.4	4.4	6.8	13.9
51	0.0	30.0	28.4	13.6	83.6	38.4	5.1	7.3	14.8
52	0.0	33.2	27.3	11.7	91.0	34.9	3.9	8.6	16.2
1	0.0	30.0	26.5	12.0	88.9	35.9	5.7	9.2	16.0
2	1.0	29.6	25.9	15.7	90.9	50.0	8.9	6.7	13.7
3	10.4	26.3	26.8	15.8	92.0	52.6	6.4	7.0	14.2
4	0.0	34.4	28.4	12.4	88.4	29.1	5.4	10.2	18.9
5	0.0	34.0	30.0	13.6	86.3	29.9	6.0	10.1	19.4
6	0.0	39.3	31.1	14.3	88.7	27.7	4.3	10.2	19.4
7	0.0	46.6	31.1	11.0	84.6	17.9	4.2	10.7	21.4
8	0.0	47.9	32.4	15.7	82.0	27.0	5.6	10.3	20.4
9	0.0	53.8	34.0	15.1	78.0	19.6	5.4	10.2	21.5
10	0.0	54.6	34.6	17.0	75.7	20.0	6.4	8.7	19.5

Appendix 3. The program used in the analysis

'Reference'	Deepsoil
'Unit'	. $ 108
'Factor'	Rep $ 3
'Factor'	SD $ 2
'Factor'	Fert $ 3
'Factor'	Spray $ 2
''Factor'	Geno $ 3
'Read/p'	Rep,SD,Fert,Spray,Geno,Parameters to be analyzed
'Block'	Rep/SD/Fert/Spray/Geno
"Treatment'	SD.Fert.Spray.Geno
'For' Z=	Parameters to be analyzed
'Anova/Prob=y' Z	
'Repe'	
'Run'	

Appendix 4. Partioning of the degrees of freedom (DF) (deep Vertisol site)

Source of variation	DF
Replication	2
Sowing date (SD)	1
Error a	2
Fertility (Fert)	2
SD x Fert	2
Error b	8
Spray (SP)	1
SD x SP	1
Fert x SP	2
SD x Fert x SP	2
Error c	12
Genotype (Geno)	2
SD x Geno	2
Fert x Geno	4
SP x Geno	2
SD x Fert x Geno	4
SD x SP x Geno	2
Fert x SP x Geno	4
SD x Fert x SP x Geno	4
Error d	48
Total	107